Public perceptions of Carbon Dioxide Removal in the US and UK

Emily Cox*, Understanding Risk Group, Cardiff University, Tower Building, Park Place, Cardiff CF10 3AT

Elspeth Spence, Understanding Risk Group, Cardiff University, Tower Building, Park Place, Cardiff CF10 3AT

Nick Pidgeon*, Understanding Risk Group, Cardiff University, Tower Building, Park Place, Cardiff CF10 3AT

* Corresponding Authors. E-mail: coxe3@cardiff.ac.uk; pidgeonn@cardiff.ac.uk

Abstract

Carbon Dioxide Removal (CDR) technologies may be needed to meet climate change targets. Currently full understanding of public attitudes towards such approaches is lacking. Here we report a mixed-methods study on public perceptions of CDR in the US and UK, focusing on bioenergy with carbon capture and storage, direct air capture and terrestrial enhanced rock weathering. A discourse of climate urgency had a substantial impact on perceptions, with CDR seen as offering too slow a response to the climate crisis. CDR also fails to reflect long-term hopes for a sustainable world, being interpreted as not addressing the root causes of climate change. A social license to operate may therefore depend upon resolving these temporal dilemmas regarding both the short and long-term implications of technology development. While research under well-controlled conditions is likely to be acceptable, at-scale deployment without corresponding efforts to reduce emissions may represent a red line for many people.

The Paris Agreement on climate change stipulates the requirement to pursue efforts to limit the average global temperature increase to 1.5°C [1], and several countries have committed to goals of net carbon neutrality by 2050. However, residual emissions from difficult-to-decarbonise sectors such as aviation and agriculture mean that this will be challenging to meet through emissions reduction alone. In order to achieve net zero across an economy as a whole there might be a need to simultaneously remove an equivalent amount of CO_2 from the atmosphere using Carbon Dioxide Removal (CDR) [2].

CDR comprises a range of different proposals, from those widely practiced such as afforestation, to those still at concept stage. Some of the newer, 'engineered' approaches such as Bioenergy with Carbon Capture and Storage (BECCS), Direct Air Capture (DAC) and Enhanced Rock Weathering (ERW) might have the potential for long-term sequestration of large quantities of CO_2 [3]. Of these, BECCS is the best understood and has the highest Technology Readiness Level, but there is considerable uncertainty over sequestration potential and cost for all three (see ref. [4] for a review).

Public attitudes and risk perceptions are important for novel technologies, as illustrated by controversies over genetic modification, fracking for shale gas, and early Carbon Capture and Storage (CCS) [5–7]. For novel CDR, as 'emerging' technologies, understanding citizen views through upstream engagement can facilitate more ethical and effective technology development [8]. Going beyond techno-scientific assessments, the actual scalable potential of CDR will depend on socio-political factors, including public perceptions (and their influence on political mandates), uptake by relevant market actors, and successful development of a social license to operate [2,9]. While public attitudes will not be the only factor driving development and deployment of CDR at scale, the current limited evidence on them represents an important gap in our understanding of the real-world potential of CDR [10].

Research on public attitudes to 'geoengineering' suggests that this tends to be viewed less favourably than emissions reduction, that ethical and justice considerations are important and often overlooked, and that framing geoengineering as a response to a 'climate emergency' slightly improves perceptions, shifting them from opposition to conditional acceptance [11–13]. However, geoengineering studies typically examine CDR alongside solar radiation management (SRM) techniques which propose to alter the earth's albedo, which are generally more controversial and speculative [14]. Assessing the two side-by-side may bias responses in favour of CDR as the 'least-worst' option. Accordingly, it is important to understand attitudes to CDR in absence of this conflation. Perceptions of 'messing with nature' may also be important for how people respond to options,[15] including when focusing purely on CDR proposals such as BECCS, DAC or afforestation [16]. People may also judge proposals by how well they fit with a desired 'vision' for the future [17], found to be important for CCS [18–20]. CCS is an important component of some, but not all, CDR techniques, and there is currently limited empirical evidence of the extent to which CCS provides a useful analogue for understanding public attitudes to CDR more generally [21].

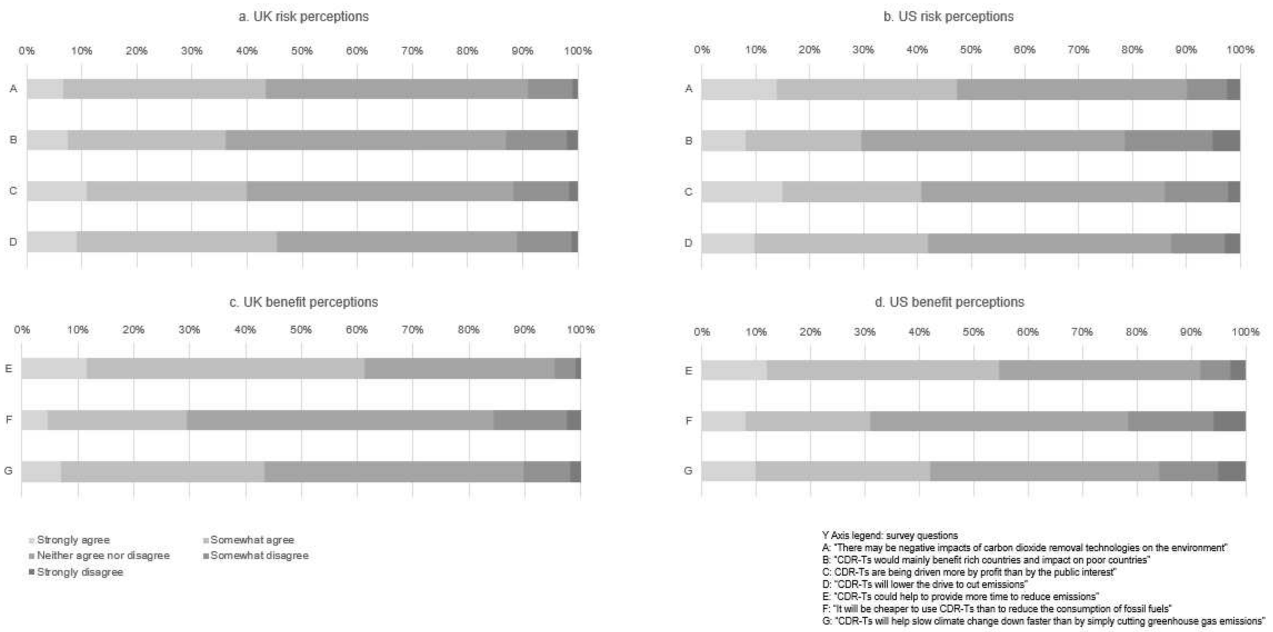
Risk perceptions of emerging technologies are influenced by people's values [17], the immediate positive or negative responses (or 'affect') that they engender for people [22], and potential benefits alongside risks [23]. Due to its novel status, knowledge and awareness of CDR amongst lay publics is expected to be low [24]. Under such circumstances survey results should be treated with caution, as they may be vulnerable to 'pseudo-opinions' [25,26]. A mixed-methods approach employing extensive deliberation alongside surveys can help to overcome this, because deliberative methods allow for in-depth learning amongst participants and increases the consideration participants give to responses [27], allowing us to build on previous studies of CDR perceptions (e.g.[16]). Essentially, large-N survey methods allow us to calculate the significance of responses across a population, whilst small-N deliberative methods enable understanding of why people respond in a certain way.

Here we integrate the findings from a nationally-representative survey in the US (n=1026) and UK (n=1000) with six 2-day deliberative workshops. As advanced industrial economies, both the US and UK would almost certainly need to deploy CDR at scale in order to come close to net zero emissions [2,28]. The survey was intended to establish current baseline awareness of CDR and explore differences in risk and benefit perceptions, and their relationship to climate change beliefs, between both countries. Respondents were presented with a brief description of CDR before answering questions relating to prior awareness and specific risks and benefits (see Methods). In each country, deliberative workshops were conducted in a large, diverse city (Cardiff, n= 8, and Chicago, n=8), a medium-sized university town (Norwich, n=8, and Champaign-Urbana, n=8), and a rural agricultural area in Norfolk (Dereham, n=8) and mid-Illinois (Charleston, n=7).

Perceptions of CDR risks and benefits

In line with expectations, the survey found exceptionally low prior knowledge: only 9.6% (US) and 5.7% (UK) said they knew "a great deal" or "a fair amount" about CDR. Figure 1 shows the survey results for seven questions on risk/benefit perceptions of CDR. The greatest perceived risks were potential negative impacts of CDR on the environment, and that CDR might lower the drive to cut carbon emissions (otherwise known as 'mitigation deterrence, cf.[29]). Risks to poor countries were less of a concern, and did not occur as a major theme in any of the workshops. The prevalence of undecided opinions, to be expected for an upstream survey, means that the workshop data are important for understanding perceptions in more detail.

Figure 1. Public perceptions of CDR risks and benefits. Percentage of respondents that provided each response option to questions relating to a) risks in the UK (n=1000), b) risks in the US (n=1026), benefits in the UK (n=1000) and d) benefits in the US (n=1026) of CDR technologies (CDR-Ts).

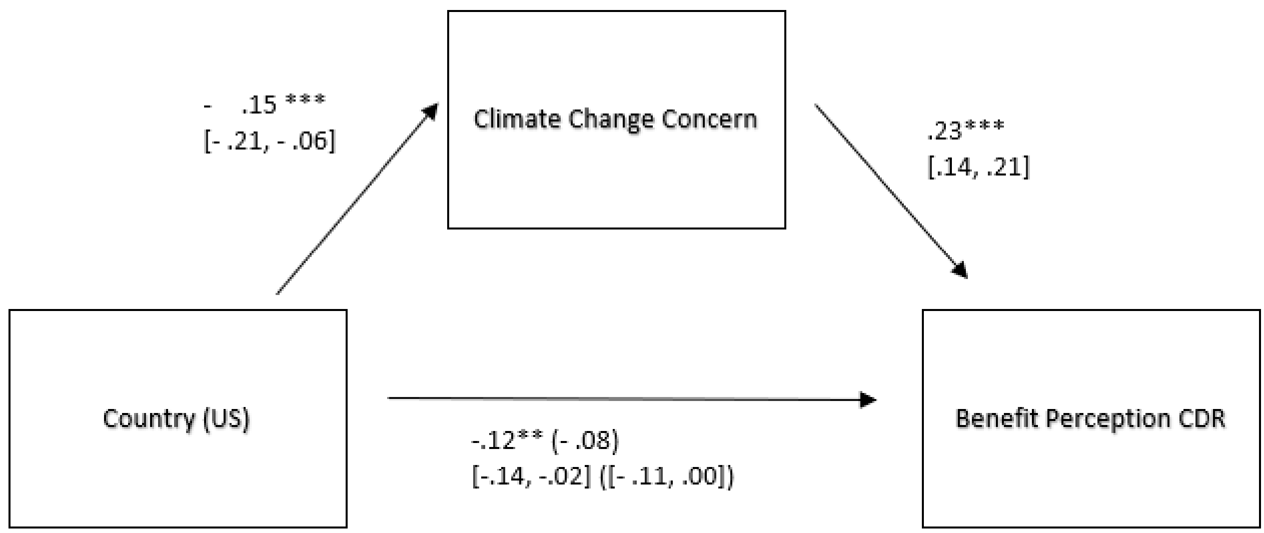


Cross-national comparison

Our protocols, facilitation and analysis were the same across both countries, giving a high degree of cross-national comparability. Using compound scales for risk and benefit perception scores derived from the items in

Figure 1, the survey showed no significant differences in risk perception between the US (M=3.34) and UK (M=3.37); $t(2012)=2.26$, $p=0.13$, 95% CI [-0.02, 0.08], $d=0.05$. The UK sample did have a slightly higher overall benefit perception (M=3.40) compared to the US sample (M=3.32); $t(1966)=2.78$, $p=0.00$, 95% CI [0.02, 0.14], $d=0.12$. Because the benefit perception items all referred to climate change, we conducted a mediation analysis (Figure 2) to determine whether climate change concern could explain the results. There was indeed a significant indirect effect of country on benefit perception through concern about climate change, b=-0.02, 95% BCa CI [-0.04, -0.01]. That is, the greater benefits perceived for CDR in the UK were in part associated with greater concern about climate change there.

Figure 2. Mediation analysis. Model of country as a predictor of benefit perception by climate change concern. The confidence interval for the indirect effect is a Bca bootstrapped CI based on 10,000 samples. **** p <0.001, ** p <0.01, * p <0.05.*
Within Country, 0 = UK and 1 = US

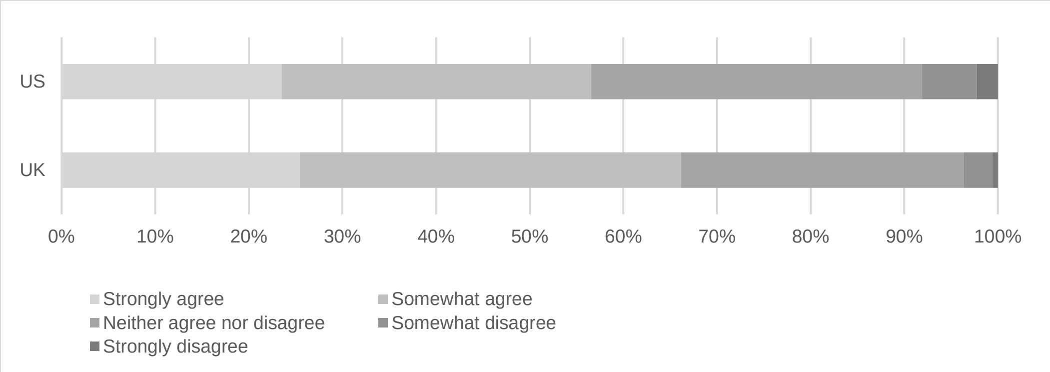


In the workshops, as expected, the analogies used by participants to understand CDR reflected national and historical contexts [12,30]. In the US, the main analogies were land contamination, cigarettes and asbestos, whereas in the UK they were fracking, plastic waste in the ocean, and landfill. Nuclear waste was used as an analogy in both countries: *"That's putting it on the same path as Hinkley Point [UK nuclear plant] as well, where they're dumping down there; they don't know what's gonna happen…" (Dave, Cardiff).* However, these context-specific examples were used to make sense of very similar underlying themes, discussed in the following section. One important exception was a prevalent focus on human health across all US groups, which was not present in the UK (where concerns more often focused on environmental health). The human health discourse appears to be connected to a history of poorly-regulated industrial activity and high-profile examples of health problems arising from land contamination in parts of the US (e.g.[31]): *"There are dried up dump sites that no-one could tell anything had been dumped there and had leached into the ground and years later, we've large areas of cancer…" (Grace, Champaign-Urbana)*.

CDR is a 'non-transition'

A consistent theme across all workshops was the idea that CDR does not necessarily reflect people's 'vision' for a sustainable future society: *"It just seems like each [CDR proposal] is kind of reactionary… I think we need to shift our whole attitude to the way we use the planet" (Tom, Cardiff).* CDR was spoken of in terms of rubbish and "dumping", analogous to radioactive waste (US and UK), landfill (UK), and industrial waste (US) as an indictment of mankind's inability to deal with waste in a responsible manner: *"They say they dump it in the middle of the ocean and it goes down, I don't know where, but it comes back" (Mariana, Chicago).* Participants spoke of *"Creating nine problems to solve one" (Shaun, Dereham)* and *"shutting the gate after the horse has bolted, [when] we should be trying to control the horse" (Amy, Norwich).* The survey also showed that very few people believed that CDR deals with the root cause of emissions (Figure 3). Such a perception, of an intervention that does not address root causes while also sustaining aspects viewed as problematic (e.g. fossil fuel dependency) has been characterised in the energy systems literature as a 'non-transition', particularly in relation to Carbon Capture and Storage [18]. Interestingly, we found that this concern emerges even when fossil fuels are removed from the discussion, as when discussing renewable-powered DAC systems: *"It goes back to, what are we leaving the generations who come behind us?" (Raven, Chicago).* This is an important insight because CDR is sometimes positioned as dealing with the causes of climate change, as opposed to Solar Radiation Management which only deals with the 'symptoms' [4,32]. The divergence found here between expert and public framings will be an important consideration in the development of communication tools for CDR.

Figure 3. Perceptions of CDR as addressing emissions. Percentage of survey respondents in the US (n = 1026) and UK (n = 1000) providing each response to the question "CDR only deals with the symptoms and not the causes of emissions"



Perceptions of the role of science in combatting climate change were an important factor underlying attitudes to CDR. The survey item "CDR technologies are being driven more by profit than the public interest" had the highest proportion of "strongly agree" in both countries, demonstrating that CDR encounters strong risk perceptions relating to scepticism about scientific motives. Workshop participants were often ambivalent, talking highly of scientific progress yet sceptical that innovation under real-world conditions will mitigate against unforeseen harms [33]. Yet scepticism was not unitary, and sparked debate amongst participants: separate discourses connected it to the abilities of otherwise responsible scientists ("*Go back 100 years and look what we thought were safe technologies and now we find out today they aren't" [Jack, Champaign-Urbana]*), and the motives of a supposedly corrupt system of scientific expertise ("*You can make your numbers match anything, you can make your science match whatever you want and a lot of money can be spent on it…" [Grace, Champaign-Urbana])*. CDR was also viewed through a lens of perceived policy inaction on climate change. In four of our groups, this led to a highly conditional acceptance of CDR, often accompanied by the proviso that it be enacted as part of a more ambitious portfolio of emission reduction measures: "*I wouldn't be willing to pay for any of them unless they were part of a package that required reduced emissions in the first place. If it's just something to try to keep us doing what we've been doing, it's a lose-lose" (Bill, Charleston).* Meanwhile the Chicago and Dereham groups generally rejected the idea of CDR entirely, voicing a strong anti-elites discourse: "*I think the ultimate solution for that would be, okay, we'll put it under the White House or we'll put it under Buckingham Palace. If you're telling us it's this safe, you won't have an issue about it" (Elizabeth, Dereham).* This distinction is important because it suggests that non-transition concerns can give rise to different conclusions amongst different publics.

Timescale and urgency

A further insight comes from the way in which participants discussed the timescale for novel climate interventions. Previous research has documented how people tend to think of climate change as psychologically 'distant' in time and space [34], and we found some statements to this effect. Much stronger, though, was a conception of climate change as immediate and urgent, connected to direct experiences of weather extremes: *"There's so much happening… flooding and wildfires and all sorts of things… The temperature is changing and now because of what we see every day" (Felicity, Cardiff)*. In the survey, of the 73% in the US and 81% in the UK who were concerned about climate change, 71% and 59% respectively thought that climate change would harm them personally. This illustrates a critical acceptability issue for novel CDR proposals, because people are aware that technology development takes time: *"How far away is it from being able to be used? Is it like 20 years away? Don't we need that a bit sooner than that really?!" (Benjamin, Norwich)*. Workshop participants perceived CDR as simultaneously too short-term (i.e. not addressing long-term transition needs) and not short-term enough (i.e. unable to address climate change within the required timescale for action). Studies on perceptions of CCS have found that it is seen as a short-term solution to a long-term problem [19,35], yet our participants saw CDR simultaneously as a long-term solution to a short-term (i.e. urgent) problem: "*I don't think [CDR] will have much impact because the damage is being done too rapidly" (Delroy, Chicago)*. Taken in concert with beliefs about non-transition, this temporal dilemma points to a further degree of ambivalence in the minds of ordinary people.

Detailed attitudes to BECCS, DAC and ERW

Table 1. Results from questionnaire distributed to workshop participants at the end of week 1, immediately following the poster task (n = 47)

	Mean	**SD**
How do you feel about BECCS? (1 = very negatively; 10 = very positively)	5.47	2.58
How do you feel about DAC? (1 = very negatively; 10 = very positively)	4.79	2.36
How do you feel about ERW? (1 = very negatively; 10 = very positively)	4.04	2.35
Would you like to see CDR included as part of an overall strategy for reducing climate change risk? (1 = not include it at all; 10 = plays a major role)	7.53	1.86

Bioenergy with carbon capture and storage (BECCS)

Table 1 shows that amongst our workshop participants (n=47), BECCS was generally the most preferred of the three CDR options, which was significant, $F(2,92)=7.958$, $p=0.001$, $\eta^2_p = 0.147$, although Bonferroni post-hoc tests showed that the only significant pairwise difference was between BECCS and ERW, $p=0.000$, 95% CI [0.60, 2.25], with no significant difference between BECCS and DAC, $p=0.162$, 95% CI [-0.18, 1.54], or DAC and ERW, $p=0.192$, 95% CI [-0.23, 1.72]. Workshop participants perceived BECCS as *"the most realistic one of the three" (Eli, Charleston)*, *"more natural" (Peter, Cardiff)*, and *"the greener option" (Kieron, Norwich)*, although concerns were also expressed about monoculture and *"destroying habitats" (Mateo, Chicago)*. The biggest concern was CO_2 storage underground (discussed below), and an association of "*any kind of combustion with harming the planet" (Tom, Cardiff)*. Interestingly, afforestation was mentioned unprompted and very positively in four of the groups; when informed of the vast scale of forestry required for equivalent CO_2 sequestration, many participants questioned whether BECCS could be justified alongside continued rainforest destruction, suggesting that people may prefer protected spaces over intervention (cf.[36]). The US farmers strongly favoured BECCS because of a perceived economic benefit, in light of declining demand for arable products due to electric vehicles or lower meat consumption. Our results reinforce the fact that the precise socio-cultural and economic context within which BECCS is to be deployed (its regulation, incentives, sustainability of processes, and impacts on local communities) will be a critical consideration [20,37].

Direct Air Capture (DAC)

Perspectives on DAC varied considerably between participants, with some preferring its perceived simplicity and lower land requirements (*"just using the air" [Daryl, Dereham]*), whilst others saw it as industrial and 'futuristic' in a negative sense. The biggest concern was CO_2 storage underground, with participants expressing both practical concerns (e.g. leakage, safety) and societal/ethical concerns. While these concerns largely reflect the existing literature [19,20,38], we also identified three novel aspects of attitudes to DAC. First, the idea of capturing CO_2 from ambient air does not appear to be particularly intuitive or easy to understand: *"I didn't understand that one at all. I read it and read it and I thought, meh, it's a little over my head" (Skyler, Charleston).* Many participants conflated CO_2 with particulate pollution, thus DAC was envisaged as an air quality measure, *"like* *what China did during their emergencies" (Lucas, Champaign-Urbana)*. This supports previous findings regarding low public knowledge about CO_2 characteristics [39], and suggests that DAC may face challenges relating to engagement and understanding. Importantly, units sited in less polluted areas may encounter puzzlement and/or scepticism about the specific goal of the project. Second, participants echoed quite sophisticated scientific concerns regarding high energy requirements in the context of wider system change, and surmised that current renewable capacity would not be sufficient to power the units whilst simultaneously decarbonising energy demand (cf.[40]). Third, the idea of a chemical process to extract CO_2 was not received as negatively as we expected, with only two participants (Amy, Norwich and Tom, Cardiff) focusing on the term "chemical process" on the DAC poster.

Enhanced Rock Weathering (ERW)

Initially, ERW experienced the lowest support of the three proposals (Table 1). Participants perceived ERW as energy-intensive (reflecting ongoing discussions in ERW research, cf.[41]) and not necessarily compatible with a climate-friendly future: *"If you're interested in climate change, you kinda warm up more to farms than to mines… a vehicle hauling huge amounts of rock materials, that's difficult to get your mind around seeing that and saying 'oh, we're doing climate work here'" (Randy, Charleston)*. Thus, framing ERW primarily as a climate measure might prove counter-productive. Framing it as a soil amendment could result in different perceptions, but may in turn have implications for scale. Participants also voiced serious concerns over ocean impacts: *"The enhanced weathering one, he said most definitely not because it would affect the wildlife in the ocean" (Samantha, Champaign-Urbana).* This may be problematic for ERW in the near-term, potentially even constituting a 'red line' for publics, because people already feel a strong emotional connection towards the ocean [42], and scientific understanding of ocean impacts is currently incomplete [43]. Viewing the ocean as a particularly fragile, interconnected ecosystem, participants were generally unconvinced that an inert material would stay dissolved in ocean water without unintended consequences: *"Who are we to say what impact these minerals have? I think it's very arrogant of us to say, 'we can do this and there won't be any impact" (Raven, Chicago).* Thus concerns about responsible waste management were not limited to CCS-based techniques, and therefore could also be relevant for CDR via mineral carbonation. Opening new mines for the rock resource may be another 'red line' for publics, due to concerns about energy requirements, ecosystem impacts and safety, and deeper misgivings about a 'non-transition': *"Where is [the rock] all going to come from? You have issues with mining now, collapses and landslides… and you don't have an infinite amount of rocks, you know?" (Keri, Dereham).* However, while we expected to find health concerns over dust from rock spreading, this was not mentioned frequently or vociferously.

Table 2 illustrates the main themes identified from the survey and workshop analysis. 'CDR' could include established techniques such as afforestation, mentioned spontaneously and favourably in several groups; the table therefore shows that some themes, notably the temporal dilemma, may be specific to novel 'engineered' solutions with low technology readiness, and the questionnaire results in Table 1 support this. Meanwhile scepticism about addressing root causes, and about scientific motives, also emerged strongly in survey responses about generic 'CDR'.

Table 2. Overview of main themes emerging from the analysis

Theme	CDR	BECCS	DAC	ERW
Low prior understanding	✓	✓	✓	✓
Doesn't deal with the root cause of climate change	✓	✓	✓	✓
Scepticism & ambivalence about scientific motives	✓	✓	✓	✓
Temporal dilemmas		✓	✓	✓
Human health: US only		✓	✓	✓
Ecosystem impacts		✓		✓
Geological storage: leakage, safety, social & ethical concerns		✓	✓	
Emissions from combustion (inc. non-CO2)		✓		
Problems understanding how the technique works			✓	✓
Energy requirements			✓	✓
Risks to oceans, ocean ecosystems, and water resources		✓	✓	✓
Opposition to new mines				✓

Discussion

This paper reports results from a cross-national, mixed methods study of public perceptions of Carbon Dioxide Removal in the US and UK, as well as detailed qualitative insights on responses to three major CDR proposals. For emerging technologies, deliberative insights are important for our understanding, because of demonstrably low prior awareness and its impact on responses in surveys and experimental studies. We draw several conclusions regarding the ethical and effective development of CDR, which might be considered as part of a responsible research and innovation programme [44]. On learning about CDR, participants expressed a range of potential benefits and risks as well as wider societal issues such as trust in science and technology governance. The workshops in particular demonstrated that non-experts can arrive at thoughtful, well-argued judgements when given sufficient time and resources to do so. Previous studies of emerging technologies found similar[45,46], and this is a message that will need to be fully digested and appreciated by scientists, regulators and entrepreneurs working on CDR research and development.

The current study involved publics from two high-emitting countries, but further research will be needed in other contexts where CDR might take place at scale, particularly in developing nations and areas disproportionately vulnerable to climate risks. Our findings suggest that views on CDR will vary across deployment context and technology type, and will be heavily dependent upon the ways in which proposals are framed (as a short vs long-term measure, as climate mitigation vs remediation, as an environmental risk or benefit, etc.). Low prior awareness, coupled with multiple points of ambivalence that emerge as people receive further information, mean that such attitudes are likely to remain at best conditional and fragile. Accordingly, if CDR is to be deployed at scale, communication approaches will need to be developed for specific technologies and locations, with no substitute for conducting bespoke empirical testing of the impacts of different message types and frames, and for engaging different publics [47]. Importantly, and congruent with ref.[16], we found that non-transition concerns may give rise to different conclusions amongst different publics, underlining the importance of attending to heterogeneity of context and people's values.

While we examined three very different CDR proposals in the workshops, the results indicate some fundamental similarities in the narratives that arose (Table 2). Whilst attitudes to CDR have not been studied cross-nationally using mixed methods before, similar themes around 'non-transition' and root cause have been found in previous work on geoengineering [12,48]. This is interesting, because we might assume that CDR would be viewed less negatively than geoengineering in this regard [49]; in fact, some of these concerns do seem to dissipate for certain types of CDR such as afforestation [16], underlining the need for caution when extrapolating results across different technology categories [14]. More surprising, however, was the focus on timescale, seemingly emerging as part of a new public discourse on climate urgency. Previous research found that urgency frames can have a positive impact on perceptions of geoengineering,[12] yet our results suggest that the opposite may be true for CDR. Our participants introduced the urgency frame themselves rather than being prompted on it, demonstrating the increasing salience of timescale as a factor influencing climate perceptions. Of course, whether such urgency discourses represent a permanent state of affairs is an open question, yet at the moment they are clearly important for perceptions of CDR, and by extension for those of any climate intervention with low technology readiness.

In conceptual terms, our study points to a critical set of dilemmas arising around the question of time and CDR deployment, which render the framing of any communication strategy, and even potential governance proposals, problematic. If climate change is now perceived by many citizens in the US and UK as the urgent issue that it undoubtedly is, CDR could be viewed as offering short-term benefits by providing more time to deploy conventional emissions reduction measures. However, in the face of climate urgency people quite rightly reason that technology development for many novel CDR proposals will take too long to make any serious short-term difference, while potentially bringing associated risks if deployed prematurely or without sufficient testing. Framing CDR alternatively as a long-term climate measure, it becomes an essential 'imaginary' embedded within existing global transition scenarios [50]. Not only does this alternative discourse sit uncomfortably with the growing belief in urgent climate action, our workshop participants went on to interpret this long-term framing as a 'non-transition', essentially incompatible with aspirations for a sustainable future society. Of course, CDR comprises a more varied collection of proposals than the three studied here, with differing degrees of technological maturity and equally varied relationships with perceptions of time. Nevertheless, it appears that engineered CDR risks a failure to achieve a clear social licence to operate if the temporal dilemmas identified here cannot be properly resolved. These temporal dilemmas are bound up with wider ethical, social, and technological questions regarding the relationship between emissions reduction and carbon removal as means for achieving 'net-zero'. Above all, while research under well-controlled conditions is likely to be acceptable, significant at-scale deployment without a corresponding major effort to deliver emissions reductions would currently appear to represent a red line for many people.

Acknowledgments

This research was funded by the Leverhulme Trust under project research grant RC-2015-029. We are indebted to members of the LC3M advisory board for their design input and ongoing support, and to the University of Illinois Extension Office and Evan de Lucia lab for fieldwork assistance. For help with survey design and workshop materials, we also thank Victoria Campbell-Arvai, Pete Ashworth, Michele Ferguson, Tim Kruger, Naomi Vaughan, Gideon Henderson, Darrick Evensen, and Alan Flewker.

Author contributions

EC, ES and NP were involved in the conceptualisation of the research; EC designed and facilitated the workshops and analysed the qualitative and questionnaire data; ES designed the survey and analysed the survey data; EC wrote the original draft; EC, ES and NP were involved in writing, review and editing of the manuscript; NP acquired funding.

Competing interests

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

References

1. United Nations. *United Nations Framework Convention on Climate Change: Adoption of the Paris Agreement*. (2015).
2. Royal Society & RAEng. *Greenhouse Gas Removal*. https://www.raeng.org.uk/publications/reports/greenhouse-gas-removal (2018).
3. Friedmann, S. J. Engineered CO2 Removal, Climate Restoration, and Humility. *Front. Clim.* **1**, (2019).
4. Minx, J. C. *et al.* Negative emissions—Part 1: Research landscape and synthesis. *Environ. Res. Lett.* **13**, 063001 (2018).
5. Bradshaw, M. & Waite, C. Learning from Lancashire: Exploring the contours of the shale gas conflict in England. *Glob. Environ. Change* **47**, 28–36 (2017).
6. Grove-White, R., Macnaghten, P. & Wynne, B. *Wising up: the public and new technologies*. (2000).
7. Terwel, B. W., ter Mors, E. & Daamen, D. D. L. It's not only about safety: Beliefs and attitudes of 811 local residents regarding a CCS project in Barendrecht. *Int. J. Greenh. Gas Control* **9**, 41–51 (2012).

8. Fiorino, D. J. Citizen Participation and Environmental Risk: A Survey of Institutional Mechanisms. *Sci. Technol. Hum. Values* **15**, 226–243 (1990).

9. Moffat, K., Lacey, J., Zhang, A. & Leipold, S. The social licence to operate: a critical review. *For. Int. J. For. Res.* **89**, 477–488 (2016).

10. Nemet, G. F. *et al.* Negative emissions—Part 3: Innovation and upscaling. *Environ. Res. Lett.* **13**, 063003 (2018).

11. Bellamy, R., Chilvers, J. & Vaughan, N. E. Deliberative Mapping of options for tackling climate change: Citizens and specialists 'open up' appraisal of geoengineering. *Public Underst. Sci.* **25**, 269–286 (2016).

12. Wibeck, V. *et al.* Making sense of climate engineering: a focus group study of lay publics in four countries. *Clim. Change* (2017) doi:10.1007/s10584-017-2067-0.

13. McLaren, D., Parkhill, K. A., Corner, A., Vaughan, N. E. & Pidgeon, N. F. Public conceptions of justice in climate engineering: Evidence from secondary analysis of public deliberation. *Glob. Environ. Change* **41**, 64–73 (2016).

14. Cox, E. M., Pidgeon, N., Spence, E. & Thomas, G. Blurred lines: the ethics and policy of Greenhouse Gas Removal at scale. *Front. Environ. Sci.* **6**, (2018).

15. Corner, A., Parkhill, K., Pidgeon, N. & Vaughan, N. E. Messing with nature? Exploring public perceptions of geoengineering in the UK. *Glob. Environ. Change* **23**, 938–947 (2013).

16. Wolske, K. S., Raimi, K. T., Campbell-Arvai, V. & Hart, P. S. Public support for carbon dioxide removal strategies: The role of tampering with nature perceptions. *Clim. Change* **152**, 345–361 (2019).

17. Demski, C., Butler, C., Parkhill, K. A., Spence, A. & Pidgeon, N. F. Public values for energy system change. *Glob. Environ. Change* **34**, 59–69 (2015).

18. Butler, C., Parkhill, K. & Pidgeon, N. F. *Deliberating energy system transitions in the UK*. http://www.ukerc.ac.uk/publications/transforming-the-uk-energy-system-public-values-attitudes-and-acceptability-deliberating-energy-system-transitions-in-the-uk.html (2013).

19. Mabon, L. & Shackley, S. Meeting the targets or re-imagining society? An empirical study into the ethical landscape of carbon dioxide capture and storage in Scotland. *Environ. Values* **24**, 465–482 (2015).

20. Thomas, G., Pidgeon, N. & Roberts, E. Ambivalence, naturalness and normality in public perceptions of carbon capture and storage in biomass, fossil energy, and industrial applications in the United Kingdom. *Energy Res. Soc. Sci.* **46**, 1–9 (2018).

21. Cox, E., Spence, E. & Pidgeon, N. Incumbency, trust and the Monsanto effect: stakeholder discourses on greenhouse gas removal. *Environ. Values* **Article in Press**, (2019).

22. Slovic, P. *The Feeling of Risk: New Perspectives on Risk Perception*. (Routledge, 2010).

23. Pidgeon, N. F., Hood, C., Jones, D., Turner, B. & Gibson, R. Risk perception. in *Risk - Analysis, Perception and Management: Report of a Royal Society Study Group* 89–134 (The Royal Society, 1992).

24. Pidgeon, N. F. & Spence, E. Perceptions of enhanced weathering as a biological negative emissions option. *Biol. Lett.* **13**, 20170024 (2017).

25. Daamen, D., de Best-Waldhober, M., Damen, K. & Faaij, A. Pseudo-opinions on CCS technologies. in *GHGT-8* (2006).

26. Fischhoff, B. & Fischhoff, I. Publics' Opinions about Biotechnologies. *AgBioForum* **4**, 155–162 (2002).

27. Jones, C. R., Radford, R. L., Armstrong, K. & Styring, P. What a waste! Assessing public perceptions of Carbon Dioxide Utilisation technology. *J. CO2 Util.* **7**, 51–54 (2014).

28. National Academies of Sciences, Engineering and Medicine. *Negative Emissions Technologies and Reliable Sequestration: A Research Agenda*. (National Academies Press, 2019). doi:10.17226/25259.

29. Markusson, N., McLaren, D. & Tyfield, D. Towards a cultural political economy of mitigation deterrence by negative emissions technologies (NETs). *Glob. Sustain.* **1**, (2018).

30. Bickerstaff, K., Simmons, P. & Pidgeon, N. *Public perceptions of risk, science and governance: main findings of a qualitative study of six risk cases*. (2006).

31. Fowlkes, M. R. & Miller, P. Y. Chemicals and Community at Love Canal. in *The Social and Cultural Construction of Risk: Essays on Risk Selection and Perception* (eds. Johnson, B. B. & Covello, V. T.) 55–78 (Springer Netherlands, 1987). doi:10.1007/978-94-009-3395-8_3.

32. National Academy of Sciences. *Climate Intervention: Carbon Dioxide Removal and Reliable Sequestration*. (National Academies Press, 2015). doi:10.17226/18805.

33. Macnaghten, P., Davies, S. R. & Kearnes, M. Understanding Public Responses to Emerging Technologies: A Narrative Approach. *J. Environ. Policy Plan.* 1–19 (2015) doi:10.1080/1523908X.2015.1053110.

34. Leiserowitz, A. Climate Change Risk Perception and Policy Preferences: The Role of Affect, Imagery, and Values. *Clim. Change* **77**, 45–72 (2006).

35. Upham, P. & Roberts, T. Public perceptions of CCS in context: Results of NearCO2 focus groups in the UK, Belgium, the Netherlands, Germany, Spain and Poland. *Energy Procedia* **4**, 6338–6344 (2011).

36. Lotze, H. K., Guest, H., O'Leary, J., Tuda, A. & Wallace, D. Public perceptions of marine threats and protection from around the world. *Ocean Coast. Manag.* **152**, 14–22 (2018).

37. Bellamy, R., Lezaun, J. & Palmer, J. Perceptions of bioenergy with carbon capture and storage in different policy scenarios. *Nat. Commun.* **10**, (2019).

38. L'Orange Seigo, S., Dohle, S. & Siegrist, M. Public perception of carbon capture and storage (CCS): A review. *Renew. Sustain. Energy Rev.* **38**, 848–863 (2014).

39. Dowd, A.-M., Itaoka, K., Ashworth, P., Saito, A. & de Best-Waldhober, M. Investigating the link between knowledge and perception of CO 2 and CCS: An international study. *Int. J. Greenh. Gas Control* **28**, 79–87 (2014).

40. Realmonte, G. *et al.* An inter-model assessment of the role of direct air capture in deep mitigation pathways. *Nat. Commun.* **10**, 1–12 (2019).

41. Lefebvre, D. *et al.* Assessing the potential of soil carbonation and enhanced weathering through Life Cycle Assessment: A case study for Sao Paulo State, Brazil. *J. Clean. Prod.* **233**, 468–481 (2019).

42. Spence, E., Pidgeon, N. & Pearson, P. UK public perceptions of Ocean Acidification – The importance of place and environmental identity. *Mar. Policy* (2018) doi:10.1016/j.marpol.2018.04.006.

43. Gore, S., Renforth, P. & Perkins, R. The potential environmental response to increasing ocean alkalinity for negative emissions. *Mitig. Adapt. Strateg. Glob. Change* (2018) doi:10.1007/s11027-018-9830-z.

44. Owen, R., Bessant, J. R. & Heintz, M. *Responsible Innovation: Managing the Responsible Emergence of Science and Innovation in Society*. (John Wiley & Sons, 2013).

45. Macnaghten, P. Researching Technoscientific Concerns in the Making: Narrative Structures, Public Responses, and Emerging Nanotechnologies. *Environ. Plan. Econ. Space* **42**, 23–37 (2010).

46. Marris, C. Public views on GMOs: deconstructing the myths. *EMBO Rep.* **2**, 545–548 (2001).

47. Pidgeon, N. & Fischhoff, B. The role of social and decision sciences in communicating uncertain climate risks. *Nat. Clim. Change* **1**, 35–41 (2011).

48. Carr, W. A. & Yung, L. Perceptions of climate engineering in the South Pacific, Sub-Saharan Africa, and North American Arctic. *Clim. Change* **147**, 119–132 (2018).

49. Bellamy, R., Chilvers, J., Vaughan, N. E. & Lenton, T. M. 'Opening up' geoengineering appraisal: Multi-Criteria Mapping of options for tackling climate change. *Glob. Environ. Change* **23**, 926–937 (2013).

50. Anderson, K. & Peters, G. The trouble with negative emissions. *Science* **354**, 182–183 (2016).

Methods

Deliberative workshops

Workshops were conducted in six locations in the US and UK, between November 2018 and February 2019. These countries were chosen because of their high share of global CO_2 emissions (both now and historically), requiring extremely ambitious action to mitigate climate change. CDR is attracting considerable policy attention in both the US and UK, and both would almost certainly need to deploy some CDR at scale in order to come close to net zero emissions [2,28]. Well-established scientific expertise means that they may be well-placed to develop CDR technology for international technology transfer. The English language was also an important practical consideration: our decision to use the same facilitators for all workshops gives a higher-than-usual degree of cross-national comparability. However, we emphasise that both developing and non-English-speaking countries may also be crucial for CDR development and deployment, and that further research will be needed in this area.

Workshop locations represented an urban/rural balance and were roughly equivalent between the two countries: Chicago (US city), Champaign-Urbana (US small university town), Charleston (US rural area), Cardiff (UK city), Norwich (UK small university town), and Dereham (UK rural area). The Charleston and Dereham workshops involved rural participants from a wide surrounding area. We targeted Illinois and East Anglia because their large tracts of arable land provide a potential deployment location for BECCS and ERW (DAC could theoretically be located anywhere). As it was not practical to conduct workshops in all 50 US States, we chose to conduct all US workshops in Illinois, but the US is large and diverse and therefore our results may not represent the whole country. All workshops lasted roughly 5 hours, split across two evenings. We did not have a technical expert present, because of previous research showing that people tend to defer to the expert [51]. When questions were directed to the facilitators, we probed the rationale behind the question ("what makes you interested in that?" "What does the rest of the group think?") before answering to the best of our ability. We used particular facilitation techniques to understand people's broader values, such as counterbalancing (e.g. providing info on costs or risks when people expressed positive responses), and encouraging participants to reflect on how their choices could impact their daily lives [52]. In response to concerns about deliberative settings being 'artificial' or overly 'controlled' by the research team [53], we conducted the workshops across two evenings a week apart, and asked people to discuss the topics with family and friends and to look them up on the internet in the intervening week. This allowed us to 'open up' to the perspectives of people's broader peer groups and to other means of information provision, thus more accurately reflecting real-world conditions.

Workshop protocol and materials. The workshop protocol was designed after extensive piloting in the UK and US. After introductions and an ice-breaker question, the facilitator delivered a short presentation on 'ways of reducing the risk of climate change', using examples of supply-side mitigation, demand-side mitigation and adaptation (Supplementary Methods 2 and 4), followed by discussion. This presentation was designed to place CDR 'in context' and to avoid discussing CDR in isolation of other climate stabilisation approaches. 'Climate change' is of course a strong framing, and the results need to be interpreted in this light. However, any initial topic would have created framing effects, and participants were highly likely to introduce the climate change framing themselves as soon as we started discussing CDR, because proposals such as DAC with storage have no other purpose [54]. Throughout our materials and facilitation, there were certain framings we sought to avoid: 'naturalness', familiarity (e.g. 'this is similar to something people are doing already'), and the role of science and technology in society. These have been shown to be important in previous research on similar topics and we wished to avoid steering the discussions toward them.

The second session introduced participants to CDR using posters of BECCS, DAC and ERW (Supplementary Methods 5), with participants free to move among them to minimise ordering bias. Participants wrote comments and questions on post-its, which we then discussed as a group. This technique worked well for a topic which people were unfamiliar with because it allowed anonymity, thus encouraging participation from everyone. The posters were designed with extensive input from a number of experts including technical specialists. Each technique was illustrated using clip-art-style drawings, because using realistic photos or artists' impressions may bias the discussion [55]. In response to expert input, we also included information on stage of development, scale, the CO_2 storage mechanism, possible benefits, and possible risks. We ended this session with a general discussion about CDR, including prompts from the facilitator such as "can you see yourselves living in a world where these are used?", "would you be willing to pay for any of these?" and "were there any of these options that you were particularly excited / unhappy about?"

We chose to focus on BECCS, DAC and ERW because they may have the greatest global long-term sequestration potential, according to a 2018 meta-analysis of existing research (see Fig. 6 in [4]). This is not to suggest that these are the most promising CDR approaches or that they should necessarily be a priority, and it is important to emphasise that there is much uncertainty regarding sequestration potentials. In our initial pilot, we included a fourth option of 'afforestation'. We removed this option for two reasons: a) we were struggling to fit discussion of four CDR proposals into a reasonable amount of time; and b) the familiarity and perceived 'naturalness' of afforestation appeared to be having a considerable impact on participants' discussions of the other CDR proposals. The topic of afforestation was mentioned unprompted in four of the groups despite our decision not to include it; further research could explore in more detail the impact that afforestation as an option may have on perceptions of engineered CDR.

Following the CDR session, the participants were given a homework task to discuss with another person what they had learnt, and departed to be reconvened in the same location the following week. No participants dropped out in this intervening period. The extreme cold weather in Illinois in January 2019 meant that we had to reconvene the Champaign workshop the following day, but most participants still managed to do the homework task. Reported internet activity was much higher in the US groups than in the UK; we do not know why this was the case. In future work, more emphasis could be placed on use of the internet, perhaps by setting a specific mandatory task for the intervening week. The first session of week 2 comprised a group discussion of the homework task, during which all participants were asked to speak.

This study was conducted as part of a broader research project on ERW; the second part of the workshops focused on ERW and is not reported here. During the first day all three proposals were treated equally. However, at the end of the second week we had a 'reflections and feedback' session, which was important for participants to voice their final thoughts about the topic as a whole. Results from this session have been reported here, therefore it is important to note that our ERW discussion in the intervening time could have influenced this (see Supplementary Methods 6). The feedback session included prompts such as "what role should technology have in addressing environmental issues?" and "who should be responsible for dealing with climate change?" We also conducted a short questionnaire at the end of week 1 and week 2 (Supplementary Methods 3). The questions were largely the same on both, but this paper only reports the results of the questionnaire at the end of week 1, immediately following the poster task.

Workshop recruitment. Each workshop recruited 8 participants. Anonymised participant details are given in Supplementary Table 2, with summary demographics in Supplementary Table 3. We had only one 'no show' (Charleston). Recruitment in the UK was carried out by a professional recruitment company. In Illinois, this type of recruitment is uncommon and we failed to find a company able to meet our specifications, therefore we partnered with the University of Illinois Extension Office who recruited using their databases of contacts. For all workshops, we aimed for gender balance and a range of ages where possible. We also asked recruiters to choose a mix of participants who broadly reflected the demographics of the area: for example, in rural areas most participants were white and slightly older, whereas Chicago was mostly black and minority ethnic. However, it is important to emphasise that no group will be statistically representative of the population as a whole. For our two rural groups, we requested a number of farmers or people with links to farms, because of the importance of the agricultural sector for deployment of BECCS, ERW, and numerous other CDR proposals. However, this led to a disparity between our Charleston group and the other groups, because the UK rural group (Dereham) had more tenuous links to farms and did not generally refer to farming experience in their discussions. The Charleston group on the other hand were very farm-focused, meaning that they may have been responding partly as economic rather than civic actors. We have taken care to ensure that the narratives discussed in this paper were found across all six groups, thus reinforcing any common messages which were found across the three heterogeneous US groups, and the conclusions from our cross-national comparison. Yet it also emphasises the importance of attending to heterogeneity between different types of publics in such research.

Recruitment was 'topic blind' to avoid self-selecting bias: we recruited people for a focus group on 'solutions to global challenges'. In retrospect, we should not have used the word 'global', because it appeals to a particular value set. Perhaps because of this, or perhaps because of self-selecting bias in general for deliberative activities, our US groups were biased toward climate change concern: although some participants were unsure or were sceptical about anthropogenic vs natural causes, there were no outright climate sceptics, which does not fully reflect the US population as a whole. It is important to interpret our results in this light. Participants were paid in cash for their time: $150 in the US, and £100 in the UK.

Workshop data analysis. All workshops were recorded using both audio and video recording devices, and the recordings edited using Camtasia software. The recordings were professionally transcribed by a third party, and transcripts checked for accuracy by the lead author and anonymised to remove names and identifying features. The dataset was analysed using established methods for thematic coding analysis [56], in which coding is undertaken in an iterative process involving multiple readings of the data and continual comparison between themes. In line with methods set out in refs. [57] and [58], the first stage of analysis involved listening to the recordings many times, to become familiar with the data and to inductively draw out key themes that were prevalent in and across the workshops. This process generated a large number of themes, ranging in theoretical complexity from basic descriptions to conceptual categories. This framework was then used to code the data using N-Vivo software, including allowing additional codes to emerge inductively from the data. Codes were then re-grouped into theoretically-relevant meta-codes that reflected our emerging concepts and insights. Theme development was informed by ongoing readings of the existing literature which provided the theoretical basis for interpretation. Finally, subjective decisions were made regarding which topics to focus on in this paper, according to the most prevalent, interesting, novel, or theoretically-relevant topics. During the process, constant comparison was made between the coded data, the recordings, and the existing literature.

The questionnaire returned quantitative data (n=47), which was analysed using a one-way repeated-measures ANOVA and Bonferroni post-hoc tests, in IBM SPSS software. Mauchly's test indicated that the assumption of sphericity had not been violated, χ^2 (2)=1.996, p=0.369, thus no correction was needed. For the ANOVA, effect size was calculated using partial Eta-squared.

Survey design and measures used

The survey was conducted online in the US, UK and Australia. For purposes of comparison, we have not reported the Australian results here. Each survey was nationally-representative (US n=1026; UK n=1000) conducted during February and March 2019. Data collection was administered online by Qualtrics on behalf of Cardiff University using quota sampling via panel databases. Samples were representative of the US and UK populations aged 18+ in terms of age, gender, education and geographical region. We report the demographic characteristics of survey respondents in Supplementary Table 1.

The survey was designed to measure public understanding of CDR, and how this related to demographic characteristics and climate change perceptions. It was designed via extensive piloting and iterative feedback with a number of technical experts. The experts used were different from those who informed the workshop materials, but the survey and workshops were designed side-by-side to ensure comparability. US experts also provided input on language and cultural appropriateness.

Climate change perceptions: The survey asked a series of questions designed to elicit general attitudes towards climate change. Respondents first answered the question, 'How concerned, if at all, are you about climate change?' Responses were on a four-point scale ranging from 'very concerned' to 'not at all concerned', with 'don't know' and 'no opinion' options also provided. Respondents were then asked, 'How much do you think climate change will harm you personally?' with a four-point scale ranging from 'not at all' to 'a great deal' to indicate their perceived level of personal harm from climate change. Next, respondents indicated the extent to which they agreed or disagreed with the following statement (five-point scale plus a 'don't know' option): 'To what extent do you agree with the following statement about science: Science and technology will eventually solve our problems with climate change' [59].

CDR perceptions: There then followed a short description of CDR (see Supplementary Methods 1) before asking about prior awareness with the question: 'Before today, how much if anything, would you say that you know about carbon dioxide removal technologies?'. Responses were on a five-point scale, ranging from 'I know a great deal about carbon dioxide removal technologies' to 'I have not heard of carbon dioxide removal technologies before today'. Respondents were subsequently asked to indicate to what extent they agreed or disagreed (five-point scale) with a set of eight statements (randomised) measuring perceived risks and benefits associated with CDR:

- There may be negative impacts of carbon dioxide removal technologies on the environment
- Carbon dioxide removal technologies will lower the drive to cut emissions
- Carbon dioxide removal technologies are being driven more by profit than the public interest
- Carbon dioxide removal technologies will mainly benefit rich countries and impact on poor countries
- Carbon dioxide removal technologies could help to provide more time to reduce emissions
- It will be cheaper to use carbon dioxide removal technologies than to reduce the consumption of fossil fuels
- Carbon dioxide removal technologies will help slow climate change down faster than by simply cutting greenhouse gas emissions
- Carbon dioxide removal only deals with the symptoms and not the causes of emissions

These specific risk and benefit perception items were mainly adapted from earlier work on unfamiliar technologies including genetically modified crops and Solar Radiation Management (SRM) [60,61]. Various aspects of CDR such as costs, impacts and usefulness in helping reduce emissions were explored, as these are all significant potential issues that are still uncertain but must be resolved if CDRs are to be deployed at scale in future [62]. Exploring specific environmental, economic and social risks and benefits of CDR cross-nationally enables us to identify broad differences in public acceptability in the US and UK.

From a principal component analysis (Varimax rotation) a two-factor solution was obtained across seven items. The item 'CDR only deals with the symptoms and not the causes of emissions' was excluded from this analysis, because it did not fit with the intended factor analysis as it does not refer to a specific risk or benefit. This topic was important in the qualitative data, therefore we have reported the results from this question separately. Respondents' scores for the seven remaining items were treated as an indicator of risk perception (Cronbach's $\alpha = 0.57$) and benefit perception (Cronbach's $\alpha = 0.61$) and were used in subsequent analyses. See Supplementary Methods 1 for full survey scales.

Ethical review statement

All components of the research were granted ethical approval by Cardiff University School of Psychology Ethics Committee. All study participants gave full and informed consent prior to the commencement of the study. For workshop participants, written consent was obtained at the beginning of the workshop, after participants had been given detailed information about the study and been informed of their right to withdraw their consent or their data at any time. No individual identifiers are reported in any phase of the research and pseudonyms have been used throughout.

Data availability

The survey data has been made publicly available in Cardiff University Open Data Repository: http://doi.org/10.17035/d.2020.0101974649 (survey data)[63] and http://doi.org/10.17035/d.2020.0106264948 (questionnaire data)[64]. The workshop audio files and transcripts cannot be made publicly available due to the need to respect participant confidentiality. However, we will consider requests to share the anonymized transcripts (for research purposes only) on a case-by-case basis after an embargo of two years, during which time our analysis continues. Any other data are available from the corresponding author upon reasonable request.

Methods-only References

51. Macnaghten, P. & Szerszynski, B. Living the global social experiment: An analysis of public discourse on solar radiation management and its implications for governance. *Glob. Environ. Change* **23**, 465–474 (2013).
52. Pidgeon, N., Demski, C., Butler, C., Parkhill, K. & Spence, A. Creating a national citizen engagement process for energy policy. *Proc. Natl. Acad. Sci.* **111**, 13606–13613 (2014).
53. Degeling, C., Carter, S. M. & Rychetnik, L. Which public and why deliberate? – A scoping review of public deliberation in public health and health policy research. *Soc. Sci. Med.* **131**, 114–121 (2015).
54. Cox, E. & Edwards, N. R. Beyond carbon pricing: policy levers for negative emissions technologies. *Clim. Policy* 1–13 (2019) doi:10.1080/14693062.2019.1634509.
55. Corner, A., Parkhill, K. A. & Pidgeon, N. *'Experiment Earth?' Reflections on a public dialogue on geoengineering*. http://eprints.whiterose.ac.uk/82861/ (2011).
56. Braun, V. & Clarke, V. Using thematic analysis in psychology. *Qual. Res. Psychol.* **3**, 77–101 (2006).

57. Macnaghten, P. Focus groups as anticipatory methodology: a contribution from science and technology studies towards socially resilient governance. in *A New Era in Focus Group Research* (eds. Barbour, R. & Morgan, D. L.) 343–363 (Palgrave MacMillan, 2017).

58. Macnaghten, P. & Myers, G. Focus groups. in *Qualitative research practice* (eds. Seale, C., Giampietro Gobo, J. G. & Silverman, D.) 65–79 (Sage, 2004).

59. Steentjes, K. *et al. European Perceptions of Climate Change (EPCC): Topline findings of a survey conducted in four European countries in 2016*. (2017).

60. Pidgeon, N. F. *et al.* Using Surveys in Public Participation Processes for Risk Decision Making: The Case of the 2003 British GM Nation? Public Debate. *Risk Anal.* **25**, 467–479 (2005).

61. Merk, C., Pönitzsch, G., Kniebes, C., Rehdanz, K. & Schmidt, U. Exploring public perceptions of stratospheric sulfate injection. *Clim. Change* **130**, 299–312 (2015).

62. Fuss, S. *et al.* Research priorities for negative emissions. *Environ. Res. Lett.* **11**, 115007 (2016).

63. Spence, E. and Cox, E. (2020) Survey data for US and UK on public risk perceptions of carbon dioxide removal (CDR). *Dataset, Cardiff University Open Data Repository*. Doi: 10.17035/d.2020.0101974649

64. Cox, E. and Spence, E. (2020) Carbon Dioxide Removal Questionnaire Results. *Dataset, Cardiff University Open Data Repository.* Doi: 10.17035/d.2020.0106264948