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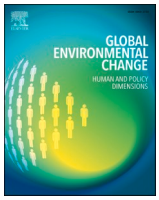

Climate beliefs, climate technologies and transformation pathways: Contextualizing public perceptions in 22 countries

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ABSTRACT

As emerging methods for carbon removal and controversial proposals around solar radiation modification are gaining traction in climate assessments and policy debates, a better understanding of how the public perceives these approaches is needed. Relying on qualitative data from 44 focus groups (n = 323 respondents), triangulated with a survey conducted in 22 countries (n = over 22 000 participants), we examine the role that climate change beliefs and attitudes towards climate action play in the formation of public perceptions of methods for carbon removal and solar radiation modification. We find that nationally varying degrees of perceived personal harm from climate change and climate worry predict support for these technologies. In addition to different perceptions of the problem, varying perceptions of the solution – i.e. the scope of climate action needed – shape publics' assessment. Various tensions manifest themselves in publics' reflections on the potential contribution of these climate technologies to climate action, including "buying time vs. delaying action", "treating the symptoms vs. tackling the root causes", and "urgency to act vs. effects only in the distant future". We find that public perceptions are embedded in three broader narratives about transformation pathways, each reflecting varying notions of responsibility: (i) behavior change-centred pathways, (ii) top-down and industry-centred pathways, and (iii) technology-centred pathways. These results suggest that support for the deployment of the climate technologies studied hinges on them being tied to credible system-wide decarbonization efforts as well as their ability to effectively respond to a variety of perceived climate impacts.

1. Introduction

Emerging climate (−intervention) technologies are increasingly prominent in climate assessments and policy debates about how to meet the goals of the Paris Agreement. These comprise carbon dioxide removal (CDR) methods, including more familiar practices such as afforestation and soil carbon sequestration, and more novel methods such as direct air capture and carbon storage (e.g. IPCC, 2022), as well as controversial proposals around sunlight reflection modification (SRM) like stratospheric aerosol injection (e.g. NASEM 2021).

Past controversies over emerging technologies such as shale gas extraction (Bradshaw and Waite 2017), genetic engineering (Hansen 2010) or carbon capture and storage (Terwel et al. 2012) have shown that attitudes and risk perceptions of diverse publics are important socio-political factors when it comes to the deployment of novel technologies at large scale. Given the increasingly central role of some climate-intervention technologies in climate plans and pledges, a growing body of social science research published in this very journal has been examining public attitudes, concerns and levels of support for various CDR (Bellamy 2022; Corner et al., 2013; Forster et al. 2020; Low et al. 2022) and SRM approaches (Bellamy et al. 2013; Bellamy et al. 2017; Cairns and Stirling 2014; Clery et al. 2021; Macnaghten and Szerszynski 2013). Empirical research on public perceptions of these approaches has so far focused on a few countries from the Global North, with cross-country comparisons and mixed-methods accounts being rare (for an overview see Sovacool et al. 2023).

Given generally low levels of familiarity with CDR and SRM in the public (Corner and Pidgeon 2015; Merk et al. 2019; Wolske et al. 2019; Cox et al. 2020), holistic perspectives situating the formation of public perceptions of these approaches in the wider context of values and

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beliefs are needed. In a two-country study Cox et al. (2020) find a positive impact of climate change concerns on beneficial perceptions of CDR in the UK and the US. Previous studies have, furthermore, identified which synergies or trade-offs publics see between the large-scale deployment of carbon removal on the one hand and wider climate action and transformation towards sustainability on the other (Wibeck et al., 2017; Raimi, 2021; Satterfield et al., 2023). These include concerns over unsustainable or unjust land use practices, particularly for approaches such as afforestation and reforestation or BECCS, as well as delays in emissions reduction and system-wide transformations (McLaren et al., 2021; Carton et al. 2023).

Such broader contextualization of public perceptions is particularly important in light of research on other climate strategies which has shown that publics are likely to judge and assess climate strategies and policies against the backdrop of their beliefs about the nature and severity of the problem of climate change (Evensen et al. 2023; Fairbrother 2022), their levels of concerns (Bouman et al. 2020) and their emotions regarding climate change (Wang et al. 2018). Just as research on climate-intervention technologies, such research on environmental psychology and climate beliefs more generally has been heavily dominated by samples from Western, Educated, Industrialized, Rich, Democratic (WEIRD) countries (Tam and Milfont 2020; Henrich et al., 2010).

Applying a mixed methods approach, this paper combines qualitative data from 44 focus groups and quantitative data from a large-scale, cross-country survey on climate change and public perceptions of CDR and SRM in 22 countries of the Global South and Global North. We (i) map geographies of climate beliefs and attitudes as well as document perceived climate impacts and harms and (ii) show how participants make sense of and assess CDR and SRM in the context of their views on climate change, climate action and transformation pathways.

2. Background and literature review

In this section, we briefly review key literature published mostly in the past 10 years on how climate evaluations shape public support for climate action in general and climate-intervention technologies in particular (2.1.) as well as on (undesirable) interactions between public discourse on climate-intervention technologies and measures targeting emissions reductions (2.2.).

2.1. Support for climate action: The role of climate beliefs, attitudes and concerns

Numerous studies have been conducted into public perceptions of climate change and the factors driving public skepticism or denial of climate change (Leiserowitz et al 2021; Lorenzoni and Pidgeon 2006), including organized misinformation campaigns (Hornsey et al. 2016), and mistrust in scientists (Alvarez et al. 2023). In addition, political ideology has repeatedly been found to be decisive for climate beliefs in the US (Hornsey et al. 2018), but less so in European and post-communist states (Smith and Mayer, 2019; Ziegler, 2017).

Research into the drivers of public rejection or support of climate policies and climate action is, however, comparatively nascent and focused on a few Global North countries (Fairbrother 2022). This scholarship – strongly informed by environmental psychological studies and predominantly based on quantitative surveys – suggests that support for different types of climate policies and action is related to beliefs about the nature and severity of climate change (Fairbrother 2022; Bliuc et al. 2015), and perceptions of the associated risks (Gregory et al. 2016). Beliefs more generally for example regarding the fairness and effectiveness of climate policies shape public support (Bergquist et al. 2022; Huber et al. 2019), as recently demonstrated in a study on the public rejection of the Swiss CO2 law in 2021 (Simon 2023). Emerging evidence, furthermore, points to the importance of second-order climate beliefs, i.e. beliefs that individuals hold about the climate beliefs of others – both within and between countries. A recent study conducted in the US and China suggests that biased second-order beliefs, underestimating the extent to which the general public acknowledges the existence and anthropogenic nature of climate change and is willing to engage in climate action, significantly lowers respondents' support for climate action (Mildenberger and Tingley, 2019). Sparkman et al. (2022) report similar findings of such a pluralistic ignorance among a representative sample of US respondents and Pearson et al. (2018) show how particularly environmental concerns of minority and low-income Americans are underestimated, acting as an impediment to addressing environmental inequities.

Furthermore, affect and emotional responses to climate change have been found to influence public support for climate action (Pearson et al. 2016; Myers et al., 2023; Wang et al., 2018). National and cultural variances require further attention here. Based on the European Social Survey in 23 countries, Bouman et al. (2020) show how feelings – particularly "worries" about climate change – can directly and indirectly affect both climate policy support and personal climate mitigation behaviours such as energy-saving. Earlier studies suggested that publics in western, industrialized countries tend to perceive climate change as a geographically and temporally distant problem, which can hamper negative emotions or strong affective responses, and in turn lower support for climate mitigation efforts (Leiserowitz, 2006; Pearson et al. 2016). Similar earlier findings on perceptions of environmental issues point to spatial optimism across a range of mostly Global North countries (Gifford et al. 2009). A more recent study confirms for nine countries in Europe, North America and Asia that the respective publics tend to perceive climate change as more of a threat to the "world" and others than to themselves (Tvinnereim et al. 2020).

Research on the role of experience with and exposure to climate impacts and climate-change related natural disasters remains inconclusive. Some scholars do not find evidence – at least in the short-term – for a direct translation of personal experiences into support for climate policies (Fairbrother 2022), or changes to pro-environmental behavior (Whitmarsh 2008). However, others find personal experience to be an influence on beliefs about climate change and intentions to mitigate its impacts (Zanocco et al. 2019) as well on support for environmental parties (Hoffmann et al. 2022). Bergquist et al. (2019) studied in an ex-post design the effects of Hurricane Irma on climate beliefs and attitudes in Florida (USA). They found that personal experience with this extreme event strengthened respondents' belief in climate change, increased their concerns about its impacts and led to higher levels of support for climate policies such as tax increases. Considering other cases and indicators for climate action support, however, blurs the conclusions. Garside and Zhai (2022) studied the impact of a major flooding event in Germany that happened shortly before the election in 2021. Taking voting for the environmentalist party (the "Green" party) as a proxy for support for climate mitigation, they did not find any evidence that the floods translated into an increase in voters' issue prioritization of climate change. They conclude that there is limited possibility for major natural disasters to catalyze local political support for environmentalist parties and their political program. Kleinberg & Toomey (2023) argue that – not last in light of inconclusive quantitative evidence – more qualitative research is needed to gain deeper understanding of how people make sense of climate change and its impacts.

2.2. Literature on how climate beliefs affect perceptions of CDR and SRM approaches

For climate-intervention technologies as one potential part of climate response, previous research has shown that public acceptance or rejection hinges on peoples' worldviews, and values regarding human-nature relations and their beliefs about the severity and urgency of climate crisis (Cox et al. 2020; Satterfield et al. 2023).

Public perception studies on SRM, for example, have shown that respondents who are highly worried about climate change are more likely to express positive attitudes toward this approach, and to consider

it as a potential solution (Mercer et al., 2011; Merk et al. 2015; Pidgeon et al., 2012; Fujiwara and Sugiyama, 2016). Perceived severity and urgency of climate change have also been found to impact support for CDR, both in general (Pidgeon et al. 2012; Braun et al. 2018; Gregory et al 2016) and for specific technologies like DACCS (Satterfield et al. 2023; Scott-Buechler et al. 2023), afforestation (Merk et al. 2023) or ocean-based approaches (Nawaz et al. 2023). This relationship is more dubious for enhanced weathering, with Pidgeon and Spence (2017) finding that concern about climate change had no influence on support for research and deployment, while Cox et al. (2020) demonstrated the urgency of climate change can also prompt concerns that any such actions would take too long. Having looked at seven different CDR options, Jobin and Siegrist (2020) identified a positive effect of concern about climate change for only three: DACCS, afforestation, and ocean fertilization – and only stratospheric aerosol injection among three SRM options. Conversely, higher skepticism about climate change and its anthropogenic nature has been shown to translate into lower support for SRM and CDR approaches among UK respondents (Corner and Pidgeon 2015). In a series of focus groups across the US, Scott-Buechler et al. (2023) have distinguished the persuasiveness of linking DACCS with climate change, e.g., with some participants in fossil fuel-reliant areas deeming climate change not relevant for that area – in some cases, recommending that economic opportunities be highlighted instead. Regarding the role of emotions, an experimental study conducted in Switzerland suggests that respondents with negative affective evaluations of climate change (i.e. those who state that climate change evokes negative feelings for them) were – if they did not receive information on SRM – more open to considering SRM approaches (Sütterlin and Siegrist 2017). In their cross-country analysis of public perceptions on SRM in Canada, China, Germany, Switzerland, UK, and USA, Visschers et al. (2017) found that those less concerned about tampering with nature as well as respondents from countries that are less engaged in climate change mitigation and adaption efforts, are more favorable of SRM.

2.3. *Discourses about climate-intervention technologies and broader climate action: Mitigation deterrence and climate delay*

Two related bodies of literature focus on how CDR and SRM technologies might introduce incentives to delay decarbonization efforts – colloquially referred to as a 'moral hazard', and more formally as 'mitigation deterrence'. The first describes public engagement studies – comprising large-n surveys, small-n, deliberative focus groups, strategic games or mixed methodologies – that attempt to gauge whether learning about SRM (Andrews et al. 2022; Cherry et al., 2021, 2023; Hart et al., 2022; Raimi et al. 2019; Kahan et al. 2015), CDR (Campbell-Arvai et al., 2017; Cox et al., 2020; McLaren et al., 2021; Satterfield et al., 2023), or combinations thereof (Austin and Converse, 2021; Corner & Pidgeon 2014; Merk et al 2019; Wibeck et al 2017) affects public reasoning and support for actions to reduce emissions. It bears repeating that almost all such studies have taken place in the Global North.

Results are mixed. For some (e.g., Merk et al., 2019; Cherry et al., 2021), mitigation deterrence plays no clear, definitive role in preferences on climate action. Political ideology and context play an under-investigated role, with a conservative inclination (at least, in the US) more likely to permit climate intervention to erode climate action (e.g., Campbell-Arvai et al., 2017; Kahan et al. 2015). Carton et al (2023) point out that quantitative studies focusing on how individuals judge their own preferences for climate action demonstrate less mitigation deterrence than studies that highlight how individuals gauge the actions of others. Meanwhile, contrasting with (much) survey work, focus groups that emphasize open deliberation tended to bring up richly detailed dimensions of mitigation deterrence (McLaren et al., 2021; Cox et al., 2020; Satterfield et al., 2023).

These dimensions have led Carton et al. (2023) to challenge studies that pin the potential scope of mitigation deterrence on individual preferences. Instead, they appeal for a 'structural' view that parses the incentives and constraints that motivate governmental and corporate actions in delaying decarbonization. This second body of literature investigates a longer arc of activities that serve as parallels or antecedents to CDR and SRM, where emission reduction efforts are arguably elided in the pursuit of so-called bridging or time-buying strategies (Low & Boettcher, 2020; Carton et al., 2020; McLaren & Markusson, 2020; Røttereng 2018; Stoddard et al., 2021). Others anticipate how incorporating CDR (or SRM) into future emissions reductions targets or policy planning processes are already introducing further incentives for delay (Jacobs et al., 2023; McLaren & Markusson, 2020). It is essential to establish the gap between public expectations and the emerging actions of government and industry.

Based on this literature review, in our analyses, we consider a broad set of climate change evaluations as those were found to be potential key drivers of climate policy support – both in general and for specific approaches such as CDR and SRM. We, furthermore, consider interactions between specific approaches such as climate-intervention technologies and public perceptions of broader climate action.

In reviewing these various bodies of research – both on climate beliefs and attitudes in general and on their relation to perceptions of climate-intervention technologies specifically – a heavy focus on WEIRD countries becomes apparent. Cross-national studies that account for diverse lived experience with climate change and situated perceptions of risks and benefits are urgently needed to provide more comprehensive support for decision-making and governance of these global phenomena.

3. Research methods

This paper adopts a mixed-methods approach, combining qualitative thematic analyses of focus group transcripts with statistical analysis of a large-n survey. In the following, we briefly describe the data collection and analysis process. More details are provided in the Supplementary Information.

3.1. *Data collection*

The selection of the 22 countries included in the study (Fig. 1) was guided by the aim of achieving geographic spread and ensuring representation of "non-WEIRD" countries and regions which have so far been neglected in the literature (South America, the Middle East and Africa) as well as inclusion of some small island developing states, given salience of severe climate threats in these countries. In so doing we join calls for better inclusion of non-WEIRD countries made by scholars from various fields, including geography and political ecology, psychology, energy and climate social sciences (Henrich et al., 2010; Furszyfer Del Rio et al., 2023; Peñasco et al., 2021; Sovacool 2021) – calls which are increasingly also made for various climate-intervention technologies (Biermann and Möller 2019; Delina 2020; Táíwò and Talati 2021; Winickoff et al. 2015).

Our original survey study included 30 countries (n = 30,284 respondents). In this article, we consider only those 22 countries that were also included in the focus groups, i.e. we rely on a reduced survey sample. The quantitative surveys in those 22 with a total of 22 222 participants were representative of the respective national population (between the ages of 18 and 83) in terms of gender, geographic region, age, income, and education (with at least N = 1,000 for each country). The composition of the focus groups was guided by diversity sampling. 44 focus groups were conducted, with one in an urban and one in a rural setting in each country, amounting to a total of 323 participants. Reflecting comparatively small sample sizes, screening for selected characteristics, and potentially driven by emergent topics and dynamics particular to each group, they are not fully representative of national publics. That said, they far surpass much existing focus group data that rely on only a few dozen total respondents, or less, or fewer than 5–8 focus groups in total. Notably, in order to establish some ground for

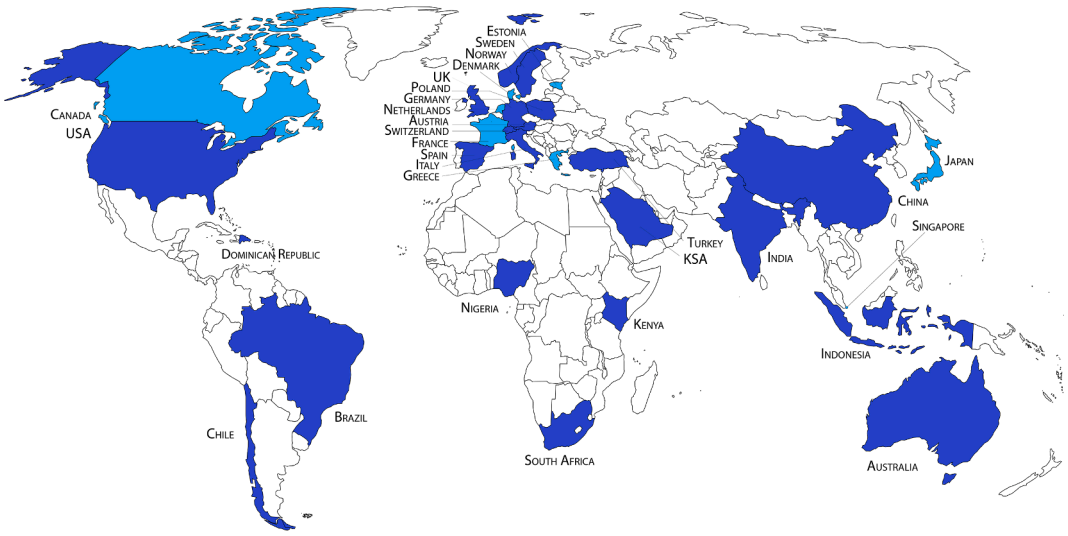

Fig. 1. Overview of countries included in the mixed methods study. Note: Dark blue: focus groups and survey; Light blue: survey only – not included in this article; following the classification of United Nations' Finance Center for South-South Cooperation the countries covered in this paper include 10 countries from the *Global South*: Brazil, Chile, India, Indonesia, South Africa, Kenya, Saudi Arabia, Nigeria, Dominican Republic, China, and 12 countries from the *Global North*: USA, Australia, Austria, Germany, United Kingdom, Sweden, Poland, Switzerland, Italy, Norway, Spain, Turkey. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

constructive discussions, climate denialism was screened out (all who answered "No" to either of two questions: "Do you believe climate change is happening?", and "Do you believe climate change is the result of human activity?"). Both the survey and the focus groups were conducted in the respective national languages and implemented by NORSTAT, a European-based data collection company.

The survey examined ten technologies, broken down into three technology types. Participants were randomly assigned to one of the following: SRM including stratospheric aerosol injection (SAI), marine cloud brightening (MCB), space-based geoengineering (SBG); CDR 1 including afforestation and reforestation (AF), soil carbon sequestration (SCS), marine biomass and blue carbon (MBBC); CDR 2 including direct air capture with carbon storage (DACCS), bioenergy with carbon capture and storage (BECCS), enhanced weathering, biochar. Short information texts and illustrations were provided for each technology, alongside a balanced presentation of potential risks and benefits (see Supplementary Material B for the full survey instrument).

The focus groups included the same SRM approaches and a slightly reduced variety of CDR approaches. We chose two biogenic sets of approaches: (1) afforestation, reforestation and restoration of vegetation, as a proxy for management of terrestrial and marine ecosystems, including blue carbon, (2) soil carbon sequestration, as a proxy for agricultural management practices, including biochar. We then chose two distinct types of chemical approaches: (3) DACCS and (4) enhanced weathering. Finally, we opted for (5) BECCS, a hybrid approach that combines a bioenergy input (and therefore, a land-use component with overlaps to biogenic approaches) with a geological storage component.

3.2. Data analysis

In our quantitative analysis of survey data, we first provide descriptive evidence for all countries by focusing on the following questions related to climate change perceptions: (1) "Do you believe that climate change is occurring, and that it is the result of human activity?" (2) "How worried, if at all, are you about climate change, sometimes referred to as 'global warming'?" (3) "Have you personally experienced the effects of a major natural disaster (e.g., flood, heatwave, wildfire, blizzard) in the last three years?" and (4) "How much do you think climate change will harm you personally?".

We center our subsequent analysis of support for different technologies around two predictors: climate worry and perceptions of climate harm. This choice is rooted in compelling descriptive evidence: while a significant majority of respondents across all countries in our sample expressed a belief in climate change (i.e., little cross –country variation), we observed a substantial divergence in the levels of climate worry and perceived climate harm. Additionally, the questions related to climate worry and perceptions of climate harm have a wider response range allowing for a more nuanced statistical analysis. In Section 4.1 we show that there is an overlap between countries where a larger share of respondents indicated that they experienced a natural disaster and the perceived personal harm. We report the results for all variables in the Supplementary Information (Fig. A.3), where we show that the results using the natural disaster variable are very similar to the main analysis presented in Section 4.2. We proxy the support level for a given technology by using the responses pertaining to a broader deployment ("How much do you support the broader deployment of each of the technologies to limit the effects of climate change?") – with response options (on a 1–5 scale) ranging from "Strictly reject","Somewhat reject", "Neither reject nor support", "Somewhat support" to "Fully support".

Our qualitative analysis relies on the transcripts of 44 focus groups which were translated to English. The empirical data were managed, coded, and analyzed with the software 'MAXQDA'. Two of the authors conducted the qualitative coding of the transcripts, following an iterative process and a "negotiated agreement" approach to establish intercoder triangulation (Campbell et al., 2013).

Guided by thematic analysis (Nowell et al., 2017), we qualitatively analyzed the reflections of focus group participants in response to the introductory question: "To start with, could you all please briefly introduce yourselves, sharing your first name and telling us how worried are you and/or your community about climate change, and why?". We, furthermore, analyzed unprompted reflections by participants about various dimensions of climate change throughout the discussion, for example in relation to questions about risks, benefits and governance of CDR and SRM. That they are spontaneous associations and were not promoted by discussion questions, suggests high salience and importance of the respective themes for participants; however, the fact that they are unprompted also means that we do not systematically have material for all groups. In reporting the results, we focus on frequently recurring themes that are addressed across focus groups in different

countries. Where possible we emphasize context specificities or variances in interpretation of themes. While counts of country mentions offer some indication on the relevance and salience of themes, group dynamics may simply have led to a focus on certain themes and a neglect of others, albeit also nationally relevant themes. References to country mentions and country counts, thus, need to be interpreted with caution.

Integration of the quantitative and the qualitative research component was guided by dimensions for integration in mixed methods research and was prepared at the level of the research design. Questions in the survey and the focus groups were linked to "sequentially deepen" and complement both the topic addressed and the type of data collected (numerical, oral turned into text). During data analysis and interpretation integration was realized through "merging" the respective datasets and creating narratives (Fetters et al., 2013).

4. Results and discussion

We, first, provide empirical insights into geographies of climate beliefs, concerns and perceived as well as experienced climate harm in 22 countries. Second, we establish climate beliefs and perspectives on climate action as an important context within which publics make sense of and form perceptions of novel climate technologies and their role in tackling climate change.

4.1. Cross-country variations in climate change beliefs, and experiences with climate impact

The survey results reveal cross-country commonalities but also variances in climate change evaluations, including climate beliefs, climate worry, perceived personal harm as well as experiences with natural disasters.

As depicted in Fig. 2 (Panel A), the majority of respondents across all 22 countries acknowledge the occurrence of climate change (at least half of the respondents), with Saudi Arabia and China being countries with relatively low shares of respondents acknowledging that climate change is occurring as a result of human activity. Asked whether respondents are worried about climate change (Panel B), a difference emergence between high income countries, mostly in the Global North, as compared to others. This trend is most pronounced when looking at the cross-country variation in response to the question "How much do you think climate change will harm you personally?" (Panel D): while in Turkey 94 % and the Dominican Republic 90 % of respondents expect to be personally affected by climate change, only 28 % say so in Norway. We further observe an overlap between countries where a large share of respondents has recently experienced a natural disaster (Panel C) and where a large share of respondents expects to be personally harmed by climate change (Panel D). These findings are aligned with previous studies, highlighting that respondents from the Global North are generally worried about climate change but do not necessarily perceive it as something that affects them personally (Tvinnerheim et al. 2020).

The focus group data allow us to qualitatively carve out some of the country variances mapped with the survey data and offer insights into lived experiences and sense-making practices of participants (Table 1).

Focus group participants shared a wide range of experiences and concerns about climate impacts (Fig. 3). Across world regions, participants mentioned "changes in seasons" including unusual temperatures and disturbed precipitation patterns, as well as worries about the living conditions of "younger and future generations" as major concerns regarding climate change. These were the most globally discussed dimensions in terms of numbers of coded segments, with particularly strong emphasis on younger and future generation in European countries. Experiences with and concerns about "heat stress, drought and its impact on agriculture" are the third dimension discussed in focus groups across all regions. There was a particularly strong emphasis on heat-

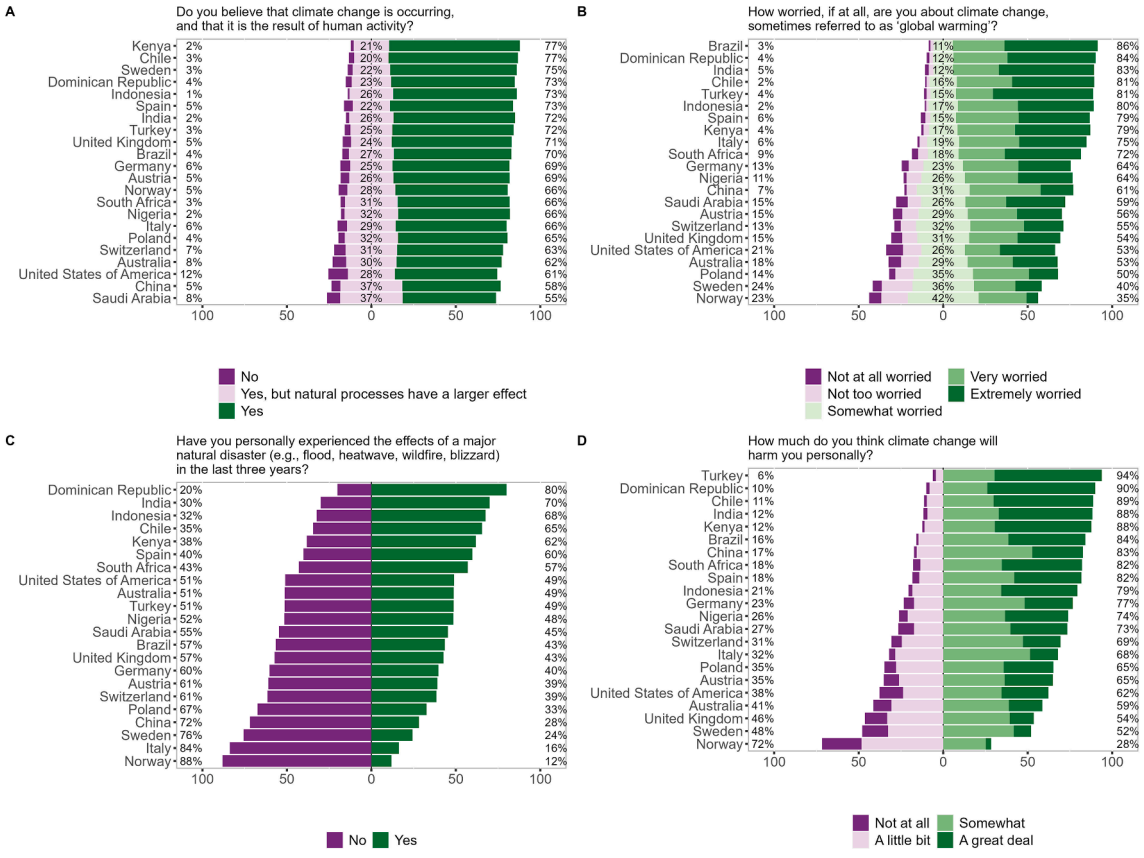

Fig. 2. Results from the survey for 22 countries for key indicators of climate beliefs. Note: The results show the percentage share of respondents for a given category.

Table 1
Overview of climate change dimensions discussed in focus groups in 22 countries.

Dimension	Anchor statements	Emphasized in
Experienced or expected climate impacts		
Changes in or shortened seasons	"I come from milk country (informal for Nakuru), where right now we are experiencing a shortage of rain due to global warming. At this time of the year we are supposed to be growing maize and other crops but now the season has changed due to global warming and that is a big concern". (Kenya urban)"I live in the northern region of the metropolitan region. The seasonal changes are worrying because we don't have winter, we have little rain, there is a shortage. The heat is very overwhelming and affects animals and crops. (…). We don't have winter; it is summer practically all the time. And it is also due to the pollution from the companies, the burning of the forests, this affects everybody." (Chile rural)	Widely mentioned across *Global North* and *Global South*
Heat stress, droughts, water shortage	"I live in the Gölbaşı district of Adıyaman and there is an unbelievable water shortage here. There was an incredible drought these past two years, especially in the summer. (…) We even bought tomatoes for canning this year. We actually have a vegetable garden. We could not get any yield from the garden we planted ourselves. The reason is drought." (Turkey rural)"It gets so hot at times that I can't stand stepping outside because of how hot it is, for example here in Dammam the humidity is high, we can't stand it to the extent we can't go outside, at summer we can't go outside, not even to the sea or parks, it gets annoying because of the climate change and global warming." (Saudi Arabia urban)	Widely mentioned across *Global North* and *Global South*
Bush and forest fires	"I live on the mid-north coast of New South Wales. I guess, it is a really big worry for us because we have had bushfires here that literally got across the road from our home, and we live in a suburban area, but then within 12 months, we also had massive floods, and I think when you look at all these really catastrophic events, events that are happening in a really small period of time, we just seem to be going from one to the other, and I just worry, obviously, about the effects for us immediately as a family and as a community." (Australia rural)	*Global North:* Australia
Floods and storms	"Yeah, basically bushfires and floods again. I live in an area which is close to flood prone area and even though our own house doesn't flood, we have trouble getting in and out transport wise and we're heavily impacted by flooding and it's the bushfires and floods seem to be getting worse in other area, which is Sydney area again" (Australia urban)"I think that climate change is a big issue. I am from a coastal area. So hurricanes and the impact of increasing climate change has been a huge issue, causing some of the worst hurricanes we've ever seen, massive evacuation and floods and huge loss of life." (USA urban)	Widely mentioned, with strong emphasis in *Global South:* Indonesia, Dominican Republic, Nigeria, South African *Global North:* Australia
Melting of glaciers and ice sheets	"That is something that weighs on me a lot and what I find unfortunate is that nature is being destroyed, especially in Switzerland where we have so many glaciers that are melting away without any chance of recovering properly." (Switzerland urban)	*Global North:* Switzerland, Italy
Biodiversity loss	"I also have grandchildren, I would like them to live healthy, I would like to preserve it, at the moment we have information that a lot of plant species are dying due to a big change in the climate, that there are no winters like they used to be, there are no summers, this is also, it seems to me, due to climate change. Animal species are dying out. "(Poland rural)	*Global North:* Turkey, Italy, Poland, Switzerland, Austria, Australia *Global South:* Dominican Republic
Sea-level rise	"Climate change really concerns me because we actually live in a low-level coastal area, down in Victoria, and so any impact is really going to influence us. We're also surrounded by new wind farms, and that they're going to be built in Bass Strait. So I actually have been looking into that renewable area quite a lot. I'm just concerned about the future" (Australia rural)	*Global North:* Australia, Austria, Norway *Global South:* Nigeria, Saudi Arabia
Economic impacts and threat to livelihoods	"Climate change is affecting us especially us who are selling in the market because I sell beans and maize in the market sometimes when it's raining we can't sell because it is not dry and we lose because the plants rot and when it's raining it can't dry and when it's hot again it's another problem because we don't get to sell in the market because the supplier says it's too hot, it's really affecting us." (Kenya rural)"Actually speaking about climate change it is quite worrying, not only as R says the health issue is so worrying because of the different diseases that exist, but also if you go into the area of deforestation how it affects the economy because when a country is deforested the land has a lot of influence and many harvests are lost. Many things in agriculture, the rivers are drying up and all of this is destroying tourism, agriculture, a lot of things that if you look at it from that point of view, we should be very concerned, we humans are the ones who are influential in making a change." (Dominican Republic rural)	*Global South:* Dominican Republic, Indonesia, Kenya, Saudi Arabia, South Africa
Health impacts	"Needless to say, I will mainly talk about the climate change. It is not cold when it should be cold, and it is not hot when it should be hot, which causes the old people's maladjustment to their bodies. Because they have many basic diseases and the weather is changing so quickly, they cannot control their own bodies, which has a great impact on individuals. I think this is very critical." (China rural) "Okay me too I am from Jeddah, […] so our area is very hot it's mostly an industrial area, the temperature is very hot in here, my main fear is the drought, the drying of land and trees and even some rivers in Jeddah, so this is one of the factors of climate change it also affects our health and causes environmental pollution and also chest diseases have increased here, even people don't come out	*Global South:* China, Dominican Republic, India, Indonesia, Nigeria, Saudi Arabia

(*continued on next page*)

Table 1 (*continued*)

Dimension	Anchor statements	Emphasized in
	nor can they enjoy nice weather or the sea, they can't go to beaches for fear of the high temperature, so global warming has lead us to only exist in closed places, it makes us use electricity more, and even entertainment places we go to [are] closed ones, and it'd the reason we have vitamin C and D deficiency so it affects our health in addition to causing some tress and rivers to dry, animals got more harmed than humans, there are many fears." (Saudi Arabia urban)	
Climate refugees	"Well, we have damaged our planet, so that we don't soon have coffee, people from Africa will soon move from Africa because they will not be able to live in those regions, and take themselves up to Europe, and we are facing a mass starvation, lack of food on the Earth." (Sweden, rural)	*Global North:* Australia, Austria, Italy, Norway, Sweden
Climate impacts distant in time and space		
Younger and future generations	"It is clear that you think about the future. I am not maybe directly worried about myself, but for children and grandchildren." (Sweden rural)"Yeah, you could say I have a split concern. For my own sake, I'm averagely concerned. I'm not sure to what degree it'll affect my life in my lifetime. But I'm very concerned on behalf of others; coming generations and people who live in more exposed areas than we do in Norway. For them, there's a big reason to be very concerned." (Norway rural)	*Global North*: Italy, Norway, Poland, Sweden, Turkey, US, UK *Global South:* Chile
Worried about impact in other regions	"We have concerns, but I wouldn't say they're riddled with anxiety. We follow the news and we see that the experts are concerned. Where we live, we don't notice anything concrete regarding the climate changes that are currently happening, but it is predicted that it'll happen. And we do what we can to reduce it. But, like L is saying, the bigger changes are happening further away than here in Norway." (Norway rural) "No, I think that, like many other Norwegians, am kind of middle of the tree. Mainly because I've not felt the climate changes and consequences of these myself. I've of course heard now it is in other countries, but one tends to think 'oh, this isn't any of my concern'. But still, subconsciously, it has affected me a little and I try to have solidarity with other countries and think about those countries where there will be more immediate climate changes in the coming 10 years and where we can already see the consequences." (Norway rural).	*Global North:* Norway, Switzerland, Sweden
Causes, scope & nature of the problem		
Unsustainable production & consumption systems (incl. resource consumption)	"I, myself, worked in sales. I am still in sales but no longer in food. I have to say, in Switzerland you can get everything in the shop all year round. We used to sell seasonal products and now you can get everything all year round. The customers are a bit spoiled. As a result, we no longer have everything available in Switzerland. If less was imported, with the transport costs and everything else, which causes pollution again […]. In the past, we simply had what was available. Today, you can buy strawberries or asparagus or whatever you want, all year round. Customers have been spoiled too much; people have been spoiled too much. That is my opinion." (Switzerland rural)"Unfortunately, we are a consumer society. As a country and as a human being, we are in a constant state of consumption. I can say that some things actually have unnecessary production." (Turkey urban)	Widely mentioned across *Global North* and *Global South*
Unsustainable land use practices, including deforestation; discussed in relation to agricultural practices and urbanization	"I worry a lot about this, especially because I see people don't worry about the environment, they don't care about the amount of trash, or deforestation. I live on the coast, and I see that everything is being deforested to build buildings, construct, and expansion of the city." (Brazil rural)"I don't believe that it is a Swiss or a European problem. If we look at the forest stands in Switzerland and Europe, it has been increasing in recent years. The problem lies in the third world, where deforestation is taking place and the land is being cleared for planting of other things that are not CO2 reservoirs. In these countries, the most useful thing is actually to plant plants along the seas that prevent erosion and create a protective layer for fish species in the mangrove forests. When these things are cut down in such an environment, that is where the greatest damage is actually done. We have to stop these from happening in these countries, for example in Brazil. One can only hope that there will be a rethinking with the new president. And we can actively help to reforest these countries." (Switzerland rural)	Widely mentioned across *Global North* and *Global South*
Inter-linked with air pollution	"I am totally worried about today's topic of climate change. Everyone witnessed that there is rainfall during Diwali which is quite odd. Yes, I am concerned about it and the air index quality is also degrading day by day" (India urban) "I can tell that we are worried about global warming because nowadays we can see day by day increase in pollution so by this people are not able to getting fresh air to breath and through this issue many are facing with deceases, so I would like to tell there should be control in pollution and global warming and even government should focus on this". (India rural)	*Global South:* India, Indonesia, Nigeria, Saudi Arabia, China *Global North:* Italy, Spain, Norway
Interlinked with waste and environmental pollution	"[W]e were worried about changes in global warming and frankly I can say these all things also happening because of our negligence towards society like still we are using plastic, throwing dirty things of industries here and there, we need to keep our city or area clean and all." (India rural)"Knowing that there is a problem, because there are so many things, for example, I complained, I went shopping recently and I shopped at Bravo, for example, do you know how many bags they have at Bravo? They don't have big bags and they gave us so many small bags and I was saying to the cashier, is there someone I can talk to? Because if they give us big bags they really prevent so many bags from being used." (Dominican Republic rural)	*Global North:* Poland *Global South:* Chile, China, Brazil

(*continued on next page*)

Table 1 (*continued*)

Dimension	Anchor statements	Emphasized in
Natural processes dominate (contesting anthropogenic nature of climate change)	"Okay, so I mean, I am worried about it, but like, like everybody else said not to the extent that I believe that it's all caused by human beings. So, you know, at one point, it was tropical in one area, then it's cold, so things you know, they change over time." (USA urban)"I am not specifically worried. Surely, the only one. I feel that we human beings don't have so much to say regarding the temperature on the Earth. As part of the older generation, I am not nonchalant at all. I think we should take care of our air much more than we do, of course. The air we breathe is really important. But we have had varying temperature over the whole history of the Earth; we have had ice ages, we have had warm periods. So, I don't think we have so much to do about the natural development. But we need to take care of the environment better than we do." (Sweden rural)	*Global North*: USA, Switzerland, Sweden, Austria *Global South:* China

Note: table lists only those countries which emphasize the respective dimensions; only dimensions with more than 5 coded segments are included, other extreme events were mentioned such as earthquakes, and landslides and worries about extreme events in general were raised; Categories overlap and are not mutually exclusive; for "causes": general references to greenhouse gas emissions not included.

related impacts in focus groups on the African continent as well as in Saudi Arabia and Turkey, where participants' narratives were often intertwined with concerns over livelihoods and the erosion of the very basis of their economic activities. "Floods and storms" are another type of climate impact that focus groups participants talk about in distinctive terms, with countless stories shared by Australian, Indonesian, Dominican Republic, Nigerian, South African participants. Country and regional variances in experiences with climate change manifest also in some of the other climate impacts that participants identified. For example, experiences with "forest and bush fires" were predominately narrated in the Australian focus groups, while the "melting of glaciers" was of primary concern in Alpine countries such as Switzerland and Italy.

4.1.1. Scale, urbanity and ruralness

While many of the experiences with and concerns about climate impacts are mentioned in both urban and rural groups, some differences in emphasis can be observed in the narratives of participants in urban and rural settings, respectively (difference of at least 5 in coded segments, see Supplementary Information, Fig. A.1.). Focus group discussions taking place in rural environments put comparatively greater emphasis on extreme weather events and natural disasters, drought, water stress and their effects on agriculture, sea-level rise, concerns over risks for livelihoods and economic activities such as tourism and worries about living conditions of younger and future generations. Experiences with and concerns about shortened or different seasons, heat stress, and air pollution are discussed more extensively by participants from urban environments.

4.1.2. Temporality and sense of impactedness

Cross-country differences can be detected in the temporalities that focus group participants associate with climate change. While some accounts of present-day impacts are tangible in all groups, the sense of personal impactedness is much more pronounced in those groups in which participants shared multiple stories of experiences with climate impacts such as floods and bushfires in Australia, drought and its impact on agriculture in Kenya or Turkey and extreme heat in Saudi Arabia, impacts on health and wellbeing in China, Dominican Republic, India, Indonesia, Nigeria, and Saudi Arabia. In line with survey results showing high perceived climate harm and reports of experienced natural disasters (Fig. 2., Panel C and D), such narratives tend to be stronger in countries of the Global South. Contrary to survey results for Australia, focus group participants also expressed high concerns about present and future climate harm. Observations about climate change-related changes in seasons are equally widespread across Global North countries. Repeated references to the melting and disappearance of glaciers in Switzerland are another example of regional variances in how participants grasp climate change in their immediate surroundings.

While in these cases climate change appears as a problem unfolding today and affecting participants' direct environment, in other cases participants speak of climate change as a problem primarily unfolding in the future and/or in distant locations. Mirroring survey results on low levels of expected personal climate harm (Fig. 2, Panel C), focus group participants from Norway and Sweden report comparatively few personal experiences with climate harm. Here, climate change appears primarily as a concern for younger and future generations and/or as an issue that affects most strongly Global South countries and regions that are vulnerable due to their geographic characteristics and adaptive capacities. In the context of reflections on strong climate impacts in vulnerable regions, focus group participants from European countries further address forced displacements and reinforced migration and refugee movements from the Global South to the Global North. Notably, Global South participants do not discuss such concerns.

Among the participants who construct climate change primarily as a problem for the future, several express high hopes in and put responsibility on younger generations to be more conscious of the environmental impacts of their action, to be more innovative and to ultimately tackle the problem.

4.1.3. Causes, nature and scope of the problem

When characterizing the nature and scope of climate change, intersecting issues, such as plastics and waste pollution and other forms of environmental pollution, including air pollution, are heavily discussed across groups, with a particular focus on these themes in the Indo-Pacific and Middle Eastern countries in our sample. This suggests that many participants think about environmental problems, related health concerns and climate change as intertwined sustainability problems that need to be addressed concomitantly.

Focus group participants mention a plethora of unsustainable practices as the root causes of climate change and environmental degradation. Discussed across countries, participants identify unsustainable land use practices, including deforestation and soil sealing related to urbanization and the expansion of the built environment as well carbon-intense production and consumption systems, including industrial and intensive farming practices and individual consumption.

In European countries a recurring and emotionally resonant theme in the context of unsustainable land use practice is deforestation – in particular of the Amazon. Narratives of the negative impacts are frequently accompanied by a criticism of profit-driven or illegal logging activities and opaque government-industry ties as well as to examples of irresponsible government leaders (at that time Brazilian president Jair Bolsonaro). In some cases, such concerns about deforestation elsewhere are advanced as an illustration of how responsibility and big levers for change are located abroad. Similar arguments "locating" responsibilities

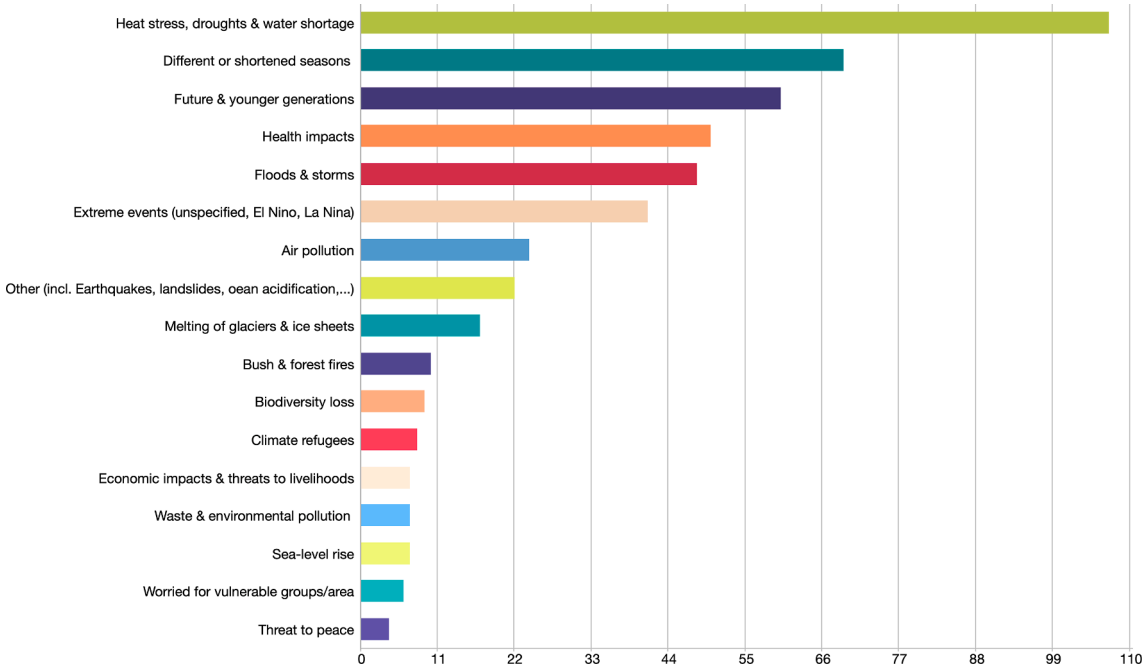

Fig. 3. Perceived present and future climate impact and harm mentioned by focus group participants in 22 countries. Note: Counts based on number of coded segments in the 44 focus group transcripts.

abroad are found in other European groups (particularly Austria, Germany, Switzerland, Sweden) where some participants share frustrations about how domestic efforts are in vain if major polluters such as China, India, Russia or the US do not follow suit.

Although persons overtly denying the existence of climate change were screened out when composing the focus groups, many participants – while acknowledging the reality of climate change – questioned its anthropogenic nature. This corroborates patterns regarding climate beliefs found in the survey, where – depending on the country – up to 37 % of respondents considered natural processes to be the main driver of climate change (Fig. 2, Panel A).

While overall concern about climate change among focus group participants can be considered high, numerous participants are worried about low awareness of and attention given to the issue in the wider population of their respective countries and observe a lack of political will and ambition. Optimistic discussions about improvements and efforts made towards tackling climate change are more widespread in focus groups in China and Saudi Arabia – where participants highlight governmental tree planting efforts (Saudi Arabia), or advancements in green technologies (China).

4.2. How attitudes towards climate change and climate action shape perceptions of climate-intervention technologies

In this section we show how perceived personal harm from climate change and worry about climate change (4.2.1.) as well as attitudes towards climate action and transformation (4.2.2. and 4.2.3) shape the formation of public perceptions on selected CDR and SRM approaches.

4.2.1. Perceived climate harm and climate worry shape perceptions of climate-intervention technologies

As described in Section 3.2, we focus our quantitative analysis on climate worry ("How worried, if at all, are you about climate change, sometimes referred to as 'global warming'?") and personal harm ("How much do you think climate change will harm you personally?") variables because of their more nuanced response range and potential for greater variation across countries compared to other variables linked to climate beliefs (see Fig. 2). We, however, report the results for other variables in the Supplementary Information (see Fig A3).

In Table 2 we provide a descriptive overview for all 22 countries on the level of support for key technologies (share of respondents that indicated that they "Fully support" or "Somewhat support" a technology to the question "How much do you support the broader deployment of each of the technologies to limit the effects of climate change?"). Across all countries we observe generally high levels of support for ecosystem-based approaches (afforestation, marine biomass and blue carbon, and soil carbon sequestration). For other CDR and SRM approaches, we observe strong regional clustering, where countries from Global North are generally more skeptical than countries from the Global South. The descriptive overview suggests that there might be a link between respondents' level of worry and perceived climate harm, and the level of support for different climate-intervention technologies.

Indeed, as shown in Fig. 4, which reports scatter plots of data aggregated at the country level (each point represents a country in the sample) and R-squared from bivariate regressions, across all technologies we see a positive correlation between perceived harm from climate change and the general level of support for a given technology (Panels A and B). A similar trend can be observed for the levels of climate worry and technology support (Panels C and D). The level of perceived harm as well as climate worry appear as good predictors particularly for support of SRM technologies and novel CDR technologies such as BECCS (higher R-squared), and less so for more established ecosystem-based CDR approaches such as afforestation and reforestation (lower R-squared).

We subsequently explore whether there is a systematic link between climate beliefs and technology support by performing bivariate regressions for each country and technology separately (Fig. 5). For almost all countries and technologies there is a positive and statistically significant relationship between technology support and the levels of perceived climate harm (Fig. 5, Panel A) or the indicated levels of worry about climate change (Fig. 5, Panel B). At the same time, variation in the size of effect becomes apparent across countries and technologies. For example, while in the US, Australia, Spain and South Africa, the level of perceived harm and climate worry are generally good predictors for higher levels of support across all technologies, the results are more sensitive to the technology type in Brazil, Norway, Italy, and Germany. This suggests that the size of the effect might depend on the local context

and wider systems of belief.

4.2.2. Perspectives on climate action shape perceptions of climate-intervention technologies

Beyond perceived personal harm from climate change and worry about climate change, the focus groups offer insights into how participants make sense of CDR and SRM in the context of their perspectives on climate action more broadly.

Asked about the benefits they see for the respective approaches, a few participants express hopes that climate-intervention technologies – SRM, and to a lesser extent CDR – might allow buying time for cutting emissions (Table 3). Furthermore, CDR approaches in general and afforestation and restoration of vegetation in particular are described as potential "accompanying measures" to deep decarbonization efforts. These reflections are often tied to critical remarks about how actions to mitigate climate change are too late and too little, thus making it necessary to consider a broad portfolio of complementary actions. Problem perceptions – i.e., views on causes and consequences of climate change – shape how participants situate the approaches in the wider spectrum of measures they consider necessary for tackling the problem. For example, participants in China, India or Saudi Arabia, who tended to stress air pollution and health impacts in framing the problem of climate change, emphasize the supplementary role particularly of afforestation and restoration of vegetation and even DACCS to other climate mitigation efforts due to their perceived co-benefits regarding air quality (Table 4).

However, focus groups participants also – and in fact much more strongly – raise critical points related to the perception that climate-intervention technologies do not or only insufficiently tackle the root causes of the problem. Such arguments are made for climate-intervention technologies in general but are stressed more with regard to the SRM approaches.

The reasoning underpinning such concerns relates – particularly regarding SRM and novel CDR approaches – to narratives about yet another interference with nature, solving one problem while creating 10 new ones, and to narratives about the illusion of solving the problem by using the same tools that have created it in the first place. High energy intensity and transport-related emissions of some approaches are considered as indicative of a continued fossil fuel dependence and extractivism, and are often brought forward regarding DACCS, enhanced weathering and BECCS as well as ships and airplanes required for SAI and MCB. Corroborating findings from earlier studies (e.g., Carvalho & Riquito, 2022), a recurring metaphor used for characterizing SRM approaches is the one of a "band-aid" or a "patch" that might alleviate symptoms for a while, but that does not offer a "cure" of any sorts.

Participants across groups, furthermore, question the temporalities related to the potential implementation of CDR and SRM technologies which make these inapt for responding to the urgency of the situation. In the case of SRM, some participants see a temporal mismatch because technology readiness and political feasibility of implementation are widely perceived to be low and conceivable in the distant future at best. In the case of CDR approaches, particularly those perceived as more natural and for which implementation is seen as feasible within relatively low delays – mostly afforestation and restoration of vegetation – participants are concerned about long lead times and problems of scaling, which results in a mismatch with the need for immediate action.

While such concerns are raised in relation to both SRM and CDR approaches, they are much more frequently discussed for SRM, followed by DACCS – and explicitly in relation to moral hazard and mitigation deterrence. In several countries from the Global North and the Global South, concerns about a decreased motivation for steep emissions reduction were closely intertwined with critical reflections on government-industry ties, profit-seeking and lack of transparency

Table 2
Climate beliefs and public support for climate-intervention technologies in 22 countries.

Country	Group	Worry	Harm	SAI	MCB	SBG	DACCS	BECCS	EW	Biochar	SCS	MBBC	AF
Turkey	GN	81	94	63	67	70	73	79	77	77	81	79	93
Dominican Republic	GS	84	90	51	62	59	64	66	53	67	74	75	78
Chile	GS	81	89	58	67	59	71	67	61	71	83	82	81
India	GS	83	88	77	81	77	84	81	76	79	86	80	88
Kenya	GS	79	88	64	71	70	77	72	60	74	85	85	92
Brazil	GS	86	84	50	57	63	73	73	61	75	82	83	91
China	GS	61	83	54	58	59	71	70	62	75	79	71	87
South Africa	GS	72	82	64	69	64	68	68	57	70	86	83	88
Spain	GN	79	82	48	54	48	64	60	52	61	78	79	85
Indonesia	GS	80	79	64	81	64	72	74	63	79	89	88	88
Germany	GN	64	77	23	30	28	39	47	35	58	79	71	87
Nigeria	GS	64	74	72	77	75	79	75	65	81	89	82	90
Saudi Arabia	GS	59	73	64	67	65	76	74	72	73	79	79	88
Switzerland	GN	55	69	39	43	42	48	52	45	53	70	67	79
Italy	GN	75	68	44	45	40	48	50	26	58	69	71	81
Poland	GN	50	65	31	37	37	51	53	43	65	72	67	85
Austria	GN	56	65	29	33	34	39	44	39	53	70	65	87
USA	GN	53	62	52	54	51	66	63	57	61	75	73	79
Australia	GN	53	59	50	58	52	56	56	53	64	79	77	77
United Kingdom	GN	54	54	43	46	43	61	58	50	63	83	81	85
Sweden	GN	40	52	30	40	29	52	50	38	58	74	73	82
Norway	GN	35	28	31	36	30	47	43	24	49	67	64	79

Note: Overview of survey results showing the percentage of respondents in countries from Global North (GN) and Global South (GS) that indicated that they "Fully support" or "Somewhat support" a technology. The technologies include: SAI = Stratospheric aerosol injection, MCB = Marine cloud brightening, SBG = Space-based geoengineering, DACCS = Direct air capture with carbon storage, BECCS = Bioenergy with carbon capture and storage, EW = Enhanced Weathering, MBBC = Marine biomass and blue carbon, SCS = Soil carbon sequestration, AF = Afforestation. Short descriptions for each technology are provided in the Supplementary Material. For the "Harm" variable ("How much do you think climate change will harm you personally?") we report the share of respondents that indicated that climate change will harm them "A great deal" or "Somewhat". For the "Worry" variable ("How worried, if at all, are you about climate change, sometimes referred to as 'global warming'?") we indicate the share of respondents that are "Extremely worried" and "Very worried". For the full range of responses for climate beliefs variables for each country see Fig. 2. Color code: Green indicates areas of (strong) support for the respective technology and high worries/perceived harm, purple indicates areas of weak support for the respective technology and low levels of worry/personal harm.

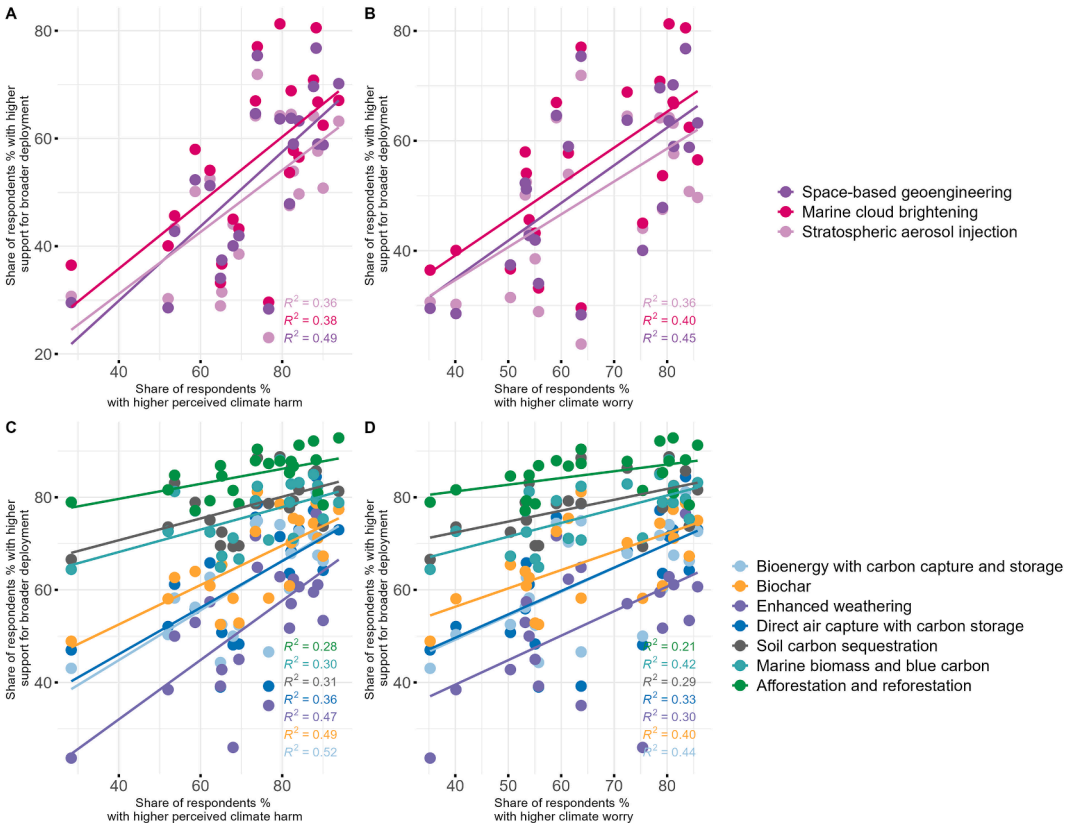

Fig. 4. Association between technology support and the share of respondents that perceives higher personal harm from climate change (Panel A and C) and the share of respondents with higher climate worry (Panels B and D) across all technologies and 22 countries. Note: The reported shares for higher perceived harm ("How much do you think climate change will harm you personally?") were calculated by considering the percentage of respondents for a given country who indicated that they believe they will personally experience a "great deal" or "somewhat" of harm from climate change. The reported shares for higher perceived climate worry ("How worried, if at all, are you about climate change, sometimes referred to as 'global warming'?") were calculated by considering the percentage of respondents for a given country who indicated that they were "extremely worried" and "somewhat worried". The reported shares for higher support for broader deployment were calculated by considering the percentage of respondents for a given country who indicated that they "fully support" or "somewhat" support deployment of a given technology.

(McLaren et al., 2021; Christiansen et al., 2023). Participants raise concerns about continued unsustainable behaviors and lifestyles and justification for environmentally harmful behaviors (Corner & Pidgeon, 2014; Cox et al., 2020). Concerns that these technologies might intentionally or unintentionally decrease the motivation to reduce emissions are corroborated by the survey data. Across all countries surveyed,

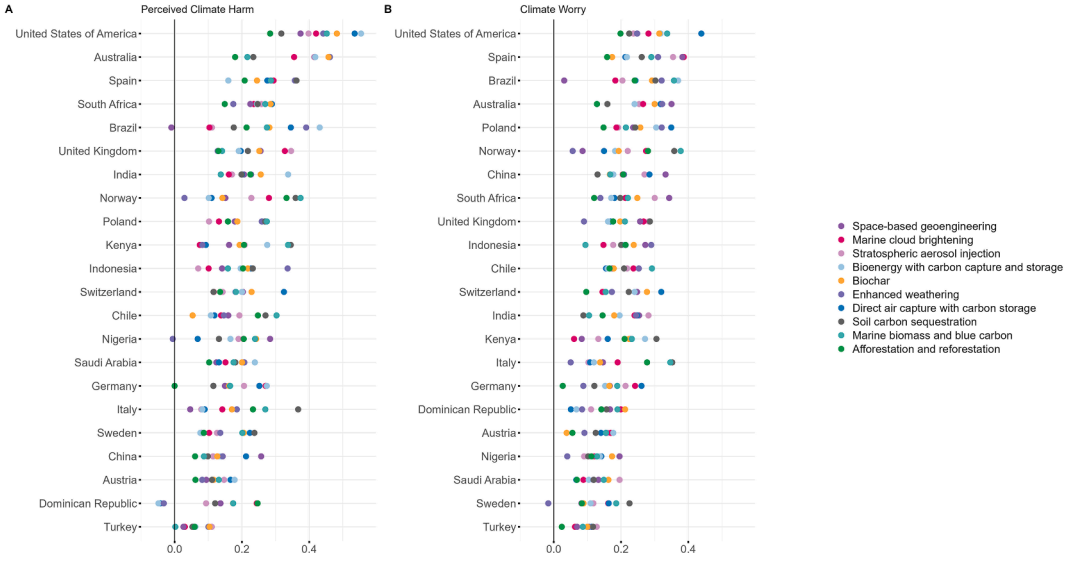

Fig. 5. Coefficient plots showing coefficients from bivariate regressions for each country at the individual level (N ~ 330 per country and technology) with climate harm (Panel A) and climate worry (Panel B) as the key predictors. Note: Values to the right of the black vertical line indicate a positive relationship and to the left of the line a negative one. Values crossing the line are not statistically significant. Each dot represents a regression coefficient for a given technology.

Table 3
Overview of themes relating assessment of CDR and SRM to climate action and illustrations from the focus groups.

Relation to climate action	Approaches emphasized	Example statement
Buying time for deep decarbonization	SRM in general and SAI; Novel CDR, particularly DACCS	"And that's why many have talked about that it would be a positive thing to for example try solar radiation management, because then you can buy yourself a little time to form or develop that type of electronics or products" (Norway urban) "I think anyone, everyone benefits and the reality of the situation is that to transition the entire world onto renewable energy is going to take a while. There's still quite a long way to go. And I think everyone agrees that that's where we've got to be eventually bit that's going to take a while and I think we have to tackle climate change now, before we tackle that transition which means while there's still energy being produced by oil and gas and fossil fuels, that energy has to be captured, otherwise it just goes into the atmosphere. Everyone benefits because it's working towards the survival of the human race."(UK urban)
Accompanying measure to deep decarbonization	CDR in general; Afforestation and restoration of vegetation	"Particularly looking […] the replanting and support of the flora… It says that was changing nature, but actually, it changes nature back to the way it was before we started affecting it. And eventually, this is the optimum we can reach, to say we rebuild healthy vegetation that can actually store some of the CO2. However, I think that we still need to change ourselves. But as we already said, I think it's an ideal accompanying measure. And above all, it's more manageable technologically. So to every regular person, this seems less abstract than the other approaches." (Austria rural)
Decreased motivation to reduce carbon emissions, mitigation deterrence	All, but more pronounced for SRM	"With regards to the risks, I do see that if we sequester the CO_2 we always have the side-effect, in communications with citizens of the earth, that their behaviour does not change because they believe that it is a solution to the excess production of CO_2. I think that's the biggest risk. If we were to sequester it through technology, then the thoughts will continue that we can allow everything to carry on as it is now because it will be captured in another way. I think we need to be very sensitive to that in our communication and only present is as a complementary solution and not a panacea for the problem that we have." (Austria rural) "And there are some other interests too. We're avoiding radiation in order to keep polluting. You know, industry is very strong, and they keep polluting, and we can't stop it." (Spain urban)
Not addressing the root causes of climate change, "band-aid"	All, but substantially more pronounced for SRM	"Number one thought is, we're not resolving anything, we're only sticking plasters over. How long can the world be sustained with sticking plasters, is my big worry." (UK rural) "The most important thing is that this method can cure the symptoms rather than the root cause. You just reflect the sun back. Then there was no solution." (China urban) "Respondent 1: Instead of storing and don't you think we should rather not be burning fossil fuels? Respondent 2: The thing is we burn for our economy to run if we don't, then it means it will not work. So those think the question should be 'How to prevent capitalism'. The problem is when everything is done excessively for profit." (South Africa rural) "I'm seeing here is like they are treating the symptoms but not the cause. What would happen if, let's say this started paying for the Aerosol injection, because this is a mechanic's, it needs to be on. …. So as you are treating the symptoms it doesn't mean nature doesn't take its course. So if we continue to not taken care of it, on the day it falls apart it might be the end of the world." (Saudi Arabia rural)
Reproducing same logic that created the problem in the first place	More pronounced for SRM	"Shooting some kind of sails out into space, dispersing something we don't know or brightening up the clouds… In my view, we are working towards the unknown again; not knowing whether those particles we let into the air will make us ill in 20 years' time. I am once bitten, twice shy. I wanted to have a bioethanol-powered vehicle. I thought it was great and ecological and everything, but then it got completely discredited due to the fact that somewhere people ran out of food because of it. I think that many small steps taken as an individual become one big step that we take as a society. I think that we are at a point where we can no longer shirk responsibility. We have to manage it ourselves." (Switzerland rural)

Note: only themes with most coded segments are listed.

publics perceived novel CDR and SRM approaches to bear greater risks of a decreased motivation to reduce CO2 emissions. Most of all, SRM and novel CDR approaches were also deemed much less cost-efficient than cutting use of fossil fuels (Baum et al., 2024).

In many cases these reflections on the role of climate-intervention technologies give rise to calls for holistic climate action where CDR approaches (e.g. Dooley et al., 2022; Buck, 2021; Low et al., 2022) – and, if at all, SRM proposals (e.g. Buck, 2022) – would accompany or be integrated into measures addressing the carbon economy, transforming land use practices and resource consumption and stimulating pro-environmental behavior changes at large scales.

4.2.3. Transformation pathways and climate action narratives

In reflecting on hopes and concerns related to climate-intervention technologies, focus group participants repeatedly addressed – without being prompted – multiple dimensions of transformation towards sustainable and low-carbon societies. These reflect contestations over how to draw the system boundaries when talking about and assessing technology-related transformation.

Participants across groups from the Global North and the Global South contextualized their reflections on climate-intervention technologies by referring to changes in individual behaviors, industrial production practices and/or top-down measures including regulation of polluting industries as well as technological change and innovation (Fig. 6.). In each of these stylized ways of thinking about transformation and climate action, climate-intervention technologies are addressed in different terms. They do overlap, and individual participants refer to several narratives linking bottom-up and top-down perspectives on transformation.

4.2.3.1. Behaviour change-centred narratives. A strong emphasis on individual actions and behavior changes as a driver of transformation becomes apparent across focus groups in all countries.

The need for behavior changes and examples of personal pro-environmental behaviors are widely mentioned, including recycling efforts, reducing plastic use and waste production, dietary changes such

Table 4
Elements of transformation pathways highlighted in the 44 focus groups.

Drivers and actors of transformation	
Individual behavior change	"We should start by ourselves, even if they are details, it is very important to start ourselves. Just by going shopping with your bags, not throwing garbage in the street, I think this is the way to go. Everything must be within us if we would like to make a change." (Chile urban)"Every person who rides a bicycle instead of a car, that affects climate change and can help" (Poland rural)."We should not forget that, unfortunately, we are living in a capitalistic society, and we do vote with the wallet. So, we can do really much. We can choose where we buy our products, and where we buy our food, and where we put our money. We can avoid many of the great emitters ourselves. We have some responsibility on us as well." (Sweden rural)
Top-down and industry-centred changes	"What I wanted to say about who I think is responsible for change, individual or on a large *meta*-level, in my opinion it's always the capitalist narrative to always shift the responsibility onto the individual. The demand creates the supply and so on. I don't agree. I think politics has the largest responsibility; they're sitting at the big lever in terms of CO2, oil prices which influences an individual's' consumer behaviour. I think it's the responsibility of the main economic players and of politics." (Austria urban)"Some production may have to make way for this. There are many operation methods or industries that may affect the environment, such as making paper or cutting wood. They need to be changed. […] That means they have to advance their technology (to avoid affecting the environment)" (China rural).
Technology-centred changes	"I keep my own idea, in the sense that I believe we need new technology and in relation to technology I never think they are absurd. Because there are things we humble humans beings do not think of, and then there are instead engineers who create new things that can solve problems." (Italy rural) "Because of the climate crisis, the energy crisis that we have – you have to think ahead, you have to be a bit of a mad scientist, because if it wasn't for them, I think we would still be stuck further in medieval age, if there weren't brave people who put the idea into practice, even 30 years ago, we didn't think that we would have smartphones, that we would be communicating like this, if it wasn't for someone brave and some resources, there must be, you know, some huge state resources, some corporations probably wouldn't really want to participate in this, but it has to happen at some point." (Poland rural).
Barriers	
Economic system & interests	"Moderator: 'Is' [name of a participant] mentioned governments, what do you think of that? And I'm thinking all levels – local level, regional level, national level, European level, etc. Respondent 1: I don't trust them, honestly. It's all talk. You saw G8, they talked about pollution, and no one does anything. It's always the same. I don't trust them.Respondent 2: There have been so many climate summits and nothing changes, because they're not interested because they have their interests. They have to produce, and climate change requires the contrary. Petrol companies complain because if we start using electric cars they won't get profits, it's all the same… So, governments are biased." (Spain rural) "You can't buy a packet of bananas without a plastic bag around them. Just even if those… I'm late to the party, anyway on this. But even if you want to make changes, it's not easy. Barriers are up against these small things we can do individually." (UK rural)
Lack of awareness	"I think what's missing is awareness because not all people know what's happening." (Brazil urban)"I'm worried about that, but unfortunately, my city is not. This is a big worry for me, but I can see people here don't care about that. Older people say they don't care because they won't be alive anymore when a big problem emerges, and the younger ones, in my opinion, would have to be something cultural, since they are children, we should explain "it's warm, icebergs are melting, penguins…", I feel it's something cultural. I have a level of difficulty, at least in my house, to explain and raise awareness with my sons because my husband doesn't care. I see that in my city people don't care because there's a lot of garbage on the streets, high use of fuel, also high use of fireworks… I don't know if fireworks influence something." (Brazil rural)
Lack of international coordination & cooperation	"I mean, governments don't even agree upon climate change, just imagine… The US didn't want to reduce their carbon dioxide emissions, let alone China. I find it extremely difficult for them to agree upon this. They can't even pass a law to control carbon dioxide." (Spain rural)"I would say that we actually need a global approach. Because as long as they don't start to rethink in India and in China – in China for example they are now building 300 coal-fired power plants. That's insane. One doesn't even have to look that far away. In Poland, they are building nuclear power plants. And we are trying to save the world while everything around us goes down the drain. It doesn't help if we think about this here. That's nice, but we need to get the large countries to do that too. Europa cannot save the earth – that's how it is unfortunately." (Austria rural)

as reduced meat consumption, low carbon mobility and various other consumption-related practices, and covering both high and low-impact behavior in terms of CO2 emissions (Cologna et al. 2022). Sometimes related to feelings of guilt, these narratives reflect strong intentions of assuming responsibility, and maintaining agency in the face of a complex and global problem. Behavior change narratives are frequently nested in calls for tackling the root cause of the problem, as opposed to treating only its symptoms. Education, information and awareness raising appear as preconditions or drivers of change. While mentioned across countries, educational aspects are particularly emphasized in Global South countries. In the context of learning – and unlearning unsustainable practices – some participants identify the need for deep transformations of value and belief systems.

The strong emphasis on individual agency and behavior informs participants' assessment of CDR approaches. Against the backdrop of behavior-change narratives the link to CDR approaches that are perceived as natural and decentralized, mostly afforestation and restoration of vegetation as well as changes in agricultural practices, is most apparent. Participants can more easily relate these to their everyday lives as well as identify entry points for engagement and support of implementation.

Mirroring debates about bottom-up vs. top-down transformation pathways found in previous focus groups in Cape Verde, China, Fiji, Sweden and the US (Wibeck et al. 2019), critical remarks about focusing on individuals as main agents of change are raised. These include questioning the origins of individual responsibilisation and highlighting the need for collective action and strong policy and supply-side efforts, thus pointing to top-down and industry-centered transformation pathways (next section). For example, one participant in Austria argues:

> *"What I wanted to say about who I think is responsible for change, individual or on a large meta-level, in my opinion it's always the capitalist narrative to always shift the responsibility onto the individual. The demand creates the supply and so on. I don't agree. I think politics has the largest responsibility; they're sitting at the big lever in terms of CO2, oil prices which influences an individual's consumer behavior. I think it's the responsibility of the main economic players and of politics."* (Austria urban)

Translated to the assessment of CDR approaches in general, participants questioning the individual-focused narratives argue that these should not divert attention from the need for systemic changes in production and consumption systems.

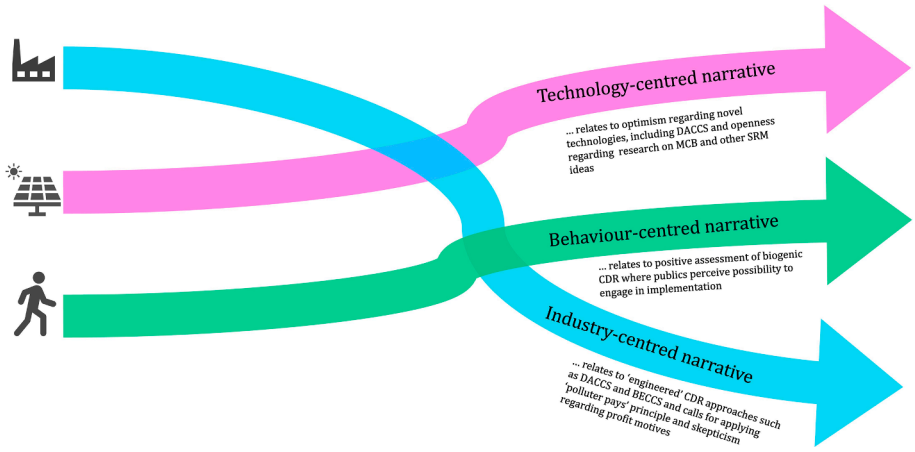

Fig. 6. Three stylized narratives about technology, behavior or industry in transformation pathways and their relation to CDR and SRM.

4.2.3.2. Top-down and industry-centred narratives. Across countries participants emphasize the industrial sector as an important actor, concerning both its major contributions to causing climate change as well as its levers for tackling climate change. Participants, however, attribute different roles and responsibilities to industry actors.

Industry-centered narratives on transformation are closely tied to focus group participants' reflection on the climate-intervention technologies discussed. In talking about the role of industries, we observe both trust in the capacities and willingness of industries to change as well as attribution of responsibility for curbing emissions and sequestering legacy emissions, paired with expectations that polluting industries – and the oil and gas industry in particular – should be held accountable and pay for the removal of the emissions they have created. Mirroring expert debates on CDR finance (e.g. Honegger 2023), the "polluter pays" principle is evoked by numerous participants who attribute a key role to industrial actors when it comes to financing and implementing novel CDR approaches, most notably DACCS:

> *"I think that the companies should be involved because they are the bigger polluters. I think they should afford this because they pollute to have more profit, so they should think about the community and do this social work." (Brazil rural)*

The emphasis on industries as change agents is greater in focus groups in those countries with strong state capacity and close state–industry relations such as in China, Saudi Arabia and to a lesser extent Norway. Several participants in these groups express comparatively high trust and confidence in the capacity of industries to contribute to the transformations needed to tackle climate change (see Brutschin et al., 2024). Differences can also be identified in the extent to which participants consider strong regulation of industries and state-intervention as necessary or think incentives and market mechanisms will suffice to instigate change and decarbonize the industrial sector. Participants' assessments of climate-intervention technologies include considerations of the possibility for profit-generation and the creation of self-sustaining markets. While some think that the possibility of generating profits will be key for any of the approaches to scale-up, others argue that societies need to overcome the capitalist logic of accumulation and growth.

4.2.3.3. Technology-centred narratives. Narratives putting technological advancements at the centre of transformation pathways are less common. Participants' reflections on the key role of technologies for transformation are often tied to historic examples of how progress was intertwined with technological inventions and innovation, as one participant from Poland argues:

> *"Because of the climate crisis, the energy crisis that we have – you have to think ahead, you have to be a bit of a mad scientist, because if it wasn't for them, I think we would still be stuck further in medieval age, if there weren't brave people who put the idea into practice […]" (Poland rural)*

Those stressing the importance of technology for transformation, tend to voice greater optimism and higher hopes regarding more engineered climate-intervention technologies, particularly when weighing them against some of the trade-offs identified for low-tech carbon removal approaches such as reforestation and restoration of vegetation.

> *"I understand the romantic side of giving back the green because we stole it from nature, which is true, but it's not that in order to improve the planet we have to go back in time. [….] What do we have to do ride a horse chart? I don't think so. I don't agree with the fact that we don't have to take land from agriculture, where should we take it – from buildings? I'm thinking loud. I don't take land from agriculture what do I do, I pull down a building? What about people living in that building? What do we do? We have people who would get upset. The answer is new technologies, new ideas that allow us to improve the environment and so on." (Italy rural)*

Across these three broad narratives, participants identify numerous barriers that hinder transformation efforts. These include strategies of economic actors that aim at maintaining the status quo and undermining transformative climate action and policies, as well as a lack of political coordination and cooperation at the international level. A frequently mentioned barrier – specifically for transformation pathways focused on individual and collective behavior – is the lack of awareness of the severity of the climate crisis in the general population.

5. Conclusion

Based on an original large-scale survey (n = over 22 000 participants) and 44 focus groups (n = 323) in 22 countries our findings show variations in emerging perceptions of climate-intervention technologies. These need to be understood in the context of publics' varying interpretations of the severity and impacts of climate change, of the causes of and perceived responsibilities for climate change, and of what desirable and/or plausible transformation pathways look like. In the following, we draw conclusions for assessment and governance of climate-intervention technologies.

First, climate harm and worry about climate change are robust predictors of public support for climate-intervention technologies, particularly for novel engineered CDR and SRM approaches. Public support for climate-intervention technologies depends on their ability to respond effectively and in a timely fashion to a variety of lived and expected climate impacts.

Mapping public perceptions of climate change across 22 countries – including "non-WEIRD" countries –, our findings show national variances in the extent to which publics perceive climate change as a direct and present threat or as distantly removed in time and space. Extending earlier research into perceptions of climate change (Leiserowitz 2006; Tvinnereim et al., 2020), we found that in most focus groups, particularly in the Global South and Australia, climate change is no longer perceived as distant in time and space, but rather tangibly unfolding and affecting livelihoods. In contrast, conceptions of climate change as a threat distant in time and space were prevalent particularly in Northern European countries such as Norway and Sweden. While participants were worried about climate change in these countries as well, they were less concerned about how it harms them personally. The extent to which comparatively low levels of expected personal harm from climate change in these countries reflects perceived high resilience and adaptive capacities requires further attention.

Irrespective of these differences, there is a strong sense of urgency among focus group participants from both Global North and Global South countries, accompanied by frustrations over insufficient levels of awareness and action in the general population and in political realms. Overall, our quantitative findings confirm and extend prior research (e.g., Zanocco et al. 2019; Hoffmann et al. 2022) on the influence of perceived climate harm and experience of climate impacts on support for climate policy and action, here articulated in terms of CDR and SRM. The greater the perceived climate harm, the greater the openness of publics to considering climate-intervention technologies.

Corroborating findings for public perceptions of CDR in the UK and the US (Cox et al. 2020) – there does not, however, seem to be a direct translation of the sense of urgency and perceived personal impactedness into outright approval and support for all of the studied climate-intervention technologies in the same way. National disparities and technology specificities warrant attention here. Survey participants' perceptions of personal harm and climate worry emerged as particularly strong predictors for participants' openness to considering SRM and novel CDR technologies, but less so for ecosystem-based CDR approaches. When considering the qualitative data an even more nuanced picture emerges: the sense of personal impactedness and urgency might not only increase openness to a wide range of measures, but – on the contrary – also translate into concerns that (some of) these technologies would take too long to deliver any notable benefits, either because they have a long lead time (e.g. afforestation and restoration) or because the technology is considered to be infant at best (SRM).

Second, public support for climate-intervention technologies hinges on them being tied to credible climate action that addresses the root causes of the problem. Publics across countries embed their reflections on climate-intervention technologies in wider systems of beliefs, and views on the types and depth of changes needed to tackle climate change. Differences can be detected in the processes and actors that are emphasized as key in such transformation pathways, including individuals, state and industry actors as well as technology developers and innovators. These differences relate to nationally varying notions of responsibility, consumerism and citizenship.

Notwithstanding the preferred transformation pathways, publics clearly identify the need for measures and actions that tackle the underlying problem. For some, predominantly in Global South countries, CDR is partly envisioned to have a role in such pathways, for others not. In both cases, publics weave CDR options into wider transformation narratives, particularly behavior-centered and industry-centered narratives. SRM is unequivocally criticized for not engaging with the root causes of the problem and appears only in technology-centered narratives of transformation. These results echo earlier reports about CDR (Wolske et al. 2019; Cox et al. 2020) as well as SRM (Wibeck et al. 2017; Carr and Yung, 2018) being seen as "non-transition" (Butler et al., 2013), i.e., as interventions which do not sufficiently tackle the root causes of the problem while potentially bearing new risks and undesirable side effects. These concerns are accompanied by worries over the perverse incentives presented for continued levels of emissions or at least reduced efforts to curb emissions. These results suggest that CDR approaches will meet more positive reactions if they are embedded in credible system-wide decarbonization efforts.

Implementing expert recommendations on separating targets for emissions reductions and carbon removal (McLaren et al. 2019), clear definitions of residual emissions (Buck et al., 2023), and transparent and rigorous standards for Monitoring, Reporting and Verification (MRV) in carbon accounting (Honegger et al. 2022), can contribute to credible responses to public concerns about mitigation deterrence. Furthermore, various intersecting problems such as air pollution and related health impacts raised particularly by publics in emerging economies and Global South countries suggest that approaches that can demonstrate co-benefits for local communities might meet more favorable public reactions (Bain et al. 2016), underlining the need for adopting a pro-active approach to policy coherence for sustainable development (OECD 2019).

Author contributions

LF, SL, CMB and BKS designed the mixed methods study. LF and SL undertook qualitative data analysis and synthesis of the focus groups, with input from CMB. EB conducted the quantitative analysis of survey data, with inputs from LF and CMB. LF wrote the manuscript, with content and reference inputs from EB, SL, CMB and BKS. LF, EB, SL, CMB and BKS edited the manuscript to completion.

CRediT authorship contribution statement

Livia Fritz: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. **Chad M. Baum:** Data curation, Methodology, Validation, Writing – original draft, Writing – review & editing. **Elina Brutschin:** Conceptualization, Formal analysis, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. **Sean Low:** Data curation, Formal analysis, Methodology, Validation, Writing – original draft, Writing – review & editing. **Benjamin K. Sovacool:** Conceptualization, Funding acquisition, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Ethical Review Statement

This research was approved by the Institutional Review Board at

Aarhus University 2021-13. Full and informed consent was given by all participants before the beginning of the study, along with all participants being notified about the fact that their data would be handled in a fully anonymous manner and in complete accordance with the General Data Protection Regulation and any other pertinent data-security regulations, that any data would be analyzed in an aggregate fashion and would not be personally identifiable in any way, and that they had the right to withdraw their participation at any time.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gloenvcha.2024.102880.

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