Southeast Asian expert perceptions of solar radiation management techniques and carbon dioxide removal approaches: caution, ambivalence, risk precaution, and research directions

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Abstract
As the climate crisis intensifies in its impacts, discussions around the deployment of geoengineering solutions in case other interventions fail or prove insufficient have figured in research and have even been on the agenda of the United Nations. There have been calls for more investigation of geoengineering techniques to address the climate crisis. Yet, this response presents technological unknowns and economic, political, and ethical risks. Producing knowledge on these techniques has been pushed in many research institutes in the global North, especially in the United States, Europe, and Australia. Still, contributions from global South researchers, including those in Southeast Asia, remain scant. This paper describes the responses of seventeen climate and energy experts from Southeast Asia on a purposively designed survey that collected expert opinions on two geoengineering techniques: solar radiation modification (SRM) and carbon dioxide removal (CDR), their risks, impacts, and governance as they pertain to their countries and region. Respondents showed ambivalence towards these techniques, with many supporting ‘natural’ CDR research and deployment while being cautious about ‘technological’ SRM and CDR research and deployment. Although respondents would welcome research on these technologies, especially their risks and impacts, they also identified critical barriers in research capacity development and funding availability.

1. Introduction
Natural and technological approaches that seek to intervene in the climate system to address climate change deliberately are proposed by increasing the Earth’s albedo to reflect sunlight away from the Earth (called solar radiation modification or solar radiation management (SRM)) and through removing greenhouse gases from the atmosphere and storing it in biological or geological sinks (called carbon dioxide removal (CDR) or greenhouse gas removal). SRM technologies could either operate terrestrially by painting roofs white to increase roof reflectivity (Gaffin et al 2012), adding reflective material to increase desert albedo (Gaskill 2004), and creating microbubbles to increase ocean albedo (called surface-based albedo modification) (Gabriel et al 2017) or at a stratospheric level through the deployment of reflective aerosol particles (called stratospheric aerosol injection (SAI)) (Pope et al 2012), aerosol injections to increase the albedo of marine stratocumulus clouds (called marine cloud brightening) (Latham et al 2012), and ice nuclei injections in the upper troposphere to reduce the optical thickness of cirrus clouds so that more longwave radiation can escape to space (called cirrus cloud thinning) (Muri et al 2014) (see IPCC 2021: table 4.7 for a summary of these approaches; also see Irvine et al 2016); CDR technologies include the enhanced biological and chemical capture and storage of carbon dioxide and other greenhouse gases on land and in the ocean (IPCC, 2021: table 5.9 for a summary of these methods; also see Minx et al 2018). CDR may be required to address hard-to-mitigate emissions in agriculture and aviation, while SRM and CDR may help meet the aspirational target of 1.5 °C warming (Vaughan and Lenton 2011, IPCC 2014, Sovacool 2021). Although the opinion on SRM approaches has been divided, both SRM techniques
and CDR methods have been suggested to be crucial complements to climate mitigation via emissions reduction for meeting the goals of the Paris Agreement to keep global temperature rise well below 2 °C (National Academies 2021, United Nations 2019). The approaches also have different controversies, although some authors frame them as critical interventions for ‘maintaining planetary systems’ (a term used in Cairns and Stirling 2014). The most common of SRM-related controversies are their potential moral hazard (Lenzi et al 2018, Lockley and Coffman 2016, Lin 2013), mitigation deterrence (Markussion et al 2018, McLaren 2016), risk response feedback (Jebari et al 2021), and their impermanence (meaning these techniques will only be a temporary gap measure (Chavez 2016, National Academies of Sciences, Engineering, and Medicine 2019). They can also distract funding for accelerated climate mitigation through rapid energy transition (Delina, 2021).

Looming large in these controversies is the technologies’ distinct social and ethical issues around public consent for research or deployment and their governance. For example, some warn about SRM through SAI dubbing the method a ‘trojan horse’ (Anshelm and Hansson, 2014) for its potential to spawn international conflicts (Bellamy et al 2013, Stilgoe et al 2020). Among the vital governance issues identified with SAI is the possibility of this technology to concentrate power in rich countries in the global North (Biermann and Møller 2019), mainly because their researchers have produced most of the SAI research to date (cf, Hamilton 2014, Frumhoff and Stephens 2018, Hulme 2014, Horton and Keith 2019). However, it should be noted that it does not necessarily follow that the location of research evidences a power imbalance in applying that knowledge. Decentralized or distributed governance models are also possible as proposed, for instance, in Lockley’s (2019) constrained unilateralism, where deployment authority by countries are constrained according to their historical emissions.

CDR controversies are also distinct depending on the technique. CDR approaches range from controversial bioenergy with carbon capture (BECCS) and direct air carbon capture and storage (DACCS) to less controversial ecosystem management or nature-based approaches such as soil carbon sequestration and biochar afforestation and reforestation, blue carbon, enhanced weathering, and ocean fertilization. Perception studies, such as those conducted by Cox et al (2020, 2021), mention BECCS-related land and energy issues to include the dangers of monocultures and habitat destruction and DACCS-related issues, including, for example, the tendency of this technology to prolong the useful lives of fossil-based power plants instead of stopping their operations in favour of sustainable energy generation.

While there are attempts at increasing the participation of researchers outside Europe, the United States, and Australia, in the study of geoengineering (see section 1.1), little is known about how experts in these countries perceive these techniques and their consequences and whether these topics are relevant and worthy of investigation to them. This paper reports one of the attempts at addressing this gap. It presents the perceptions of a multidisciplinary cohort of climate and energy experts in Southeast Asia about the prospects of studying geoengineering in their countries.

The perception study focuses on Southeast Asia for several reasons. Southeast Asian countries, both continental and archipelagic, have already been exposed to the dire impacts of climate change. These climate consequences include, most significantly and among others: frequent and stronger typhoons in the Philippines (Takagi and Esteban 2016) and Vietnam (Takagi 2019) and cyclones in Thailand (Faikrua et al 2020) and Indonesia (Mulyana et al 2018), prolonged droughts and El Nino contributing to reduced crop yields (Qian et al 2019) and transboundary forest fires in Malaysia, Indonesia, and Singapore (Samsuddin et al 2018); and intense rainfall affecting crops and flooding in many of the region’s cities and villages (Venkatappa et al 2021). The exposure of Southeast Asian peoples to climate-related hazards is compounded by their heterogeneous social, political, and economic situations, including poverty, maldevelopment, power imbalances, and violent conflicts (Marquardt et al 2022). Their vulnerability to these risks is exacerbated by multiple, often cascading, hazards (Brown et al 2019, Delina and Guiam 2018). Therefore, it is not surprising for climate adaptation and resilience to become the climate policy of choice or focus area amongst many governments in Southeast Asia (Marquardt et al 2022). In light of their multiple climate vulnerability exposures, however, CDR and SRM techniques may appeal to them. Yet, we know very little about how the region’s climate and energy epistemic community appraises (or seeks to evaluate) these proposals.

This paper reports an output of a survey collected from seventeen Southeast Asian climate and energy experts about their perceptions of SRM and CDR research and deployment in their countries and region. Section 2 provides a short review of public and expert perceptions of geoengineering in other parts of the world and the state of research on these techniques in countries outside Europe, the United States, and Australia. Section 3 describes the expert selection process and the survey instrument. Section 4 presents the results arranged according to their thematic sequence in the survey. Section 5 discusses these results, the limitations of the survey, and some suggestions for future research.
2. Public and expert perceptions of geoengineering and the state of geoengineering research in the global South and Southeast Asia

Perception studies on geoengineering approaches, particularly for SRM, were conducted for a large population (public) and less with experts. Studies on public perception of geoengineering and its techniques reveal ambivalent attitudes towards these technologies, particularly with SRM (see Burns et al 2016 and Cummings et al 2017 for general reviews). Corner and Pidgeon’s (2014) study in the United Kingdom and Merk et al (2015) work in Germany, for instance, suggest that UK and German respondents define SRM techniques in vague and broad terms. In other affluent countries, public perceptions of risk appeared to be crucial in SRM research (e.g., Pidgeon et al 2013 in the UK; Mercer et al 2011 in the US, Canada, and the UK), where respondents were cautiously open to understanding SRM impacts but reluctant to support deployment. In terms of CDR, nature-based solutions such as ecosystem management and reforestation appear to be more publicly acceptable than technology-focused carbon capture and storage, as shown in Wallquist et al’s (2012) study in Switzerland, for example.

There are also attempts at expanding the public understanding of geoengineering, as shown, for example, by workshops on SRM techniques convened by Winickoff et al (2015) and by the Solar Radiation Management Governance Initiative (SRMGI) (SRMGI, 2021a). These events targeted mixed cohorts comprising experts and the general public outside Europe and the United States. One rationale for expanding work in these countries is that geoengineering might help vulnerable communities who live in these places (e.g., Keith, 2017), thus, the need for their engagement (Suarez et al 2018, Flegal and Gupta 2018). However, no events, to the author’s knowledge, have reached these most vulnerable communities and groups, such as indigenous populations.

While most, if not all, documented outreach events had engaged lay citizens, some workshops were also geared exclusively at experts who may have some interest in geoengineering. The knowledge produced outside Europe, the United States, and Australia, particularly in the global South, is crucial since it could increase our understanding of geoengineering’s social, political, and economic impacts, especially with regards to persistent poverty, maldevelopment, and inequalities in these places (Anshelm and Hansson 2014). Ensuring that these traditionally marginalized voices are heard and able to participate in geoengineering knowledge production has justice implications (cf Delina and Sovacool 2018). SRMGI, in cooperation with local partners, had made strides in this regard through their convenings of national workshops in India, China, and Pakistan and a subregional workshop for participants from Bangladesh, Thailand, and the Philippines (see Sugiyama et al 2017). SRMGI was also a co-convenor of a two-day regional conference at the Nanyang Technological University in Singapore in 2011 (RSIS Centre for Non-Traditional Security Studies 2011). However, these events have been relatively small in scale and did not result in a stable research base (Winickoff et al 2015). In recent years, Sugiyama et al (2017) convened an expertise workshop for Asia and the Pacific and Delina (2020)—with support from SRMGI—for Southeast Asia. These last two workshops were attended by select climate modelers, energy scientists, and other experts from these world regions. These workshops, held in Tokyo (Sugiyama et al 2017) and Bali (Delina 2020), suggest the openness of climate and energy knowledge producers from these locations to research the impacts, governance, policy, and social studies of geoengineering.

Research on modeling the impacts of SRM through SAI has already taken off in Asia, although their geographic reach remained limited to a few countries to date. In China, for instance, climate modelers from the Beijing Normal University (Kravitz et al 2020) have studied the regional impacts of sulfate aerosol injection to Asia’s glaciers (Zhao et al 2017). John Moore from the Beijing Normal University and Long Cao of Zhejiang University have been involved in this modeling work with about USD 3 million funding from China’s Ministry of Science and Technology (Temple, 2017). Moore and Cao are perhaps the most published scholars on geoengineering amongst China-based researchers. Some of their well-cited outputs include Moore et al 2021, Kravitz et al 2014, and Jones et al 2018. India also has conducted some SRM research. The Indian Institute of Science had received public funding from the Indian Government to research the sensitivity of the South Asian monsoon to SAI (Bala and Gupta, 2019). SRMGI (2021b) has supported SRM modeling research in other developing countries through its Developing Country Impacts Modelling Analysis for SRM (DECIMALS) Fund. This fund led to several research publications on SRM impacts, including from Pinto et al (2020) for Sub-Saharan Africa, Da-Allada et al (2020) for west Africa, and Karimi et al (2020) in north Africa. In 2021, Kuswanto et al (2021) published their SRMGI-supported modeling work for Indonesia. Besides Kuswanto et al’s work, we know little about how SRM deployments could impact other Southeast Asian countries. Noticeably lacking are studies conducted and published by Southeast Asian authors on the different aspects of SRM and CDR, including their social, political, legal, governance, and economic implications.

Governing SRM is crucial given its international implications and impacts (Callies 2019, Jinnah et al 2019, Jinnah and Nicholson 2019). Geoengineering governance broadly means ‘the goal-oriented, sustained, and explicit use of authority to influence behavior’ (Reynolds 2019) and involves state-imposed rules and regulations (National Research Council’s Committee on Geoengineering Climate 2015) and non-legally binding ‘rules
developed, implemented, monitored, and enforced by non-state actors’ (Reynolds 2019). SRM governance is different from CDR governance. With SRM research already taking place and outdoor experiments in the offing, governing SRM research has become an immediate challenge (Jinnah et al 2019). Yet, no literature has emerged from authors outside Europe and the United States on geoengineering governance. The literature suggests SRM research governance could include safeguards to ensure that SRM research does not head down a slippery slope towards testing and deployment (Callies 2019). If ever deployed, SRM governance, thus, should consist of the monitoring and attribution of resulting climate impacts, liability, compensation in case of unequal outcomes, and institutional guarantees against premature termination (Parker and Irvine 2018, Parker et al 2018, Jinnah et al 2019, Jinnah and Nicholson 2019). Deployment of CDR techniques, especially large-scale ones, also needs to be governed to strengthen accountability and address adverse impacts on biodiversity, groundwater, soil, air quality, and the challenges around liability and compensation (Mace et al 2021). These are areas that have significant implications for Southeast Asian countries and peoples.

A challenge, thus, is how research could advance on the various dimensions of SRM and CDR with inputs not only from Southeast Asian climate modelers but also from their counterparts in the social sciences, humanities, and policy analysis. Before these epistemic communities could even consider geoengineering research, it is also essential to raise the question of whether SRM and CDR are worthwhile research focuses for Southeast Asian experts. In addition to the slippery slope argument, there are other considerations, including how to address the general lack of observational and climate data, funding, and capacity to conduct these types of research (including research staffing and time) (Delina 2020). Addressing these concerns is essential since many Southeast Asian experts have limited capacity to expand work on new areas. Allocating resources to advance geoengineering studies in these places could also reduce research money available to other climate research (cf with the moral hazard argument, see Gunderson et al 2019). To understand these challenges better, this study deployed a survey to select Southeast Asian climate and energy experts. The following section describes that methodology.

3. Methods

3.1. Expert respondents

Seventeen Southeast Asian climate and energy experts were recruited online through a snowball approach from July to September 2019. The same participants participated in the regional workshop supported by The World Academy of Sciences and SRMGI (Delina 2020). The workshop required the experts to accomplish the online survey in advance. The survey was deployed in October 2019, a month ahead of the workshop. Section 3.2 describes the survey instrument in more detail.

This purposeful sampling or purposive approach to respondent selection is a widely used qualitative research technique that relies on identifying and selecting individuals who are especially knowledgeable about a phenomenon of interest (Creswell and Plano 2011)—in this study, climate change research—for the most effective use of limited resources—in this case, limited funding available (Patton 2014). The purposive approach also requires the availability and willingness of the respondents to participate (Bernard 2002) and their ability to articulate, express, and reflect upon their opinions. Consent was secured from the respondents before they responded to the survey. In contrast to probabilistic or random sampling, purposeful sampling does not generalize its findings.

Nine of the survey respondents are male, while eight are female. Although there is a one person skew towards men, the cohort has closely achieved gender balance. Eleven worked in universities as professors; two in governments; two in research institutes; one in an international organization, a civil society organization, and the private sector. Their claimed expertise is also diverse, reflecting their multidisciplinarity: social sciences and humanities (seven respondents); natural and physical sciences (five); engineering (three); and one each for statistics and law. In terms of disciplinary homes, nine identified with ‘climate,’ nine with ‘policy and governance,’ seven with ‘energy,’ six with ‘modeling,’ five with ‘development,’ two with ‘advocacy,’ and one each with ‘education,’ ‘politics of expertise,’ and ‘history and humanities.’ Two of the respondents were authors of the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Despite twelve participants disclosing expertise on climate and seven on energy, only one claimed expertise in geengineering. Seven respondents had postdoctoral experience, six had doctoral degrees, and four with master’s degrees, suggesting the respondents’ high level of education. Nine respondents have between five and ten years of experience; three have between eleven and fifteen years; two have between sixteen and twenty years; one has more than twenty years of experience. Five respondents worked or lived in Singapore; four in Indonesia; three in the Philippines; two in Vietnam; two in Malaysia; and one each in Thailand, Laos, and Brunei Darussalam. All ten countries that make up the Association of Southeast Asian Nations, thus, are represented in the survey (see appendix A for the description of the respondents). Figure 1 shows some demographic profiles of the respondents.
3.2. The survey
The survey was conducted online using Qualtrics. The respondents first completed an online consent form before answering a series of demographic questions (reported in section 3.1). They then responded to open-ended questions that reviewed their knowledge of climate action. These questions included topics beyond climate adaptation (Topic 1); the 'continuing-as-usual' option (Topic 2); 'conventional' mitigation options through emissions reduction in the energy sector using voluntary mechanisms, increasing the deployment of renewable energy technologies, carbon pricing, nuclear energy, and coal energy with carbon capture and storage (Topic 3); reducing emissions from the transport sector, as well as from the agriculture and forestry sectors (Topic 4); and the 'loss and damage mechanism' in the United Nations Framework Convention on Climate Change (Topic 5).

The respondents were then asked of their views on options beyond adaptation and mitigation (Topic 6), appraising and reflecting upon proposals for research and deployment of techniques that would reflect sunlight to space (Topic 6. a) and remove carbon dioxide from the atmosphere (Topic 6. b). These questions did not introduce the concepts of SRM and CDR yet to check on the respondents’ prior knowledge and understanding of these techniques. They were then formally introduced to SRM and CDR through the following prompt:

Deliberate, large-scale interventions in the Earth’s climate system, known collectively as climate intervention or climate engineering or geoengineering, comprise an array of proposals/technologies that can broadly be divided into two types: carbon dioxide removal (CDR) and solar radiation management (SRM), each of which poses unique opportunities but also risks of adverse impacts and unintended consequences. This led to calls for more inclusive and responsive modeling/scenario-building and governance of climate intervention technologies that explore possible effects and implications and adequately account for them in technological development and decision-making processes.

The respondents were then asked to appraise and reflect by weighing the benefits and the risks and the pros and cons of conducting geoengineering research in their country and Southeast Asia (Topic 7) on the modeling of SRM and CDR techniques, their risks, and impacts (Topic 7. a); the governance of SRM and CDR research and deployment (Topic 7. b); and the barriers for inclusive SRM and CDR research (Topic 7. c). Appendix B presents the survey instrument.

The respondents answered the questions in phrases, clauses, or sentences. Two respondents (Respondents 10 and 13) did not answer the survey in its entirety. These responses were analyzed according to their topical results, based on the section composition of the online survey. The following section reports the survey results. The exact text responses are used in this paper, with minor changes introduced or inserted by the author for clarity. Square brackets mark these changes.

4. Results
4.1. Understanding climate change and climate action
The respondents had an up-to-date understanding of climate issues, especially adaptation and mitigation through emissions reduction across various emission sectors. They possessed a thorough knowledge of
near-term climate impacts, especially those related to intense precipitation, flooding, and drought. When asked about options beyond adaptation and mitigation, responses include: rethinking existing development paradigms, climate justice for the poor and vulnerable people, international cooperation, and education. Despite the specialization of SRM and CDR topics, the respondents were familiar with the broad climate change literature.

4.2. Researching and deploying SRM techniques
Four respondents said they were unfamiliar with SRM or any of its techniques. Respondent 8 said they ‘just heard [SRM for the] first time, [and that they] have no idea [about it].’ Respondent 14 had ‘no idea about this technique.’ Respondent 6 was ‘not familiar with this technology.’ Respondent 11 ‘did not know enough.’ The majority, i.e., thirteen, however, claim some level of familiarity with SRM.

When asked about whether Southeast Asian researchers should research SRM, nine respondents support SRM research while raising caution (Respondents 1, 3, 5, 6, 7, 9, 14, 16, and 17). Respondent 1 suggested the ‘need [for] further scientific evidence.’ Respondent 3 agreed that SRM is ‘a good idea’ but asked, ‘what are the possible consequences.’ Respondent 5 noted that ‘we never know exactly how the impacts would be; however, after some scientific evidence, [maybe] it is worth trying this technology.’ Respondent 6 raised the questions: ‘Is it going to work; how much does it cost; who is going to cover the cost and enjoy the benefits?’ Respondent 7 would like to know the ‘co-impacts due to the installation and implementation of the system, [applying] the life cycle approach, for example, in evaluating [these techniques].’ Respondent 9 remarked that ‘these are technologies we should carefully and cautiously study; and that the effects of the technologies must be weighed … whether these are good or bad for the environment.’ Respondent 14 said that ‘this idea may be an option for reducing global warming; however, it should have further research on the long term and cumulative impacts of the sulfate particles on the atmosphere and living beings.’ Respondent 16 noted that SRM ‘is a new way of tackling the climate change [challenge and that they] would love to learn more about this, especially on how [their] country might contribute.’ Respondent 17 acknowledged that SRM ‘is relatively new and has a potential to complement mitigation and adaptation measures; [hence] SRM research should be supported.’ Two (Respondents 12 and 15) do not support conducting SRM research. Respondent 12 asked: ‘if we can reduce emissions through [renewable energy, where its] price is getting cheaper, and technologies are getting more mature, why do we need such expensive technology?’ Respondent 15 likened it to ‘playing god,’ asking: ‘do we know its impacts? how many technologies have we seen that we thought were beneficial only to discover that they are monsters?’ Three (Respondents 4, 8 and 11) have no position on the issue.

When asked explicitly about SRM deployment, respondents are, once again, divided in their views. Eight respondents are cautiously supportive (Respondents 1, 2, 3, 4, 5, 9, 16, and 17) Respondent 1 pointed out the ‘need [for SRM] to be assessed on [their] cost and risk,’ a view that Respondent 3 shared while also asking about the technique’s ‘possible consequences.’ Respondent 4 suggested it ‘might be a back-up solution,’ while Respondent 2 suggested SRM ‘should be considered a last resort.’ Respondent 5 said ‘it might work well’ but noted that SRM ‘needs more studies on its impacts and feasibility.’ Respondent 9 said, ‘if this method proves to be effective and have minimal bad consequences, [they would be] supportive of this strategy.’ Respondent 16 said they ‘would love to know how these techniques could really work in solving the climate change crisis, how the studies on this matter [is] going on, and who are the stakeholders willing to contribute in this deployment.’ Respondent 17 had a similar opinion, saying: ‘while the concept has its merits, the deployment of this technique needs further assessment in terms of its overall mitigation benefits, costs, impacts, and other unintended consequences.’ Three respondents did not support the idea (Respondents 2, 12, and 15). Costs and impacts are an issue to Respondent 2, who said SRM is ‘too costly and limited to only reducing temperatures [and has no impact on reducing] ocean acidification rates.’ Respondents 12 and 15 had the same responses for the question on SRM research. Five (Respondents 6, 7, 8, 11, and 14) have no position on the issue.

4.3. Researching and deploying CDR techniques
Compared to the respondents’ divided opinions on SRM, fourteen respondents were generally supportive of CDR research and deployment. Respondent 2 suggested that research and development on [CDR] need to be accelerated as it is preferable to SRM.’ Respondent 12 suggested CDR research ‘should be encouraged more.’ However, it is essential to note that the prompt question for these responses broadly defined CDR to mean ‘techniques to remove carbon dioxide from the atmosphere, such as capturing carbon dioxide from the ambient air, tree planting, etc.’

Most significantly, four respondents have welcomed the research or deployment of CDR techniques involving natural or nature-based approaches, such as reforestation and afforestation. Respondent 17, for example, said, ‘large scale tree planting is a win-win option, and its deployment should be supported.’ Respondent 9 shared that tree planting activities ‘are already being conducted in the micro-level [locally or at the
community] and are naturally effective and tested strategies.’ In addition to reforestation and afforestation, Respondent 16 suggested ‘coral transplantation and mangrove field reconstruction.’ Respondent 15 agrees that carbon capture through ecosystem management ‘has a potential, especially if it becomes a source of income for poor farmers.’

In addition to ecosystem management techniques, Respondent 7 also suggested working on ‘innovations that can capture, deploy, and turn carbon dioxide into other valuable products, such as generating electricity and producing hydrogen fuel’ or what can be called chemical-based CDR approaches. Respondent 17 also supported the idea of ‘large scale removal of CO₂ from ambient air through chemical processes accompanied by storage.’ Respondent 14 further suggested more research on these chemical-based and other DACCS approaches. Respondent 2, however, was ‘unconvinced that techniques involving artificial carbon capture technology can be as effective as reforestation or afforestation,’ highlighting the ‘natural-artificial’ divide.

Respondent 5 said that more studies are needed about CDR techniques, while Respondent 15 opined that CDR is ‘promising, but the jury is still out.’ Respondent 3 also raised the questions: ‘where [these techniques will be deployed], who will govern [these deployments], are there adverse effects we don’t know about or cannot yet predict, and who will be liable for any (transboundary) harm caused?’

4.4. Researching the impacts of SRM and CDR in southeast Asia

Eleven respondents support the study of SRM and CDR, including the modeling of their impact in their countries and in the Southeast Asian region. Respondent 4 suggested that ‘academic research should be conducted to test the effectiveness of [SRM and CDR].’ Respondent 15 recommended ‘conducting more research on [SRM and CDR] to understand it better.’ Respondent 16 considered this field as ‘an opportunity for many researchers to stimulate the development of more creative solutions to face the climate crisis.’ Respondent 5 opined that ‘[SRM and CDR research] would be beneficial and urgent because Southeast Asia might be the most vulnerable [region] to the impact of those technologies.’ Respondent 17 even saw an opportunity for building new SRM and CDR research to complement their ongoing work, saying:

We would be happy to carry out a national study and participate in a regional or global study on this research area. We are currently doing scenario simulation analysis for the CO₂ emissions target for [country name]. Our current study is on emissions, but it would be interesting to broaden the scope to cover risks and impacts.

Respondent 14, however, preferred researching CDR impacts and had reservations on SRM research: the proposed study will benefit the current science-technology program of [name of country] regarding CO₂ removal technologies. Still, it may get some objections in terms of direct intervention in solar radiation.

Respondent 2 had no comment while Respondent 11 said they ‘don’t know enough’ to make a comment.

4.5. Researching geoengineering governance

CDR and SRM governance research are welcomed by eleven respondents stating that this work is ‘very important’ (Respondent 12), ‘a must’ (Respondent 9), ‘definitely needed to be done’ (Respondent 5), or ‘very necessary to promote technology development and strengthen the effective application of the technologies’ (Respondent 14). Of these four responses, only Respondent 14 expanded on their response, saying that ‘research will help define clearer responsibilities of different stakeholders in climate intervention technology governance.’ Respondent 3 mentioned that ‘there used to be a research program at [name of a Singapore university-based research institute],’ but the respondent is ‘not sure if it is still ongoing.’ Respondent 17 saw SRM and CDR governance research as an opportunity to expand their ongoing governance research, suggesting further that they ‘would be happy to participate in a regional analysis.’

Respondent 15, however, opined that this question is ‘too soon’ for the asking, suggesting instead the need to understand first what these technologies are. Which ones have greater potentials to succeed? Then, we can think about governance. Discussing governance without clarity on what needs to be governed is problematic.

Respondent 7 supported this view saying:
I think it’s a good starting point to safeguard and facilitate the implementation of climate intervention technologies. However, identifying and assessing the effectiveness and co-impacts of those technologies must be conducted to prove their necessity and feasibility. After gaining the recognition of a particular country, the governance scheme should be considered.

Respondent 2 made no comment. Respondent 4 said they are ‘not familiar’ with the question. Respondent 11 said they ‘don’t know enough’ to make a comment.

4.6. Barriers for inclusive SRM and CDR modeling and governance research

When asked what could hinder inclusive research on SRM and CDR techniques in Southeast Asia, respondents pointed to (1) lack of funding (4 responses from Respondents 1, 4, 7, 15, 16); (2) absence of policy support and direction (2 responses from Respondents 7 and 16); (3) lack of knowledge, capacity or expertise to conduct this
kind of research (3 responses from Respondents 4, 5, 9 and 12), such as on modeling (Respondent 17); (4) lack of access to high-quality data (3 responses from Respondents 8, 9 and 14) and modeling tools (Respondent 17); (5) the difficulty in locating test sites (Respondent 9); (6) lack of access to industry perspectives (Respondent 3); and (7) lack of competition on these research areas (Respondent 3).

Respondent 17, however, recognized that ‘participating in a regional or global initiative would perhaps address some of these barriers.’ Respondent 6 also cited ‘the diversity of [the region’s] political systems that may slow down political processes required to reach regional consensus on climate intervention.’ Notably, Respondent 15 raised the need to be ‘socialized with these technologies suggesting ‘to start the conversation first’ before any research on impacts and governance could start.

5. Discussion and conclusion

This paper presented the results of an expert survey to highlight the opinions of purposively sampled Southeast Asian climate and energy experts on SRM and CDR research in their region. The paper, thus, offered one of the very few and first attempts at addressing one of the critical gaps in what had been dubbed a predominantly European, Australian, and US-led, -funded, and -researched geoengineering research work. Seventeen climate and energy experts, working across ten Southeast Asian countries, provided their perspectives on these techniques, focusing primarily on whether researchers from this region should also study them and, in case, how this research and these techniques, if deployed, could be governed.

Nine respondents support SRM research but with reservations suggesting openness among Southeast Asian climate and energy experts to research these techniques and their impacts. Respondent 4 had even framed geoengineering, particularly SRM, as a ‘last resort,’ which is consistent with other perception studies where respondents consider geoengineering techniques as an emergency measure or Plan B (see review by Harmsch et al. (2015) and the cautions against using this narrative frame in Gunderson et al. (2019) and Horton (2015)). Eleven respondents also registered their ambivalence towards SRM deployment. Respondent 12 used the moral hazard argument against SRM, where energy transition and other mitigation techniques could be foregone with SRM research and deployment, echoing Delina (2021) and Lin (2013), among many others. But there is broad support for modeling their possible impacts, especially from four respondents, echoing earlier calls from, for instance, Kravitz and MacMartin (2020). The respondents’ cautious support of SRM is evident in the salience of risk governance and the appreciation of uncertainties amongst this cohort, which is also consistent with other studies (e.g., Dai et al. 2021, McLaren and Corry 2021). As novel technologies that, on the one hand, hold immense promise and, on the other hand, warn of substantial danger, SRM requires an emphasis on the possibility of nasty surprises and building a margin of safety (Randall 2011); areas of concern that the respondents voiced out in their responses.

Fourteen respondents support CDR, especially those techniques that require ‘natural’ interventions such as ecosystem management, BECCS, and other nature-based solutions. This preference can be attributed to the use of the word ‘natural’ in framing these techniques vis-à-vis ‘technocentric’ SRM and chemical-based CDR techniques. This framing makes ‘natural’ CDR more ‘acceptable’ than SRM and ‘technological’ CDR such as DACCS, echoing earlier work by Corner et al. (2013). The respondents’ relative approval of nature-based solutions can be attributed to the salience of Southeast Asia’s agriculture, forestry, and coastal sectors and their individual lived experiences.

While the survey had produced new insights into the opinions of Southeast Asian climate and energy experts towards SRM and CDR, the survey instrument had some limitations common in qualitative research, especially those relying on purposeful sampling. The first of these challenges is related to the size of the cohort. Although the respondents conducted their work in all ten Southeast Asian countries, the purposeful recruitment approach opened the study to a selection bias, especially in terms of seniority and age (Crosowell and Plano 2011, Patton 2014). Funding constraints meant that not everyone in the region’s pool of climate and energy experts could be invited to participate. A scaled-up expert opinion survey, using a random approach, thus, would be ideal for expanding our understanding of whether Southeast Asian climate and energy experts wanted to research SRM and CDR and in what particular aspects.

The second limitation pertains to the limited scope of the survey topics. The survey did not cover specific SRM and CDR technologies. However, Respondents 2 and 17 explicitly discussed SRM in their responses, and Respondents 7, 14, and 16 specifically mentioned some CDR approaches such as ecosystem management, BECCS, and DACCS. The limited number of topics covered is due to the limitations of the survey design and purpose itself. The workshop, by which the survey is fed onto, sought to seed select Southeast Asian researchers with broad geoengineering ideas rather than diving deeper into each SRM and CDR technique—which could have taken more time and resources (Delina 2020). For the same reason, the survey also excluded questions...
regarding the viability and feasibility of pilot projects and deployment, as well as their possible locations. Future expert surveys in the region could, thus, include questions on these missing items.

The survey also missed considering some emergent themes on the role of Southeast Asian-produced knowledge on SRM and CDR. Of particular interest for future research, thus, can include a study about the dominance of North American, European, and Australian geoengineering researchers, which led to an imbalance tantamount to neocolonialism as some authors have claimed (Biermann and Møller 2019, McLaren and Corry 2021). This argument follows that much geoengineering research is being funded and, thus, most likely, will be deployed in wealthy countries. There are already calls for researchers outside Europe, the United States, and Australia to take in geoengineering research (e.g., Rahman et al 2018, Sugiyama et al 2020 Delina 2020) but, apart from those mentioned in section 2, very few had taken this challenge. The reasons for this are complex and are only briefly explored in the present survey. Also important to note regarding devoted geoengineering research is the embeddedness of nonepistemic values in research and modelling (Galbraith 2021).

SRMGI (2021b) addresses funding gaps by providing grants to non-European/American/Australian modelers, including the Indonesian team mentioned above (see section 2). Yet, very little to zero funding was made available to other experts, particularly in policy, social sciences, and the humanities, despite their interest in doing the work (Delina, 2020). Some social studies research areas that they wanted to pursue include historicizing geoengineering in the region, fostering transparency across different geoengineering epistemic communities (i.e., modelers, policy analysts, and social scientists), separating the familiar weather modification approaches (such as cloud seeding) from SRM, democratizing geoengineering governance, and analogizing geoengineering with other large-scale technological systems that Southeast Asian experts are more familiar with, among others (see Delina 2020 for more detail).

In closing, the idea of Southeast Asian experts actively producing new knowledge on SRM and CDR research and contributing to the local, national and international understanding of these techniques, their risks, and potentials has its appeal. Yet, it is also important to note that these researchers may not excitedly respond to calls for engagement for reasons already mentioned. For inclusive geoengineering research to take off, where Southeast Asian scholars actively participate in knowledge production in these specialized areas, South-South and South-North collaborations and research initiatives are imperative. It is also worth examining other concerns and preferred research directions from different world regions. One can start by deploying similar but expansive expert surveys in the Pacific, south Asia, Latin America, and sub-Saharan Africa. These results can then be compared and analyzed so that funding and capacity development efforts, and collaborations could be more targeted based on actual needs and preferences.

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Data availability statement

The data generated and/or analysed during the current study are not publicly available for legal/ethical reasons but are available from the corresponding author on reasonable request.

Appendix A. Descriptions of the survey respondents.

| Code | Description |
|------|-------------|
| Respondent 1 | Male, with postdoctoral experience, engineering background, and more than five years’ experience in climate; Worked in a research institute in Indonesia. |
| Respondent 2 | Male, with postdoctoral experience, background in the natural and physical sciences, and more than ten years’ experience in climate and governance; Worked in a university in Singapore. |
| Respondent 3 | Female, with master’s level education, background in the social sciences, and more than five years’ experience in climate, energy and governance; Worked in a university in Singapore. |
| Respondent 4 | Male, with postdoctoral experience, background in the natural and physical sciences, and less than five year-experience in climate, modeling, and scenario building; Worked in a university in Malaysia. |
| Respondent 5 | Male, with postdoctoral experience, background in the mathematical sciences, and more than five years’ experience in climate, modeling, and scenario building; Worked in a university in Indonesia. |
Appendix B

Survey instrument

Demography

1. Where are you currently working/Working sector: academia, industry, research institute/think-tank, government, international organization, other.
2. Which country are you currently working in?
3. Area of work/disciplinary specialism: climate, energy, development, policy/governance, scenario building/modeling, advocacy, others.
4. Years working: less than 5, 6–10, 11–20, 21 above
5. Educational specialization: social science, humanities, law, engineering, science, others
6. Highest educational attainment: bachelor’s, master’s, doctorate, post-doctorate
7. Sex: M/F

Personal attitudes

8. Beyond adapting to climate change, what other climate action responses should humanity do to reduce its impacts?
9. At your discretion, what do you think of the ‘continuing as usual’ option?
10. At your discretion, please tell us your appraisal and reflection of the following ‘conventional’ climate mitigation options:
10.1 Reducing emissions from the energy sector
10.1.1 Voluntary reductions in domestic, commercial, and industrial energy use
10.1.2 Increasing the proportion of energy provided by small and large renewables such as wind turbines, solar photovoltaics, hydropower, and geothermal powerplants
10.1.3 Carbon tax and market-based carbon trading
10.1.4 Nuclear energy
10.1.5 Coal energy with carbon capture and storage
10.2 Reducing emissions from the agriculture, transport, and forestry sectors
11. At your discretion, what do you think of the ‘loss and damage mechanism’?
12. What other ‘beyond adaptation and beyond mitigation’ options do you have in mind that you like to share?
13. At your discretion, please tell us your appraisal and reflection of the following ‘beyond conventional mitigation and beyond adaptation’ options:

| Code | Description |
|------|-------------|
| 6    | Male, with a doctoral degree, background in the social sciences, and more than ten years’ experience in energy, development, policy, governance, and scenario-building; Worked in a university in Singapore |
| 7    | Female, with postdoctoral experience, background in the social sciences, and more than five years’ experience in climate, energy, governance, and scenario-building; Worked in a government agency in Vietnam. |
| 8    | Male, with a doctoral degree, background in engineering, and more than five years’ experience in climate, modeling, and scenario-building; Worked in a university in Laos. |
| 9    | Female, with master’s degree, background in law, more than five years’ experience in climate, energy, development, and governance; Worked in a research institute in the Philippines. |
| 10   | Male, with a doctoral degree, background in the natural and physical sciences, and less than five year-experience in advocacy; Worked in a university in Myanmar. |
| 11   | Female, with postdoctoral experience, background in the humanities, and more than five years’ experience in social science research; Worked in a university in Singapore. |
| 12   | Female, with a doctoral degree, background in engineering, and more than ten years’ experience in climate, energy, policy, and governance; Worked in a research institute in Indonesia. |
| 13   | Female, with postdoctoral experience, background in the social sciences, and more than five years’ experience in energy, development, and governance; Worked in a university in Singapore. |
| 14   | Female, with a master’s degree, background in the natural and physical sciences, and more than 15 years’ experience in policy; Worked in a government agency in Vietnam. |
| 15   | Male, with a doctoral degree, background in the social sciences, and more than 15 years’ experience in climate and development; Works in Cambodia, Indonesia, Myanmar, the Philippines, and Thailand. |
| 16   | Female, with master’s degree, background in the natural and physical sciences, and more than ten years’ experience in climate and education; Worked in an international organization based in Indonesia. |
| 17   | Male, with a doctoral degree, background in the social sciences, and more than 20 year-experience in climate, energy, policy, governance, modeling, and scenario-building; Worked in a university in Brunei Darussalam. |
13.1. Research and development on the use of techniques that would reflect sunlight to space, such as through injecting reflective sulfate particles in the stratosphere

13.2. Research and development on techniques to remove carbon dioxide from the atmosphere, such as capturing carbon dioxide from the ambient air, tree planting, etc.

13.3. Deployment of techniques that would reflect sunlight to space

13.4. Deployment of methods to remove carbon dioxide from the atmosphere

14. Deliberate, large-scale interventions in the Earth’s climate system, known collectively as climate intervention or climate engineering or geoengineering, comprise an array of proposals/technologies that can broadly be divided into two types: carbon dioxide removal (CDR) and solar radiation management (SRM), each of which poses unique opportunities but also risks of adverse impacts and unintended consequences. This led to calls for more inclusive and responsive modeling/scenario-building and governance of climate intervention technologies that explore possible effects and implications and adequately account for them in technological development and decision-making processes. At your discretion, please tell us your appraisal and reflection—this could be your weighing of the benefits and the risks, the pros, and cons—on the following:

14.1. Conducting academic research on the modeling or scenario-building on climate intervention technologies, their risks, and impacts in your country and Southeast Asia

14.2. Conducting academic research on the governance of research/deployment of climate intervention technologies in your country and Southeast Asia

14.3. The key barriers and challenges for inclusive and responsive scenario-building/modeling and governance research on climate intervention technologies in your country ad in Southeast Asia

End of survey.

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