Scientific Advice Mechanism
to the European Commission

SAPEA Evidence Review Report (ERR)

Solar Radiation Modification (SRM)

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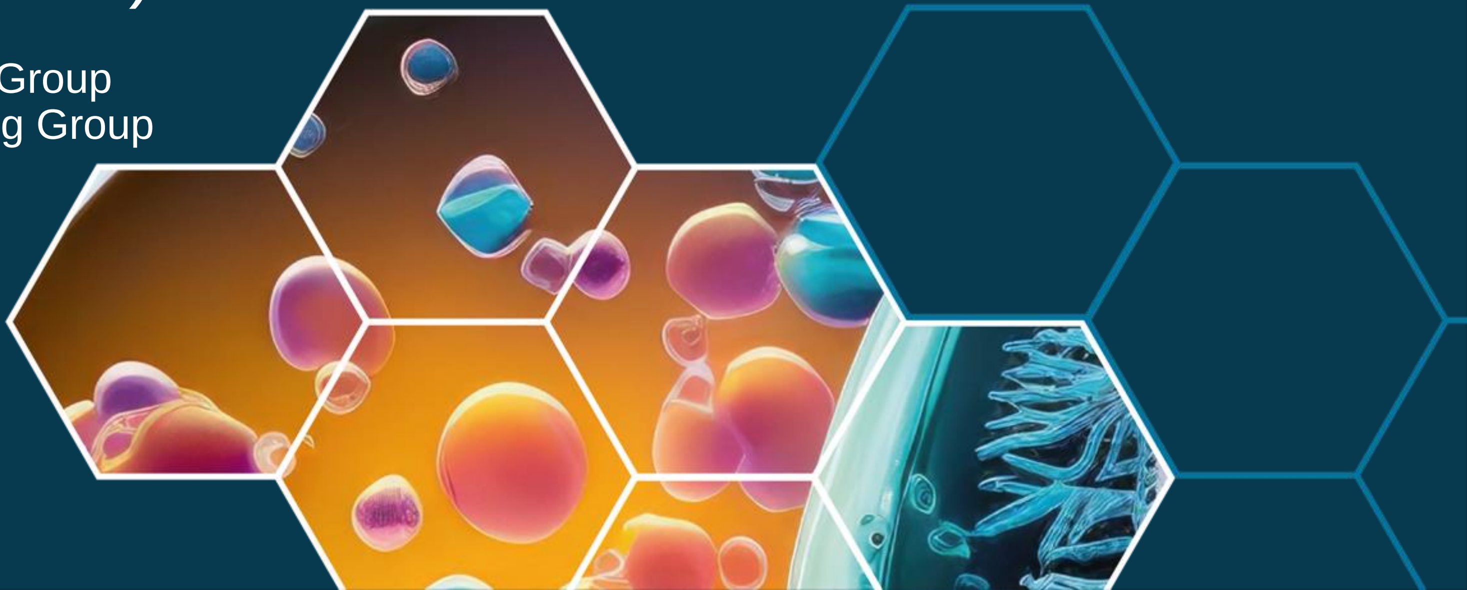

Members of the working group

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Overall structure of the report

Solar Radiation Modification – why consider it?

- Definition of SRM
  - A deliberate and potentially large-scale intervention in the Earth's climatic system, with the aim of temporarily or permanently reducing some of the impacts of elevated greenhouse gas concentrations

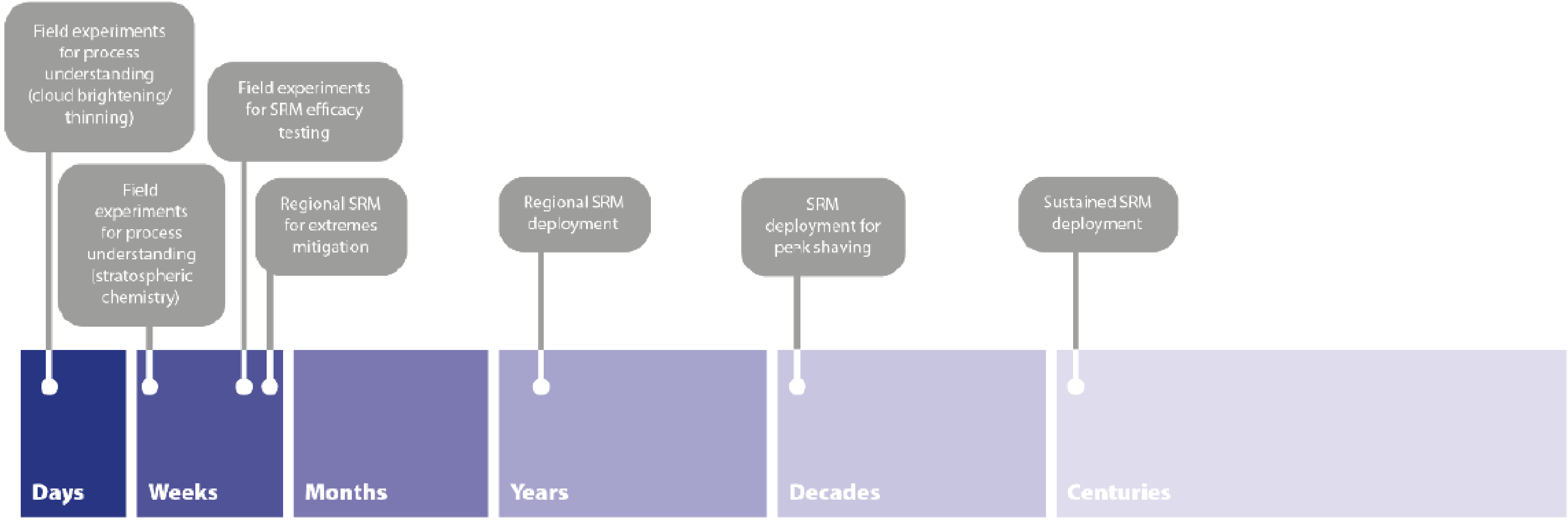
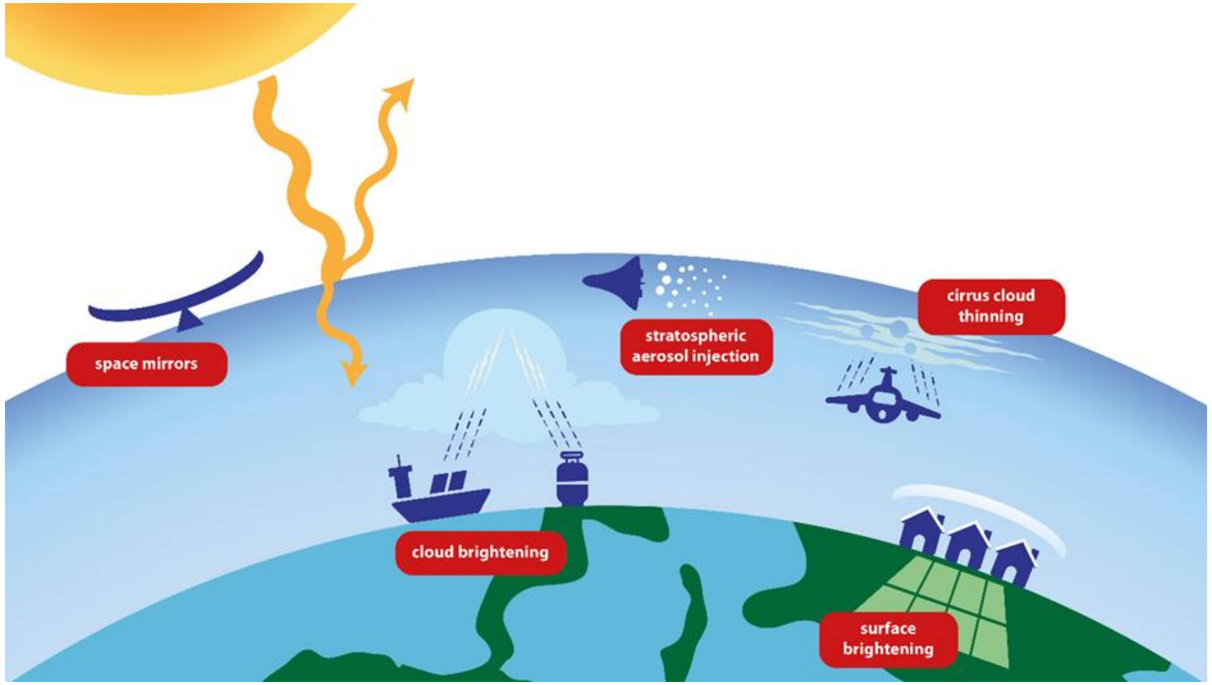


Fig. 1. Temporal scales of SRM deployment and SRM outdoor research. The temporal scales go along with spatial scales. Field experiments are typically of order tens to a few hundreds of kilometres in extent (e.g., Seidel et al., 2014). Regional deployment is at sub-continental scales (e.g., Quaas et al., 2016). Peak-shaving or sustained deployments are global in extent. The temporal scale of SRM for peak shaving assumes net-zero greenhouse gas emissions are achieved in this timeframe.

What are the technologies?

- Reflect sunlight (or more emit more infrared)
- Net cooling effect
  - Stratospheric aerosol injection (SAI)
  - Cloud brightening
  - Cirrus cloud thinning
  - Surface brightening
  - Space mirrors



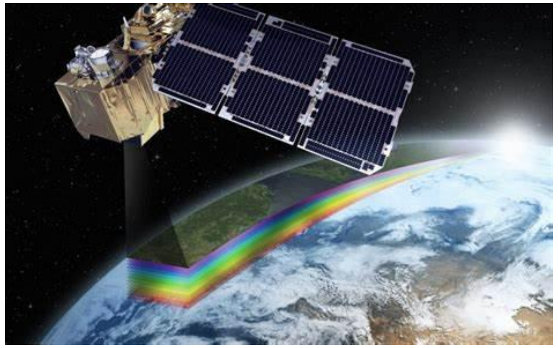
What are the potential effects, impacts and side-effects of SRM?

- SRM has the potential to counteract the impacts of greenhouse gas
- SRM does not address the direct impacts of CO_2 (e.g., ocean acidification)
- SRM would have regionally diverse impacts on temperature
- SRM acts on the hydrological cycle i.e. rainfall patterns
- Multiple other effects (e.g. changes to plant growth, energy system)



What are the technical and scientific requirements and prerequisites for SRM?

- Studied so far only in climate models
  - Models not yet able to anticipate all effects and impacts
  - Some relevant processes are only coarsely integrated or still missing
- Satellite monitoring technologies to detect and quantify SRM exist
  - but some of such instruments not yet on operational European satellites.
- Technology readiness level (TRL) is very low



Risks and challenges facing SRM deployment

Method	Cooling potential (model studies)	Uncertainty of effects	Observational "analogue"	Lifetime	Regional option	Technological readiness	Remark
SAI	Global (2.1.1)	Moderate (2.1.3)	Volcanic eruptions (2.1.2)	> 2 years (2.1)	Possibly polar (2.1)	Low (2.1.4)	Additional side effects (3.2)
CB	Up to global (2.2.1)	Moderate to high (2.2.5)	Diverse tracks (2.2.2)	Weeks (2.2.1)	Yes (2.2.1)	Low (2.2.4)	
CCT	Unclear (2.3.1)	Very high (2.3.2)	Little (2.3.2)	Weeks (2.3.1)	Yes (2.3.1)	Very low (2.3.4)	Terrestrial spectrum (better compensation)
MCT	Unclear (2.3.1)	Extremely high (2.3.2)	Little (2.3.4)	Weeks (2.3.1)	Yes (2.3.1)	Extremely low (2.3.2)	
Surface brightening	At best local	Low	Land cover diversity	Decades	Only local	High	No option for global cooling
Space mirrors	Global	Low	None	Decades to centuries	No	Virtually zero	

Who are the actors and networks, and what are stakeholder perceptions of SRM?

- Variety of actor coalitions that support SRM, oppose it or are ambivalent
    - State actors such as governments but also commercial actors, civil society groups, scientific bodies, and academic institutions
- The public is largely unfamiliar with SRM options
    - Preferences appear to be strongly context dependent, particularly by perceptions and experiences of climate change, and strongly informed by values
- Perceptions held by experts and those involved in decisions to fund research, implement policy, or shape deployment outcomes outline rationales in favour of SRM but also several points of concern

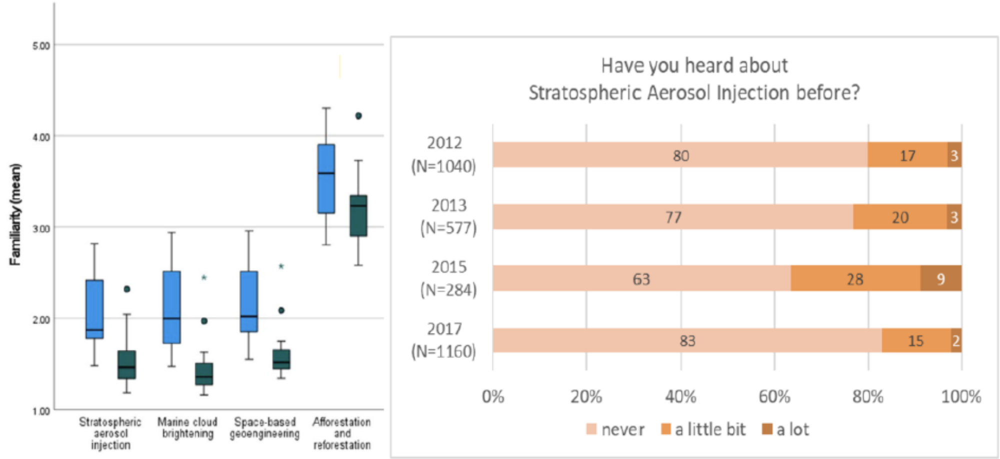


Figure 5. Public familiarity with SRM options. The left panel based on Baum et al (2024), 1=never heard of it, 5=very familiar. The right panel shows awareness about Stratospheric Aerosol Injection in public perceptions surveys in Germany 2012, 2013, 2015, and 2017; all surveys use the same question and response format after study-specific descriptions of SAI. For description of data collection see: 2012: Merk et al (2016); 2013: Braun et al (2018); 2015: unpublished data description of data collection see Merk et al (2016); 2017: unpublished data (Merk, Baatz & Rehdanz, in prep) description of data collection see survey 1 in Merk et al (2019).

Authors	Year	Country focus	Technology (only SRM methods listed)	Methods
Shepherd	2009	UK	Geoengineering in general	Four focus groups + opinion poll (1000 respondents) + specialist workshop
Ipsos MORI (NERC)	2010	UK		Workshops in 3 UK cities (85 participants) + final event; discussion groups; online survey (65 respondents); open access events
Bellamy and Hulme	2011	UK	Geoengineering in general	Email questionnaire (287 participants - students) + focus groups (15 participants - students)
Mercer et al.	2011	UK, US, Canada	SRM in general	Survey (3105 participants)
Borick and Rabe	2012	US	SRM in general	Survey (887 participants)
Bostrom et al.	2012	Austria, Bangladesh, Finland, Germany, Norway, USA	Stratospheric aerosol injection	Survey (664 participants - economics undergraduate students)
Pidgeon et al.	2012	UK	Geoengineering in general	Semi-structured interviews (53 participants); Survey (1822 participants)
Hiller and Renn	2012	Germany	Geoengineering in general	International media analysis, 2008-2010
Corner et al.	2013	UK	Geoengineering in general (including Stratospheric aerosol injection)	Deliberative workshops in 4 UK cities (11x4 participants)
Pidgeon et al.	2013	UK	Stratospheric aerosol injection	Deliberative workshops in 3 UK cities (32 participants, in three groups)
Macnaghten and Szerszynski	2013	UK	SRM in general	Deliberative focus groups in 3 UK cities (around 50 participants, in seven groups)
Corner and Pidgeon	2014	UK	Geoengineering in general	Survey experiment: three treatment groups (610 participants)
Scheer and Renn	2014	Germany	Geoengineering in general	Literature review and Group Delphi workshop for experts
Wright et al.	2014	New Zealand, Australia (quantitative)	Stratospheric aerosol injection; Cloud brightening; Mirrors in space	Semi-structured interviews (30 participants) and quantitative brand image analysis (2028 participants)
Amelung and Funke	2015	Germany	Geoengineering in general (interview) and	Semi-structured interviews and budget-allocation task (98 participants - students)

The main themes that emerge from public perception studies (see Table 1) on SRM are as follows:

1) Moral hazard: the possibility that the development and implementation of technological measures to reduce the impact of climate change may generate a perceived permission structure for citizens, industries, and governments not to have to reduce emissions as much. Evidence of moral hazard is empirically very challenging to generate. Existing analyses are inconclusive as some studies observe some moral hazard effects, whereas others find no results or even an increase in support for emissions mitigation after exposure to the notion of SRM (Corner and Pidgeon 2014; Visschers et al. 2017; Amelung and Funke 2015; McLaren et al. 2016; Merk et al. 2016, 2019; Raimi et al. 2019; Fenn et al. 2023; Baum et al. 2024b).(See also mitigation deterrence below).

2) 'Messing with nature': the perception that human beings may, by intervening or tampering with climate processes be acting in contravention to the natural order, with accompanying expected consequences from the natural elements and/or religious connotations. While many studies observe 'messing with nature' sentiments, some also find that with closer interaction, SRM can be viewed to remedy humanity's degrading impact on nature (Mercer et al. 2011; Corner et al. 2013; Corner and Pidgeon 2015; Wibeck et al. 2015, 2017; Asayama et al. 2017; Visschers et al. 2017; Buck 2018; Carr and Yung 2018; Jobin and Siegrist 2020; Klaus et al. 2020; Raimi et al. 2020; Carvalho and Riquito 2022; Bolsen et al. 2023; Fenn et al. 2023; Baum et al. 2024a, 2024b).

3) Unnaturalness of SRM techniques: related to the previous point, aversion to those techniques perceived to be more "unnatural", with this factor an important predictor of the potential acceptability of SRM. While initial reactions tend to view SRM as unnatural, this effect can vary with framing effects (e.g. relating to the Anthropocene or SRM seen as counteracting a reduction in bunker fuel emissions (Mercer et al. 2011; Corner et al. 2013; Corner and Pidgeon 2014, 2015; Bellamy et al. 2016; Raimi et al. 2020; Mahajan et al. 2019; Bolsen et al. 2023; Baum et al. 2024b).

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4) Climate change harms and exposure: the degree to which individuals or groups perceived climate change to have a severe impact on their lives, or were directly harmed by climate change or natural disasters, has a crucial influence on support for SRM techniques and more support for SRM research has been found in Global South countries (Mercer et al. 2011; Borick and Rabe 2012; Bostrom et al. 2012; Pidgeon et al. 2013; Merk et al. 2015, 2016; Gregory et al. 2016; Visschers et al. 2017; Braun et al. 2018b; Sugiyama, Asayama, and Kosugi, 2020; Sugiyama, Asayama, and Kosugi, 2020; Raimi et al. 2020; Jobin and Siegrist 2020; Klaus et al. 2020; Cherry et al. 2021; Bolsen et al. 2023; Rosenthal et al. 2023; Baum et al. 2024a, 2024b; Hussain et al. 2024)

5) Less preferable than other climate solutions: there is consistent evidence of the public assigning SRM approaches, most of all stratospheric aerosol injection, less support and viewing them to have greater risks versus benefits than carbon dioxide removal and, especially, emissions reduction approaches like renewable energy, energy efficiency and energy conservation (Bostrom et al. 2012; Wright et al. 2014; Amelung and Funke 2015; Bellamy et al. 2016; Merk et al. 2019b; Carlisle et al. 2020, 2022; Jobin and Siegrist 2020; Bellamy 2023; Müller-Hansen et al. 2023; Baum et al 2024a).

6) Need to establish fair regulation/need to distribute benefits and costs fairly: among those who do not oppose SRM on principle, there emerges a call for the establishment of precise regulation delimiting its use, as well as questions over the extent to which this would be feasible (Macnaghten and Szerszynski 2013; Bellamy et al. 2016, 2017; Asayama et al. 2017; Buck 2018; Sugiyama et al. 2020; Hussain et al. 2024). Intergenerational fairness has long been a consideration with calls to ensure future generations are properly equipped to take decisions on the potential use of SRM (Betz, 2012; Goeschl, Heyen, and Moreno-Cruz, 2013, Quaas et al. 2017).

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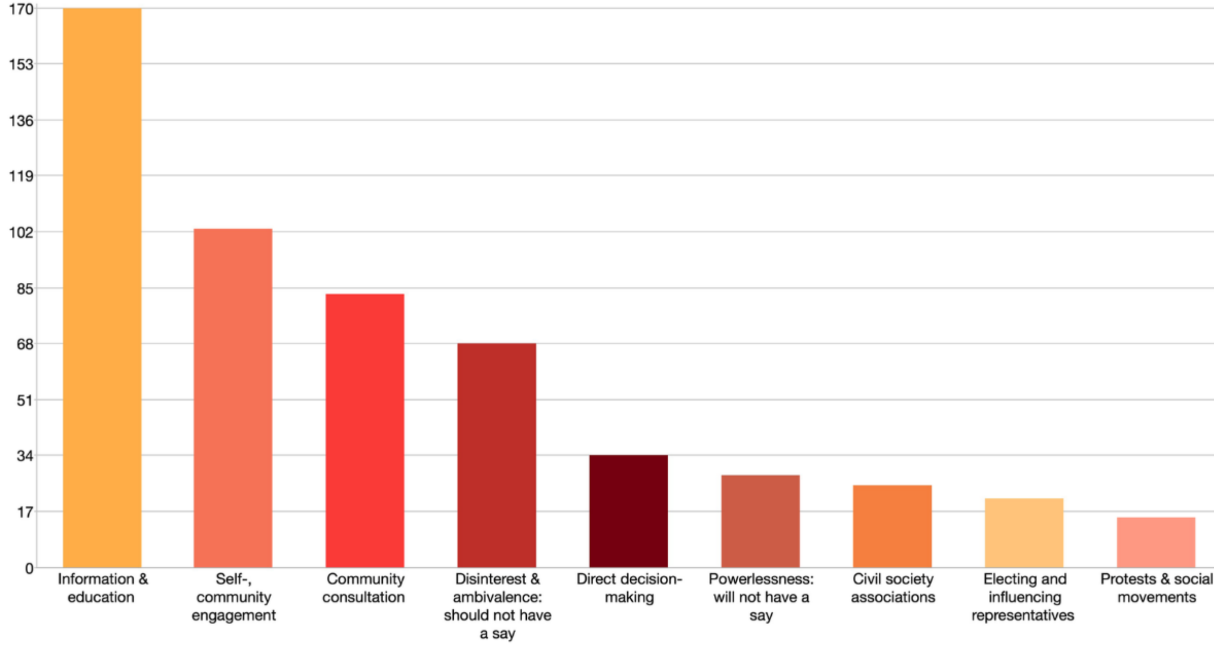
7) Need to inform and consult citizens prior to development and deployment: connected to the previous point, respondents express the need for choices about these technologies to be made with the involvement and consent of citizens, both out of justice considerations and in accordance with democratic principles (Macnaghten and Szerszynski 2013; Bellamy et al. 2016, 2017; McLaren et al. 2016; Asayama et al. 2017; Buck 2018; Sugiyama et al. 2020; Baum et al. 2024a, 2024b) .

8) Conspiracy thinking: though a smaller strand in the literature, there are established connections between discourse and discussions on SRM in the public sphere and prevailing conspiracies (notably, on chemtrails), with this revealed at the individual level through surveys (Mercer et al. 2011; Tingley and Wagner 2017; Bolsen et al. 2022) and in a more general manner through social media analysis (Debnath et al. 2023; Müller-Hansen et al. 2023).

How to involve the public? Recognize ‘ecologies of participation’

- Fritz et al. (2024) conducted 44 focus groups in 22 countries to ask a representative sample of the public their preference for community governance involving SRM options such as SAI, MCB and space shields
- They noted preferences across an entire ecology of participation including self-governance, having petitions, and supporting citizens assemblies and plebiscites.

A)



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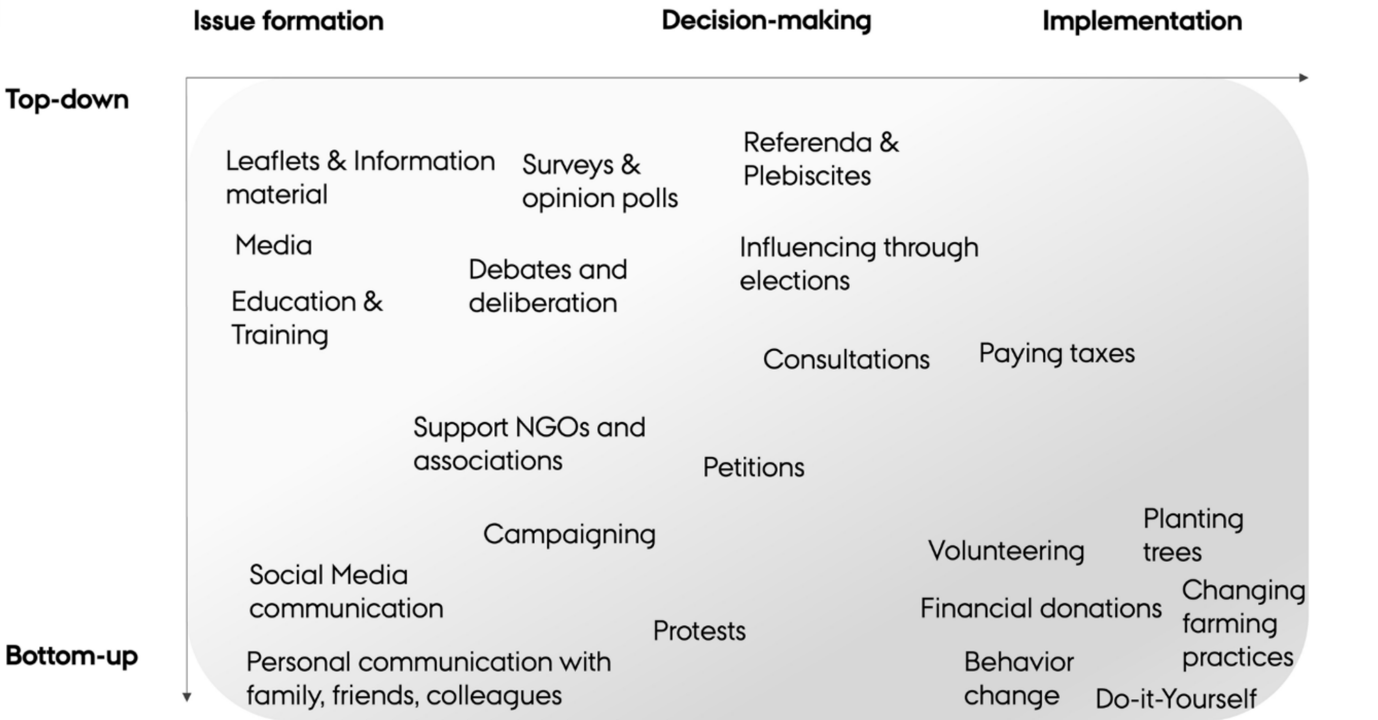

Risk considerations and future work

- Moral hazard – framing SRM as a 'solution' to climate change
- Slippery slope – lock-in or path-dependency
- Regional inequalities
- Prediction uncertainty
- Pre-existing legal commitments
- Socio-technical systems dynamics