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Environmental and climate justice and technological carbon removal

Maya Batres [c,*], Frances M. Wang [c], Holly Buck [f], Rudra Kapila [d], Ugbaad Kosar [a], Rachel Licker [e], Deepika Nagabhushan [b], Ester Rekhelman [g], Vanessa Suarez [a]

[a] Carbon180, United States
[b] Clean Air Task Force, United States
[c] ClimateWorks Foundation, United States
[d] Third Way, United States
[e] Union of Concerned Scientists, United States
[f] University at Buffalo, United States
[g] University of Virginia, United States

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ABSTRACT

Environmental justice (EJ) and climate justice are becoming central foci of climate policy. Awareness is also growing on the need for some amount of carbon dioxide removal (CDR) to curb warming to 1.5 °C. In this paper we map dimensions of environmental and climate justice that stakeholders and communities will need to consider – from local to global scales. Mapping issues is a step towards developing frameworks to undertake CDR in an environmentally just way.

1. Introduction

Permanent carbon dioxide removal (CDR) measures have been deemed necessary to limit global warming to 1.5℃ over pre-industrial levels in various integrated assessment models (IAMs), including in the models used by the Intergovernmental Panel on Climate Change (IPCC) Special Report on 1.5℃ Warming (IPCC, 2018a). Specifically, in these scenarios — in which 100-1000 Gt of CO_2 are removed over this century — CDR serves the function of compensating for residual emissions as well as returning global warming to 1.5 °C after an overshoot (IPCC, 2018b). CDR also brings the possibility of removing legacy emissions; the emissions that have been building in the atmosphere since the Industrial Revolution. While there are various approaches to CDR, in this paper we narrowly consider direct air capture (DAC); machines that pull in atmospheric air and separate the CO_2, creating a supply of CO_2 which can be used in products or permanently stored deep underground. DAC machines may be paired with, or share infrastructure with, other types of point source carbon capture and storage (CCS), like natural gas with CCS, or CCS on steel or cement plants. Some studies suggest co-location of DAC and industrial or power CCS is likely to occur in the early stages of DAC development, where it will be economically advantageous to share infrastructure and industrial workforces (Friedmann et al., 2020). We focus on DAC as a carbon *removal* strategy, which is different from, but is likely to have a relationship with, carbon capture approaches and infrastructure, which are *mitigation* strategies.

IAMs are helpful "tools [to] integrate social, economic, and physical models for the purpose of understanding how different decisions drive emissions and emission mitigation" (Wilcox et al., 2021), but they do not always capture the nuance of local or global inequities of policy decisions in the pathways they identify (Realmonte et al., 2019). Yet even studies that better integrate environmental and social justice considerations into models call for some amount of CDR (McQueen et al., 2020). So while these analyses are helpful to illuminate possible technology mixes and scales, additional investigation into socio-political barriers and risk management of those pathways is needed. This is especially true in the context of understanding environmental justice (EJ), which must be a central tenet in designing and implementing technological CDR policy and project development.

Currently, governments, companies, academics, and non-governmental organizations focused on CDR are considering justice and equity in their policy positions and in reflections on their internal culture. At the same time, awareness is growing around the intersection of race, class, gender, and other characteristics in climate vulnerability as well as overlapping inequities and power asymmetries in new energy

* Corresponding author.
E-mail address: maya.batres@climateworks.org (M. Batres).

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regimes (Kaijser and Kronsell, 2014; Johnson et al., 2020). The new vocabularies of intersectionality, environmental justice, climate justice, and equity are meeting growing recognition and use in public discourse. To apply an intersectional approach to technological CDR, we must start with the local, global, sectoral, and intergenerational issues that are raised in the context of project and policy development. Through issue identification, communities and EJ leaders can begin to create the frameworks to facilitate environmentally just development and deployment of CDR measures.

Ultimately, each carbon dioxide removal project or policy will have unique benefits, trade-offs, risks, and opportunities for communities and for the global effort to address climate change. Defining and addressing specific issues will be critical to ensuring that if these technologies are scaled, it is done in a way that fairly distributes responsibilities and burdens to people and nature, while accelerating the reduction and removal of emissions from the atmosphere in a way that prioritizes the needs of communities already impacted by climate change. There is substantial work to be done on site-specific technical assessments and community education to empower the public to make informed decisions about the role technological CDR may play in their community (Healey et al., 2021). This is also true for the integration of global justice perspectives into domestic and international policymaking, particularly in the Global North. Finally, we note that technological CDR approaches are not a substitute for mitigation of emissions, nor should they be used to extend the lifetime of polluting industries. Indeed, some jurisdictions have set or are considering different removal and mitigation targets to address this concern (Wang and Aragones, 2021). As policy practitioners, scientists, and academics, we can use our expertise to highlight issues and solutions, and recognize that we are a small part of a larger group that needs to build the frameworks for addressing environmental and climate justice in the CDR space.

In this paper we identify common themes in local community engagement related to EJ, explore issues in the context of EJ in the U.S., given that the U.S. currently has the largest capacity to develop and deploy technological CDR approaches including DAC, we then explore global EJ considerations, and finally offer a summary of findings.

2. Local environmental justice

Communities where projects may be located should be at the core of decision-making, and their priorities should be central to any process through which they are engaged or lead. Aside from the global warming implications of removing excessive carbon dioxide, most impacts from these projects are necessarily local. Therefore, we must go beyond a broad technological assessment and to a project-by-project approach (Morrow et al., 2020). While it would be impossible to fully characterize the range of environmental, health, and social considerations across all dimensions of DAC, since those will be unique to the communities in which these projects may go, we identify common impacts through our work with communities in addition to research and engagement with groups focused on EJ.

2.1. Impacts to built and natural environments

Work and research on technological CDR suggests that air and water quality, land use and ecological integrity, impacts to human health and safety, and energy needs are priority topics (Buck et al., 2021). Despite this importance, research, policy design, and community education on these topics is mostly nascent, with most work focused on energy requirements of DAC (Realmonte et al., 2019; McQueen et al., 2020). A project-by-project technical analysis and feasibility study is the most important step in determining whether it is environmentally responsible, and this assessment should include the entire lifecycle of the project to most transparently identify impacts.

DAC has high thermal and electricity needs and therefore siting of a project will need to be a central consideration in order to minimize adverse ecological impacts of the associated energy infrastructure. To minimize this indirect energy footprint, DAC should be paired with clean energy sources that have smaller land densities (McQueen et al., 2020). It will also be important to plan for the transmission and distribution infrastructure to lessen potential ecological disturbances. Identifying co-location opportunities with waste heat streams or excess wind and solar curtailment, and siting projects on already degraded landscapes can help reduce footprint and environmental harm. Some initial research on the availability of these co-location opportunities has already been done, but more site-specific work is needed (McQueen et al., 2020). Proactive identification of lower-impact areas is also possible through environmental site suitability analysis such as the ones developed by Wu et al., which are used to assess wind and solar infrastructure (Wu et al., 2020). This type of approach could also incorporate mapping of geologic storage for co-location to reduce the amount of CO_2 transportation infrastructure needed. DAC does not require arable land, allowing for flexibility in siting and reducing competition with land requirements for food production. Still, understanding the needs for clean energy within a community will be key to deciding how much, where, and what infrastructure may be appropriate to build.

Issues and analysis related to air quality impacts on a community will reflect the specific ambient air quality and air quality control laws of the location, as well as technologies and transportation needed for a project. Indirect and direct air quality impacts of technological CDR are some of the greatest gaps in information surrounding CDR, in part because few projects exist that can serve as examples to study. Because there is little public information on air quality implications, positive or negative, it is difficult to empower communities to make decisions informed in science. To minimize air quality impacts of a direct air capture facility, clean or renewable resources will be critical. Air quality is also relevant in the context of the construction of a project, where some communities may have unique sensitivities around increased trucking or power generation during this phase.

After CO_2 is captured, it requires transport by pipeline, rail, truck or barge to its final end use or destination. Each transportation method has different and highly local implications for communities that need to be considered, whether it be new physical infrastructure, use of roads or waterways, and/or air quality impacts. When and if the final destination of the CO_2 is geologic storage, infrastructure impacts at the injection site will also be relevant.

Finally, to fully characterize impacts to built and natural environments, we must also consider the lifecycle of materials needed to construct a project, as well as their end-of-life fate. Concrete and steel are key materials for all DAC approaches; this may bring benefits to communities in the form of jobs, but also invokes questions on recycling of material when it is no longer in use (McQueen et al., 2020). These lifecycle questions are not unique to DAC and apply to all clean energy infrastructure and manufacturing. Because inaction is not an option, as policy practitioners and researchers, we ask ourselves: how can communities access research to be informed on how a project might impact them, as well as upstream and downstream neighbors? What are the synergies across sectors of the economy that might allow us to reduce impacts?

2.2. Health and human safety

As with any industrial facility, siting, planning and ongoing monitoring of the operations of a DAC project will be essential to maintaining human health and safety for workers and communities. While it is highly unlikely that CO_2 injected into properly sited and highly regulated deep saline geologic formations will make its way back to the atmosphere, one of the primary concerns for communities is leakage of CO_2 from the geologic storage site (National Academies of Sciences, Engineering, and Medicine, 2019). Two critical factors help to minimize risk of atmospheric CO_2 leakage are 1) site selection based on its inherent ability to trap injected CO_2 in its pores and the existence of overlying impermeable rock layers such as shales that fluids or gases cannot pass through, and 2) robust monitoring and reporting plans that require projects to identify and mitigate potential risk of leakage from pathways such as abandoned wells, or natural conduits such as faults and fractures (National Academies of Sciences, Engineering, and Medicine, 2019). Over fifty-year track record of industrial knowledge of CO_2 injection provides strong evidence in very low probability of significant CO_2 leakage. It should be mentioned that when CO_2 is stored in geologic formations via carbon mineralization, leakage and reversal is further minimized as the CO_2 is bound within rocks.

2.3. Local community engagement and procedural justice

In addition to considerations around the built and natural environment, some communities are wary, or outright opposed, to carbon capture and removal for a variety of reasons: lack of case study projects that center justice in their development, involvement of powerful and extractive industries such as oil and gas and "big ag", moral hazards (e.g. continued use of fossil fuels), misuse of tax credits for geologic sequestration, lack of structures to support procedural justice for communities, and lack of clarity on basic issues like who owns pore-space rights for storage and who determines fair compensation for those rights. Additionally, historical disempowerment and disenfranchisement at the hands of industries, governments, and developers creates a sense of distrust when these parties introduce carbon removal projects. Most research and public engagement have focused on point source carbon capture and storage (CCS) approaches rather than on CDR measures. Because of the potential locational and infrastructure synergies with CCS, we can learn from some of this work, but more CDR specific research is needed. Focus groups previously conducted with communities in New Mexico, Texas, Ohio, and California on carbon capture and storage as part of the Department of Energy's Regional Carbon Sequestration Partnerships found that social factors like benefits and experiences with government were of greater concern than the risks of the technology itself (Bradbury et al., 2009), and that a sense of community empowerment can protect the community against the risk of government or corporate neglect (Wong-Parodi and Ray, 2009).

In 2020–2021, the Livermore Lab Foundation conducted a survey of community views on carbon capture and geologic storage (CCGS) projects in California's Delta region and Kern County. The survey showed a positive but cautious trend in respondent reactions after learning more about CCGS, with slight apprehensions to project siting near respondents' homes (Buck et al., 2021). Support for new CO_2 infrastructure and related activities—pipeline construction, well drilling, CO_2 injection and storage, transportation trucks, and location—was less than 50 % in both counties. Reactions in the Delta region revolved around understanding the need for CCGS, potential risks and opportunities, secure storage, infrastructure, and location. Given the familiarity of Kern County with CCGS resulting from the oil industry's strong presence in the county, respondents expressed optimism in the opportunity for energy leadership, economic benefits, and safety of processes. Detailed public engagement, creation of new permanent jobs, and strict protections for land, water, and wildlife were found to be the most valued project components across both counties.

Survey results illuminated community priorities and perspectives with potential implications for environmental justice. Respondents' citing of air and water quality, jobs, and the economy as top concerns is understandable given the counties' social, political, and economic contexts (London et al., 2018; Williams, 2021; Hartzog et al., 2017). These communities have long endured pollution burdens from various sources, including industry, agriculture, oil production, among others (Berg, 2017; Reshaping Kern County's agricultural approach to pesticides and health, 2019; Sierra Club, 2021; Herr, 2021). Furthermore, Kern County and the Delta region, as well as the greater San Joaquin Valley, contain many economically disadvantaged communities (Hartzog et al., 2017; Flegal et al., 2013). The oil industry has provided employment opportunities in these communities, explaining why some respondents are concerned over loss of jobs in the oil industry (Cox, 2021; Brostrom, 2021). The importance of jobs, robust public engagement, and environmental safeguards across counties emphasizes that CDR and CCS projects must provide tangible non-climate benefits that align with community priorities, as well as inclusive and participatory processes that empower communities in project implementation for community acceptance. Moving forward, two key questions to keep in mind are who should be responsible for building capacity in communities? And what does the process for capacity building look like in policy or regulatory decision-making?

3. Technological carbon removal and environmental justice in the U.S

The United States has the most developed policy landscape and capacity to deploy and regulate technological CDR. It also has one of the most robust policy discussions on the intersection between environmental and climate justice, race and class, and thus serves as an important case study. Tax incentives for permanent CO_2 removal and reductions have been enacted at federal and state levels, including 45Q and the Low Carbon Fuel Standard, respectively. Additionally, the Environmental Protection Agency (EPA) through the Underground Injection Control program has a dedicated regulatory system to oversee permitting of geologic storage of carbon dioxide. U.S. government spending on federal research, development and demonstration (RD&D) for technological carbon removal has grown from $11.5 million in 2019 to $32.5 million in 2020 (United States House Appropriations Committee., 2021). Moreover, major corporate commitments to procure CDR have increased attention and demand for projects and removals in the U.S. and beyond. This increase in regulatory and policy structures to support CDR has brought attention to technological CDR in the context of EJ and the benefits and tradeoffs of using it as a tool in the climate portfolio.

Perspectives on DAC within the environmental movement fall on a wide spectrum. Some environmental organizations support the development and deployment of DAC to address residual emissions and for non-climate benefits such as job creation (Bipartisan Policy Center's Direct Air Capture Advisory Council, 2021). Other environmental leaders oppose CDR approaches, categorizing them as 'false solutions' meant to maintain the status quo by extending the life of polluting industries and "greenwash" continued fossil fuel extraction (Geoengineering 101, 2021; Kusnetz, 2020). As has been widely documented, fossil fuel extraction and industrial processes have a legacy of disproportionately impacting Black, Brown and Indigenous communities (Banzhaf et al., 2019). The 1987 landmark study *Toxic Waste and Race* found that race was the greatest determining factor of whether someone lived near a polluting waste facility — the deliberate outcome of local, state, and federal land use policies (United Church of Christ, 1987). Anthropogenic pollution has stripped many marginalized communities of their human dignity by denying them the right to, for example, clean water in areas such as Flint, Michigan, while simultaneously politically disenfranchising them from any of the policy decisions that will directly affect their health. Therefore, *who* influences and shapes technological CDR policy and projects and *how* they do it is critically important to some of the core concerns within environmental justice groups.

The question of *who* shapes technological and DAC policies is particularly relevant given that lack of funding for EJ movements and organizations has been identified as the greatest barrier to achieving EJ goals of organizations (Baptista et al., 2019). To our knowledge, very few U.S. based organizations have dedicated programs and staff capacity on DAC and environmental justice. Without capacity to design mechanisms to assess equity components of existing and future programs, or to participate in the policy development, there is both a perceived and real risk that projects could exacerbate the status quo with continued impact on communities of color who live near fossil fuel or industrial facilities.

In addition to addressing health and environmental impacts, phasing out fossil fuels is a fundamental step to address the climate crisis – as noted by the International Energy Agency that "if governments are serious about the climate crisis, there can be no new investment in oil, gas, and coal, from now- from [2021]" (Harvey, 2021). While necessary for climate, this sectoral shift will have significant economic and social impacts on fossil fuel workers and their communities, many of whom are already facing economic hardship and impacts to social identity amidst a market transition, and who are frontline communities themselves (Cha, 2020; Storrow, 2021). In the U.S., policy makers, labor unions, and companies should be asking questions including – can technological DAC offer an economic pathway for a transition away from reliance on fossil fuels and towards climate friendly technologies? Who should be responsible for designing a transition away from fossil fuel use that also supports impacted communities? What are the timeframes during which that should be planned? What structure can governments and companies put in place to center the priorities of environmental justice constituencies? What could careers in carbon removal look like? What lessons can be learned from examples in clean energy economy workforces, such as solar and wind?

The Department of Energy (DOE) is already starting to put these questions to practitioners through recent funding opportunity announcements (FOAs) for the advancement of DAC technologies. Some of the FOAs DOE released will require applicants to submit, for the first time, a comprehensive summary of the environmental justice implications and jobs impacts of their project. The jobs and environmental justice summaries must focus on creation of job opportunities in economically disadvantaged communities harmed by the adverse impacts of these industries, and remediation of legacy environmental impacts, potential co-benefits for air pollutants, and community involvement plans. This type of template could be adopted by other U.S. jurisdictions to ensure jobs and environmental justice considerations are analyzed and summarized at the outset.

4. Global environmental and climate justice

Ethical considerations are the primary focus of discussions beyond local and national boundaries – namely who, when, and how much CDR should be deployed. The underlying assumption is that international climate policy on CDR will have implications at the local and community-level. Currently, there is no clear agreement on the ethical framework to direct responsibility-sharing, though the Fair-Share Principles have recently been cited in literature (PCC, 2014). Many parallel examples and paradigms can also be drawn upon, such as scholarship around international development and the on-going discussion around Loss and Damage (Bouwer et al., 2019). Bilateral and multilateral agreements around CDR will likely impact global supply chains through trading of CDR-construction materials and carbon markets, which could pose, inter alia, intellectual property challenges around technology transfer and creates socioeconomic implications to all countries involved.

4.1. Geopolitical responsibility sharing

One set of literature examines geopolitical responsibility sharing by using the principles in Responsibility, Capability, and Equality (Pozo et al., 2020). Scientists ask the question "who should pay for and deliver CDR" by comparing those who are most responsible for climate change (responsibility), those who are most capable of paying (capability), or by examining CDR as a shared responsibility by every individual (equality). Countries' share of CDR varies greatly depending on which principle is applied, but most importantly, the results highlight that unilateral action will not help achieve the total removal needed to reach 2050 and 2100 goals due to national biophysical limits (Pozo et al., 2020). In general, the results show that large emitters such as the US, the European Union, and China should be responsible for most of the carbon removal (Fyson et al., 2020a). However, most models use emissions data based on production, not consumption in responsibility calculations. In 2018, U.S. consumption-based emissions were higher than production-based emissions, whereas in China, consumption-based emissions are 14 % lower than production-based emissions (Our World in Data, 2018). This calls into question whether the regions that produce and export goods should be responsible for the share of emissions for products consumed in wealthier nations with more emission-intensive lifestyles. It also begs the question as to where these projects should go and at what scale, recognizing that if CDR projects are pushed from the Global North to the Global South, it may further entrench climate inequities (Healey et al., 2021).

It is necessary to create rubrics to ensure those countries and entities that have contributed the most to climate change carry the responsibility for drawing down carbon from the atmosphere and mitigating future emissions in order for society at large to achieve the goals of the Paris Agreement. This repaying of their carbon "debt" is an essential component in the pursuit of justice in the global climate change arena. For example, as of 2017, the United States has emitted nearly 400 billion tons of carbon dioxide, or approximately twenty-five percent of the world's cumulative carbon dioxide emissions since pre-industrial times (Ritchie and Roser, 2020).

Beyond nation-states who can be a party to global conventions such as the United Nations Framework Convention on Climate Change, there are industries and entities who have contributed to the global climate crisis who would both be involved in some of the types of carbon removal projects discussed here, and who bear a distinct responsibility for the existence of the problem. Research has shown that since at least the mid 1960s, the fossil fuel industry has been aware of the climate-related risks of their products; some entities in the fossil fuel industry have employed tactics to mislead the public and generate doubt about climate science, and shift the responsibility for climate change to consumers (Franta, 2018; Supran and Oreskes, 2017, 2021). Research has further been able to identify the amount of carbon emitted into Earth's atmosphere that can be traced to products from these entities, as well as the impacts tied to these emissions (Heede, 2014; Ekwurzel et al., 2017; Licker et al., 2019). For example, 63 percent of the world's industrial carbon dioxide and methane emissions since pre-industrial times can be traced to the products of the 90 largest carbon producers, which includes oil and gas companies and cement manufacturers. What, if any, responsibility or role should these actors play in removing their historic emissions?

4.2. Global technology transfer

In the context of technological CDR, we must also consider how the uneven distribution of this innovation knowledge may perpetuate hidden politics in global action and decision making. The movement, or transfer of technology, from one country's societal landscape to another is multilayered and complex and is a subject that spans several disciplines. Crucially, the 'North-South' transfer of technology is historically and inherently tied to the legacy of colonization and imperialism. It is therefore useful to explore economic development in order to understand the various means of technology diffusion between rich and poor nations (Balasubramanyam, 1973; Brandt, 1980; Lall, 1984i; Rosenberg and Frischtak, 1985; Mehrotra, 1990; Talalay et al., 1997; Josephson, 2006).

One issue in global technology transfer is the lack of transparency; traditional technology transfer processes for example, such as turnkey projects, have been opaque, and there has been a tendency to treat technology as a 'black box' entity when being transferred from one country's social landscape to another (Boyce, 1987). This lack of transparency often impedes any boost to local knowledge systems, and fails to foster any innovative activity in the long-term because the inner workings of a technology are unknown to the recipient country and no adequate attempt at translation or assimilation is made by the provider. Despite the prevalence of more modern approaches to technology transfer, including Foreign Direct Investments (FDIs) and joint ventures, the 'black-box' mentality persists, creating a paternalistic tendency that impedes global equity in technological advancement (Lall and Urata, 2003; Malairaja and Zawdie, 2004; Thorne, 2008). This is further exemplified by the discourse that links the lack of transparency within technology transfer processes and the issue of protecting intellectual property rights (IPR). More broadly, issues surrounding IPR are a key barrier to the wider transfer of climate and clean energy technologies globally and locally (Ockwell et al., 2012). Moreover, IPR conditions have shown to be, especially in the case of capture solvents used in some DAC approaches, an impediment for the accelerated deployment of CDR technologies, even in the Global North (Elliott et al., 2021).

CDR technologies exist in large, complex, sociotechnical systems, which have specific characteristics associated with their innovation, development, and deployment. Notably, these technologies are being developed predominantly in industrialized nations and within the innovation systems of the Global North. As time is an imperative in the climate challenge, the policies and incentives that would facilitate technology transfers either do not exist, or they are only just beginning to be considered and supported under established institutional and regulatory frameworks specific to only certain countries in the Global North. Not only do CDR approaches have to reach beyond the RD&D phase, but they need to be adapted to new country's societal landscapes for successful implementation. This is particularly relevant for the Global South, as historically, such large complex technologies, (e.g. coal power plants) have been transferred without much thought to local environmental and social conditions, and international development organizations such as the World Bank have been questioned on the appropriateness of this kind of technology transfer due to its gatekeeping of proper implementation of this technology in the receiving nation (Marston, 2011; Ebinger, 2011; Chellaney, 2012). Currently, CDR technologies are largely being developed by those countries that historically have fossil-fuel based energy systems and the associated expertise (e.g. subsurface characterization, turbine and power plant design, pipeline technology etc.).

In light of these considerations, important EJ centered questions still stand: what are the necessary frameworks so that CDR improves collective action on climate change rather than preserves unjust international relationships between the Global North and the Global South? (Sovacool, 2021) How can, or should, Global North countries undertake efforts to develop capacity on responsible deployment in the Global South?

5. Intergenerational perspectives on justice and CDR

From an intergenerational equity perspective, investment from current generations to CDR RDD&D, and governance frameworks can help to reduce future generations' burdens. While some are concerned about the use of CDR to delay mitigation, progress has been made to address the moral hazard of 'mitigation deterrence' (Markusson et al., 2018) through the creation of separate targets for removal and reduction, like in the European Union. Furthermore, current mitigation and future CDR are intrinsically linked. Fyson et al. estimated that delaying near-term mitigation means that for every additional 1 Gt of carbon emitted, 20–70 Gt of carbon will need to be removed through CDR measures over the century (Fyson et al., 2020b). Due to significant delays in climate action, researchers estimate delaying CDR would cost an additional \$146−232 billion per year in CO_2 removal costs (Galán-Martín et al., 2021). As research improves in estimating the amount of removal needed, higher removal needs means higher future costs from delayed CDR deployment. Thus, technological CDR must be considered from a whole-of-systems perspective to account for the intersection with other emissions mitigation, adaptation and removal approaches. That is, the scale of technological CDR could grow or be reduced depending on our success in mitigating emissions quickly enough. Major questions still left to answer are: How should the world approach CDR decision making under climate action uncertainty? How will decisions around RDD&D in CDR approaches now impact future generations?

Scholarship on intergenerational equity defines it as "such a generation would want to receive the planet in at least as good condition as every other generation receives it and to be able to use it for its own benefit" (Weiss, 2008). With the world already observing the impact of locked-in warming, such as a reduction in natural sinks or where natural sinks have become CO_2 sources, the burden for future generations to address and live in a climate-damaged world is already greater (Duffy et al., 2021; Harris et al., 2021). Inaction in the near-term on either mitigation or building the human and infrastructural capacity for carbon removal will increase the financial and implementation burdens down the line. Procedural and participatory approaches can add additional time and space to project planning, yet can often be improperly handled when time is limited. Therefore, to properly give due consideration to EJ, longer time frames are needed to plan and deploy CDR projects at the scale needed. This upfront investment has potential to ease implementation down the line, as more science emerges on the scale of technological CDR that is needed.

6. How can organizations start working on environmental justice?

Collectively we believe that the first step towards productive policy work, community engagement, and project planning on environmental justice issues begins with personal and professional anti-oppression learning. In the workplace, this includes diversity, equity and inclusion (DEI) initiatives, which may involve reflections on hiring practices, workplace bias, and company culture, and the achievement of justice in policy or projects. Building a diverse, equitable and inclusive clean technology industry is necessary to change existing environmental disparities, and is a source of competitive advantage for companies (Parwana and Mohnot, 2020). Companies, governments, nonprofits and individuals can also look to the ample research and recommendations by environmental justice groups on the integration of equity and justice in climate research (Creger, 2020). Environmental justice groups have also provided broad recommendations on how others can support the environmental justice movement (Pennington, 2016).

7. Conclusion

Across all CDR approaches, bottom-up and community-driven strategies are critical for developing and deploying equitable carbon removal projects. However, communities often lack the necessary resources to meaningfully engage and invest in these efforts, including decision-making processes and relevant information on project components that impact their environmental and public health. The scaling of carbon removal must empower communities to meaningfully engage and oversee decision-making surrounding the development and deployment of technological CDR projects, as well as bring ownership of these projects to frontline communities through dedicated investments and incentives. Moreover, the benefits and resources from carbon removal must be equitably distributed in deployment processes, and safeguards must be put into place that ensure new harms are not created, existing harms are not exacerbated, and any adverse impacts are not borne by already overburdened communities.

Environmental justice also requires us to examine the global role of technological CDR and the responsibilities therein. How much technological CDR is needed will depend on decisions we make now across various emissions reductions strategies, including how we apply EJ principles in those approaches. If mitigation is delayed, or proposed strategies are not effective at permanently removing CO_2, it is possible that more technological CDR will be needed. If CDR is taken off the table as a tool now, future generations may be more burdened with scaling it

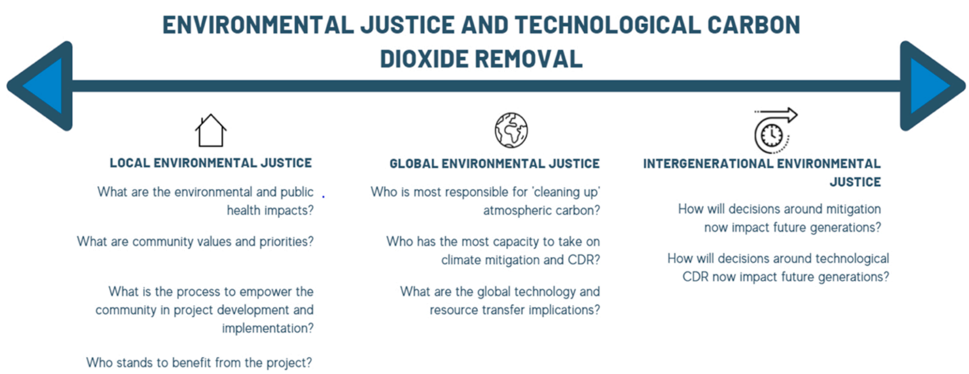

Fig. 1. Mapping environmental justice considerations in technological carbon dioxide removal.

at a faster pace later. In Fig. 1, we map out the key considerations discussed in this paper.

Mapping the issues is only a start. Developing the frameworks and parameters for communities, local and global, is a necessary next step to ensure EJ is integrated in the development of technological CDR. As we watch climate change impact our communities with increasing frequency and severity, the climate crisis begs us to do the hard work of taking on these questions. We hope you will join us.

Declaration of Competing Interest

The authors declare no conflicts of interest.

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Maya Batres: Maya Batres is the associate director for the Carbon Dioxide Program at the ClimateWorks Foundation. She has over a decade of experience in climate and energy law and policy, human rights and social justice, is the recipient of an Upper Midwest Human Rights Fellowship, and an AmeriCorps VISTA alumni. She is a board member for Justice Outside. Maya earned her J.D. (Energy and Environmental Law) and her B.A. (Spanish Studies, African American Studies, Political Science) from the University of Minnesota.

Frances Wang: Frances leads the governance workstream to advance technological and ocean CDR at ClimateWorks Foundation. Before joining ClimateWorks, Frances worked in interdisciplinary environmental research with a focus on action-oriented solutions. At McGill University, she helped to lead and design innovative monitoring and evaluation frameworks for climate adaptation governance. She is the author of multiple academic publications featured in journals such as Nature Climate Change and Global Environmental Change. Frances holds an M.Sc. in Environmental Change and Management from Oxford University and a B.A. in Economics from McGill University.

Holly Buck is an Assistant Professor of Environment and Sustainability at the University of Buffalo. Dr. Buck is an expert on the social and political dimensions of environmental policies, and of strategies and technologies for preventing and adapting to climate change. Her book **After Geoengineering: Climate Tragedy, Repair, and Restoration** examines best-case scenarios for carbon removal. She has written on several aspects of climate engineering, including humanitarian and development approaches to geoengineering, gender considerations, and human rights issues. She holds a doctorate in Development Sociology from Cornell University and a MSc in Human Ecology from Lund University, Sweden.

Rudra Kapila is the Senior Policy Advisor for Carbon Management, advocating for policies to put the United States on the fastest and fairest path to net-zero emissions by 2050. She holds a BSc Hons in Environmental and Ecological Studies and a PhD in Earth Sciences and International Relations from Univeristy of Edinburgh and a MSc in Enviornmental Chemistry and toxicology from Imperial College London. Also, she is the Co-Chair for the Climate Change Working Group at Women of Color Advancing Peace and Security (WCAPS), a non-profit organization committed to promoting diverse perspectives from WoC leaders within foreign policy and national security.

Ugbaad Kosar supports Carbon180's federal policy work, leading the organization's environmental justice initiative and forestry efforts. Ugbaad holds a dual M.Sc in forest sciences and renewable resource management from the University of Alberta and the University of Freiburg, and a B.Sc. from Carleton University.

Rachel Licker is a senior climate scientist with the Climate & Energy Program at the Union of Concerned Scientists. In her role, Dr. Licker communicates climate science to policy-makers, the public, and the media. She analyzes new developments in climate science and works to defend climate science budgets and programs. Dr. Licker earned her Ph.D. in environment and resources, and her B.S. in biology from the University of Wisconsin-Madison. She also holds an M.S. in environmental studies and sustainability science from Lund University in Sweden.

Deepika Nagabhushan is program director of the Carbon Capture Program at the Clean Air Task Force. Her work involves policy research, policy development and analysis as well

as advocacy management to enable carbon capture technologies become widely available as a climate solution by mid-century. She led macro-economic modeling project to test the impact of 45Q tax credits for carbon capture in the U.S. power sector. Her current policy work includes development of next generation policies to enable rapid carbon capture deployment by supporting basin scale management of geologic Co2 storage. She is also leading research to quantify the relationship between adding carbon capture on industrial plants and associated reductions in criteria air pollutant emissions.

Ester Rekhelman is a rising senior at the University of Virginia studying Global Environments and Sustainability. Her research experience includes working on a report evaluating potential for carbon sequestration in the state of Virginia and analyzing the effects of ozone in Virginia's forests.

Vanessa Suarez works on federal policy across land-based and technological carbon removal with an emphasis on environmental justice. She holds a B.S. in conservation and resource studies from UC Berkeley, and prior to C180 she worked on environmental justice policy and rangeland soil carbon storage research.