Discussion

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Author for correspondence:

Glen Dowell

e-mail: gwd39@cornell.edu

Rooting carbon dioxide removal research in the social sciences

Glen Dowell¹, Jeff Niederdeppe², Jamie Vanucchi³, Timur Dogan⁴, Kieran Donaghy⁵, Rory Jacobson^{7,8}, Natalie Mahowald⁶, Mark Milstein¹ and T. Jane Zelikova^{7,9}

¹SC Johnson College of Business, ²Department of Communication, ³Department of Landscape Architecture, ⁴Department of Architecture, ⁵Department of City and Regional Planning, and ⁶Department of Earth and Atmospheric Sciences, Cornell University, Ithaca, NY 14853, USA

⁷Carbon180, Oakland, CA, USA

⁸Yale School of Forestry and Environmental Studies, New Haven, CT 06511, USA

⁹Department of Botany, University of Wyoming, Laramie, WY 82071, USA

GD, 0000-0003-3829-7404

Reports from a variety of bodies have highlighted the role that carbon dioxide removal (CDR) technologies and practices must play in order to try to avoid the worst effects of anthropogenic climate change. Research into the feasibility of these technologies is primarily undertaken by scholars in the natural sciences, yet, as we argue in this commentary, there is great value in collaboration between these scholars and their colleagues in the social sciences. Spurred by this belief, in 2019, a university and a non-profit organization organized and hosted a workshop in Washington, DC, intended to bring natural and physical scientists, technology developers, policy professionals and social scientists together to explore how to better integrate social science knowledge into the field of CDR research. The workshop sought to build interdisciplinary collaborations across CDR topics, draft new social science research questions and integrate and exchange disciplinary-specific terminology. But a snowstorm kept many social scientists who had organized the conference from making the trip in person. The workshop went on without them and organizers did the best they could to include the team remotely, but in the age before daily video calls, remote participation was not as successful as organizers had hoped. And thus, a workshop that was supposed to focus on social science integration moved on, without many of the social scientists who organized the event. The social scientists in the room were supposed to form the dominant voice but with so many stuck in a snow storm, the balance of expertise shifted, as it often does when social scientists collaborate with natural and physical scientists. The outcomes of that workshop, lessons learned and opportunities missed, form the basis of this commentary, and they collectively indicate the barriers to integrating the natural, physical and social sciences on CDR. As the need for rapid, effective and successful CDR has only increased since that time, we argue that CDR researchers from across the spectrum must come together in ways that simultaneously address the technical, social, political, economic and cultural elements of CDR development, commercialization, adoption and diffusion if the academy is to have a material impact on climate change in the increasingly limited window we have to address it.

1. Introduction

Recent reports from the UN IPCC as well as the US National Climate Assessment have highlighted the importance of researching, developing and deploying carbon dioxide removal (CDR) approaches in order to mitigate the worst effects of climate change and meet agreed-upon climate goals [1,2]. To date, two National Academies of Science reports have outlined a CDR research agenda for the natural sciences and engineering, focusing on filling the research gaps and promoting the

development of breakthrough carbon removal technologies and solutions [3,4]. None of these reports have addressed the social elements on which those technologies and solutions depend upon for success, acknowledged the social sciences that study those elements or articulated a vision for how all critical disciplines can collaborate in an integrated fashion to propel broader CDR research agendas. Our goal with this commentary is to encourage our peers in the social, natural and physical sciences to actively engage one another: not as ‘add-ons’ to core disciplinary work, but from the earliest stages of research design when research questions are formulated and the research approach is developed. Such an approach will enable CDR technology research to account for the non-technical economic, social and political elements that determine actual adoption and diffusion rates, and for CDR social science to be grounded in critical natural and physical opportunities and limitations. Should each discipline to continue to fundamentally look past the value the other offers for creating more insightful knowledge, CDR research as a whole risks falling victim to mistaking aspirational myopia rooted in traditional research processes for robust scholarship needed to bring real, lasting change to a world in need of it.

The body of social science scholarship in CDR is large and growing, but remains disconnected from the CDR research that is traditionally dominated by natural sciences and engineering, which itself operates on its own separate set of tracks. CDR solutions would have greater potential to meet societal needs and become widely adopted if their development was informed by social science and socio-economic considerations before there is substantial investment in these ideas. Models from large-scale socio-technical changes can help anticipate issues that might emerge to better inform CDR social science contributions [5].

While research in physical science and engineering seeks to establish technological feasibility, social science research examines factors at the individual, community and societal level that will influence whether CDR technologies would, could, or should be adopted and, if so, how. Both domains are of interest to and inform the other. Managing the transition to an economy that sequesters more carbon than it emits will require the widespread adoption of technologies and land management strategies that remove carbon from the atmosphere (e.g. direct air capture, bioenergy carbon capture and sequestration (BECCS), reforestation, soil management, carbon mineralization). Recent research, for example, has examined factors associated with acceptance of BECCS and found that acceptance of that technology depends not only upon the perceived effectiveness of the technology but also on the policy through which BECCS was implemented [6–8]. Unfortunately, such research, where nascent or as-yet-unseen technologies are assessed, is all too rare, because the primary role of social scientists has been to assess the effects—intended and unintended—of given technologies or the perception of such technologies (e.g. [7,9,10]).

Mitigating climate change will require dramatic and rapid changes that will disrupt the economy and broader social order. Social science research holds the key to understanding barriers and catalysts that these disruptions require. Disciplines such as behavioural science, economics, law, humanities, planning and design, communication and other social sciences are essential to understand how a transition of this scale might play out. Moreover, as climate mitigation efforts, including CDR, are deployed at scale, we must

consider how various groups might disproportionately benefit or suffer [11].

In this short commentary, we argue several key questions about CDR adoption that social science should shape, and we provide a case for why research designs that include teams comprised natural, physical *and* social scientists can help ‘bake in’ considerations that ultimately determine what, how and why CDR technologies are likely to emerge, work effectively, succeed or fail. This more complex integration of the social sciences with the natural sciences and engineering research can catalyse the conversations and research design necessary to ensure the full suite of impacts are considered and addressed through the research questions that guide projects and programmes. Those questions include (i) why will people care about or want a given technology? (ii) Who will benefit from the deployment of a given technology, and who would suffer? (iii) Who will pay for technology development and implementation, and who will bear the costs of externalities and unintended consequences? And finally, (iv) who will decide how CDR is deployed? The answers to these questions are foundational to our understanding of CDR climate mitigation.

2. Why will people care?

As Buck [5] argues, analogies from prior socio-technical transitions can hold powerful lessons for CDR. One such analogy from public health offers useful lessons for understanding how close collaboration between social and technical scientists can produce research that successfully impacts socio-technical change. Health officials, doctors and public health agencies sounded the alarms about tobacco use when it became clear that smoking causes tremendous negative health outcomes for individuals, carries high healthcare costs, affects workplace productivity, and generates a variety of other negative outcomes [12]. Technical and social solutions to smoking had to account for the fact that it is highly addictive and health effects of smoking tend to unfold decades in the future, while the benefits of smoking occur in real time [13]. Ultimately, a massive reduction in cigarette smoking in the United States evolved over the last 50 years because research approached the issue from different perspectives at multiple levels of analysis—from the institutional elements of agricultural policy to the individual behaviours that drive markets for tobacco products and various technical substitutes (e.g. nicotine gum, vaping) that emerged over time. The example is not orthogonal to CDR where, similar to tobacco, our ‘addiction’ to CO₂ and CO₂’s temporally displaced impact on the world make the benefit of shifting away from it seem secondary compared to the immediate pleasure we derive from consuming it today.

Efforts to reduce tobacco use have been successful because they addressed a complex social problem at many levels—industry regulation (e.g. product design and marketing), price modification (via taxes), technological innovation (e.g. developing alternative nicotine delivery products; pharmacological treatments), medical intervention (e.g. evidence-based clinical practice recommendations) and individual behaviour change campaigns. Successful social change campaigns do not assume that all stakeholders are driven by the same social goal (like public health or climate change mitigation), nor do they assume that behaviours of relevant entities are

driven by considerations related to that larger societal goal (like quitting smoking for health benefits or investing in CDR technology to address climate change). Successful interventions target the root of why people, corporations or even governments engage in socially costly behaviour(s) in the first place, and they use this information to develop multi-faceted strategies that target the underlying factors driving these behaviours [14]. For someone quitting smoking, these may be the cost of cigarettes or the desire to set a good example for a child; for CDR, these may be the likelihood of profit or the desire to support a local business.

All told, it is clear that large-scale efforts to radically change human behaviour cannot assume that health, environmental or economic justifications for the development of CDR are shared by the people that are likely to be affected by its deployment or not benefit from it. Instead, it is critical to understand how motivations and values influence acceptance and tailor solutions (both technical and political) to fit those values [7].

The social science frameworks which consider the values and social dynamics that drive behaviour and identify whether or not proposed technical solutions resonate with these values are essential for CDR research. By bringing such frameworks to bear on CDR development and deployment early and often, we can ensure that climate mitigation solutions have the highest probability of sustainability and success and that solutions do not leave people behind.

3. Who benefits and who loses?

Social science research also considers costs and benefits of social change, both in terms of the direct economic costs and benefits and in terms of how social change affects and is affected by power structures in society. In the tobacco example above, while smoking cessation has direct economic benefits for both smokers who quit and for the healthcare system, there are entities that are harmed by the efforts to stamp out smoking, including tobacco companies, investors in these companies and tobacco-producing states, to name a few. When designing CDR solutions and policies, understanding power structures and the way that incumbent industries actively resist change should shape the development of CDR approaches and deployment efforts.

The costs and benefits of CDR are complex and difficult to measure. Benefits diffuse widely across geographies and take many years to come to fruition, but careful attention to measuring and aggregating benefits for health, economic gains and social improvements is necessary on shorter time scales [15,16]. The question of who benefits and who loses is central, but may be particularly salient for some pathways of carbon removal. Changes in land management to increase carbon sequestration, for example, will undoubtedly increase economic pressures on some individuals, organizations and jurisdictions [5,17]. As farmers transition to practices that restore healthy carbon-rich soils, they are likely to rely less on chemical inputs like fertilizer. This creates a conflict between a farmer's own interests that prioritize sustainable and resilient farming operations and the interests of the fertilizer companies that are incentivized to sell more product. These issues will require careful assessment from a variety of social science perspectives, including assessment of economic and societal impacts and a deep understanding of

how agricultural producers make decisions and the cultural and economic pressures they face [18].

Over and above the assessment of costs and benefits, CDR approaches are immersed in complex economic and social systems, where changes in one part of a system can have unanticipated and drastic consequences for other parts. Research from disciplines such as economics, policy and business can be harnessed together to model these effects and where possible, insulate against damaging impacts. Many of these effects are asymmetric; simply put, actors are more attuned to losses than gains [19], and those who perceive CDR as harming their economic or social positions will fight to retain their standing. Research that examines how these actors operate will provide insights into how to ensure the costs and benefits are more equally distributed and when necessary, understand which forces need to be neutralized.

4. Who pays?

At the most basic level, the need to reduce CO₂ in the atmosphere is already an issue of 'who pays?' Externalities are side effects of economic transactions that affect parties not involved in these transactions and carbon dioxide represents perhaps the purest form of externality that economic activity has yet created. Carbon dioxide and other greenhouse gases (GHGs), of course, do not honour political boundaries and move across the planet, with impacts on communities that do not significantly contribute GHGs. These gases also accumulate in the atmosphere and threaten people not yet born.

Economically disadvantaged and marginalized communities pay a disproportionate price for climate externalities and also environmental degradation, whether from direct pollution or from processes that are outlawed in richer societies and 'exported' to poorer countries. These same issues are critical to address as we develop and deploy CDR approaches. Ensuring no further injustice is visited on already vulnerable communities across the globe requires a deep understanding of how a particular approach to CDR is implemented and the social structures under which the solution operates. Such an understanding often requires attention to systemic issues and how to ensure that technological solutions do not 'shift the burden' from rich to poor [20]. For example, if shifting land management practices is key to maximizing soil carbon sequestration, determining where and how those shifts occur must also be guided by the fields of sociology, planning and design, economics, and law. Bringing together these and other social science disciplines can shed light on how best to ensure that changes are not disproportionately imposed on the poor and less powerful actors without any sacrifice on the part of those with more resources, voice and power.

5. Who decides?

Converting our economy to one that sequesters carbon rather than emits it will require buy-in from all geographies and levels of society. Often, when we consider how technologies diffuse, we prioritize governments (national or state) and corporate actions, but individual decision-makers will also be important for CDR deployment. As discussed above, it has to make economic sense, for example, for an individual stakeholder to change their practices or adopt new technologies. Such decisions are not simply made using economic logic;

psychological acceptance is also vital. In order for individuals to make such choices, there must also be concerted efforts by institutional actors to take these ideas and present them to the stakeholders. This is, clearly, an enormous and cross-disciplinary undertaking. For example, the economic and policy analysis needs to be complemented with the disciplines of design and planning to ensure that these new technologies and practice are integrated into homes, communities, cities and society.

For this reason, we believe that the integration of social sciences within the disciplines of physical and natural science must begin from the inception of new research questions and projects. Natural and physical scientists will need to more actively engage and collaborate with social scientists, to ensure that the appropriate stakeholders are consulted and the necessary social, political and economic questions are answered. Moreover, this mode of interdisciplinarity should explicitly work to avoid a subordination-service dynamic, by empowering social scientists to cooperatively develop and incorporate their own research questions in partnership with biological, physical and engineering projects.

6. Conclusion

Technical solutions in and of themselves will not solve the climate crisis. Like social, cultural, economic and political elements, those solutions are necessary but not sufficient. Transitioning from a carbon emitting to a carbon sequestering economy requires innovation and technical capabilities as well as successful business, policy and behaviour changes. The call for natural, physical and social scientists to work together, early and often, may not be a new call to many, but in light of how we continue to train and develop as disciplinary researchers, our collective fields' slow pace of doing

things differently gives this call a new urgency as it relates to addressing climate change through CDR.

We are heartened to see some examples start to emerge in related fields where both social and technical challenges are paramount. Chen *et al.* [21] describe the introduction of a real-time energy feedback system into college dormitories and outline the technical parameters and usage rates of the system. That same project formed the basis of a behavioural experiment that Delmas & Lessem [22] use to understand how user behaviour is influenced by the way that information is provided to them. This collaboration between engineering researchers and behavioural scholars demonstrates the important insights deep integration of disciplinary knowledge can have on peers from different fields. Of course, the energy feedback system is far less complex and systemic than CDR technologies, but that complexity is exactly the reason why collaborations in the latter area should be pursued. Changes as complex and far-reaching as CDR technologies *will* involve uncertainties and in all likelihood, mistakes. Close collaboration among natural, physical and social scientists is needed to more rapidly develop, evaluate and employ CDR approaches to meet our climate goals.

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