Community perceptions of and preconditions for direct air capture in the U.S.

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Abstract

Direct air capture (DAC) has gained traction in climate policy as a promising method for carbon dioxide removal. How – and whether – DAC should be pursued as a climate strategy and deployed as local infrastructure, however, will rely on its ability to secure social license to operate (SLO), given the frequent disconnect between broad public perceptions of technologies and perceptions among host communities. There is also a growing need for the deployment of climate infrastructure like DAC to be responsive to environmental justice (EJ) and just transition (JT) principles. However, relatively little research exists on how communities may respond to DAC deployment locally, and the EJ and JT considerations they may evoke. In this study, we use a mixed-methods approach to evaluate public and community perceptions of DAC. We find that while communities may be generally open to the idea of DAC being deployed in their communities, the conditions under which DAC is realized are likely to determine levels of acceptance and support. The most important determinants of project support are community involvement in planning and implementation and expected benefits. This is perhaps especially important for infrastructure like DAC, which offers few if any direct local benefits (i.e., clean energy or air quality improvements). Building on recent trends, policies aimed at advancing DAC could include designated resources for community involvement and benefits in order to improve the likelihood of projects securing SLO and abiding by EJ and JT principles.

Introduction

The Intergovernmental Panel on Climate Change (IPCC) has concluded that carbon dioxide removal (CDR) is likely to be a necessary complement to rapid decarbonization and phase-out of fossil fuels in meeting the most ambitious global climate goals (IPCC, 2022). A trillion extra tons of long-lived carbon dioxide is currently in the atmosphere, much of which will remain there for thousands of years without intervention. Global CDR capacity may need to reach between 1 and 2 $GtCO_2$/yr to upward of 20 $GtCO_2$/yr after 2050, depending on rates of decarbonization, in order to meet the goal of limiting warming to 1.5°C above pre-industrial averages as prescribed in the 2015 Paris Climate Agreement (Waisman et al., 2019; Fuss et al., 2018; Minx et al., 2018).

Meeting negative emissions needs is likely to require a portfolio of multiple CDR pathways (Tan et al., 2022). Compared with bioenergy with carbon capture and storage (BECCS) and afforestation, the two most commonly cited CDR methods, direct air capture (DAC) has smaller land and water footprints, and estimates of its global capacity range from 0.5 to 5 $GtCO_2$/yr by 2050 (Realmonte et al., 2019; Fuss et al., 2018). Despite DAC's promise in contributing to negative emissions needs, only a handful of projects are presently operational (McQueen et al., 2021).

The immense scale-up of DAC necessary to meet even conservative estimates of its potential will require pricing carbon pollution, technological improvements to decrease energy intensiveness, and cost reductions, which have been the focus of much of the DAC literature (Fasihi et al., 2019; Qui et al., 2022; Shayegh et al., 2021). Despite the importance of this work, however, social considerations that will also determine DAC's viability have received far less attention from the scientific community (Wolske et al., 2019; Cox et al., 2020). In particular, social science literature points to the need to secure social license to operate (SLO) for large-scale infrastructural development, and to ground climate action in principles of environmental justice (EJ) and a just transition (JT) (Avila, 2018; Sze & London, 2008; Campbell-Arvai & Lindquist, 2021; Zaunbrecher & Ziefle, 2016;

Voyer & van Leeuwen, 2019; Hall et al., 2015). SLO is defined as “broad, ongoing approval and acceptance of society to conduct [an industry’s] activities” (Prno et al., 2012). EJ and JT, however, take an expressly justice-oriented approach to industrial activities. EJ seeks to address the unequal distribution of environmental benefits and harms (Bullard, 2001; Sze & London, 2008) while also acknowledging the history of disproportionate harms that low-income communities and communities of color have been forced to bear. A just transition seeks to build energy and climate solutions that center equity and justice for communities, especially those that have traditionally relied economically on carbon-intensive sectors or have suffered disproportionate health and environmental impacts of industrial activity (Wang & Lo, 2021; Filipović et al., 2022; *Just Transition, 2022*). Given significant pushback from many community organizations to technologies with similar features and conflation with these technologies, such as carbon capture and storage (CCS), adopting JT and EJ frameworks may help assuage fears that DAC is a “false” climate solution that reinforces current injustices in infrastructure placement and pollution in poorer communities (Bonacini, 2021). SLO, EJ, and JT are important lenses for infrastructure deployment, especially for stakeholders who are expected to interact most closely with the technology through proximity, employment and other economic dependence, cumulative environmental burdens, or sociocultural ties to the land (Bellamy et al., 2019; Buck et al., 2018; Buck et al., 2016; Carton et al., 2020).

In 2021, the U.S. Congress allocated $3.5 billion for direct air capture and storage, representing the largest single government investment in the technology to date. This funding will support four regional direct air capture hubs that demonstrate “the capture, processing, delivery, and sequestration or end-use of captured carbon” and “could be developed into regional or interregional carbon network[s] to facilitate sequestration or carbon utilization” (DOE, n.d.). Perhaps recognizing the importance of securing SLO, especially through EJ and JT principles, the U.S. Department of Energy (DOE) requires applicants to submit community benefits plans detailing how projects will engage communities and offer financial, labor, and/or other benefits. Despite substantial policy movement on DAC, little is known about public perceptions of or equity considerations for DAC in the United States, or how communities that are proximate to potential DAC projects may respond. Sovacool et al. (2022) point to the need for DAC policy and implementation to adopt “[p]ublic and regulatory engagement in line with the principles of a just transition”. This builds on a growing body of work calling for equity and justice, especially at the community level, to be central to CDR policy and deployment (Batres et al., 2021; Pozo et al., 2020; Morrow et al., 2020; Healey et al., 2021). Batres et al. (2021, p. 2) identify the need for procedural justice, placing communities at the core of project-level decision-making processes and advocate that the research community “go beyond a broad technological assessment and to a project-by-project approach.”

In the case of DAC—which, unlike other climate infrastructure, does not provide immediate co-benefits that can be realized by the community—it is especially important to offer ancillary benefits like employment and community investment to enable acceptance and, ideally, support of DAC (Fyson et al., 2020) that is situated within JT and EJ principles. While enhanced soil carbon sequestration can produce increased crop yields and reforestation can promote biodiversity (Field & Mach, 2017; Turner et al., 2018), DAC offers a global good (reduced atmospheric CO2 concentrations) with local burdens (infrastructure development and operation). Understanding whether, and under what conditions, communities might support DAC development at the local level will be critical to understanding whether DAC can be realized at scale. Indeed, schisms often exist between how the public conceives of infrastructural projects like renewable energy in the abstract and how

local publics conceive of projects to be built in their proximity (Sütterlin & Siegrist, 2017; Pidgeon & Demski, 2012). It is thus important to develop models for adapting climate-relevant infrastructure (i.e., renewable energy, public transit, or DAC) to local community contexts.

In addition to considering just transitions for communities as a whole, a just transition for workers in industries like oil and gas specifically will require that those communities assess for themselves through coordinated multi-stakeholder planning the kinds of financial assistance, new forms of employment, and training they need to pivot (Ravikumar & Latimer, 2022), as well as the risks of potential new industries. Self-determination is especially important for communities that traditionally have been excluded from decision-making processes, including rural communities and fenceline communities that have borne disproportionate environmental harms (Eisenberg, 2018). As McCauley & Heffron (2018) define it, a true JT advances distributional, procedural, and restorative justice in the pursuit of a post-carbon economy, tailored to meet social, cultural, and environmental needs in addition to providing economic opportunities to communities. It is therefore important to understand not just perceptions and potential acceptance of the physical infrastructure of new industries, but also the process by which it may be produced in communities—topics that lend themselves to more place-based qualitative research. Further, Batel et al. (2013) identify that "acceptance" refers to a passive relationship the community has with infrastructure, whereas "support" implies a more active and positive relationship, which may be beneficial to both the project and the communities—especially when the latter feels invested in project outcomes.

In addition to advancing justice principles, community engagement may lead to more efficient and equitable project development. Failure to attain SLO at larger scales (i.e., at state or national levels) can produce negative publicity and adverse policy outcomes, and a lack of SLO within project-adjacent communities can lead to slower and/or more costly deployment (Moffat et al., 2016). Susskind et al. (2022) examined renewable energy projects across multiple U.S. states and found that, where conflict occurred, 34% of projects experienced significant delays and 49% were canceled. They identify seven sources of opposition, among which are "public perceptions of unfair participation processes or inadequate inclusion in light of regulatory requirements" that additionally interact with other sources of opposition. Similarly, Sovacool and Ratan (2012) identify participatory project siting as one of nine factors key to determining acceptance and eventual success of solar and wind energy projects. Taken together, the literature underscores a need for meaningful participation in project planning and implementation toward ongoing engagement and benefits sharing that can secure community SLO (Wang, 2012). However, relatively little research exists demonstrating how these considerations can be incorporated from project planning to project implementation.

In this study, we seek to bridge this gap to provide insights across broader socio-political acceptance (among the general public, as well as among voters) and local community acceptance (among those who interact most closely with its infrastructure) of DAC. To do so, we use a mixed-methods approach to understand community perceptions of DAC under various technology, policy, and implementation configurations. We conducted qualitative focus groups to explore which components of DAC might influence local perceptions of potential projects, including perceptions of risk, benefits, trade-offs, and equity. We then tested public salience of and support for DAC using a nationally representative survey. Combining findings from these approaches, we identify how implementation of existing policies and creation of future policies can effectively meet public and community needs through EJ and JT lenses, and potentially enable DAC SLO.

Methods

To address the research gap on community acceptance of DAC, this study pairs a national survey (N = 1,195) with four focus groups in Houston, Texas; Monaca, Pennsylvania (with Beaver county-wide participants); Bakersfield, California; and Rock Springs, Wyoming (with Sweetwater county-wide participants). Due to population density, in Houston and Bakersfield, recruitment occurred at the municipal level; in Monaca and Rock Springs, recruitment occurred at the county level (referred to subsequently as Beaver County and Sweetwater County, respectively). These communities were chosen for their proximity to geologic storage opportunities and with recent or ongoing carbon-intensive industrial projects—criteria laid out by Congress in IIJA. We conducted focus groups in industrial areas, especially those with heavy concentration of fossil fuel production, processing, or transportation. This allowed us to explore DAC in the context of a JT for industrial workers and fossil fuel-dependent local economies, which has been proposed in the literature (Sovacool et al., 2022). Beyond these two fundamental criteria, we selected geographically and demographically diverse communities, thus providing insights on how different publics may respond to potential DAC siting and development. In addition to the qualitative data collected, pre- and post-focus group surveys provided quantitative data addressing self-reported knowledge of and support for DAC. Across the four sites, we had a total of 73 participants.

Table 1
Demographic profiles for each focus group site.

Site	Demographics	Under Poverty Line
Houston, TX	23% Black, 7% asian, 47% white, 1% AI/AN, 45% Hispanic	20%
Beaver County, PA	7% Black, 1% asian, 90% white, 0% AI/AN, 2% Hispanic	11%
Bakersfield, CA	7% Black, 7% asian, 58% white, 1% AI/AN, 52% Hispanic	16%
Sweetwater County, WY	1% Black, 1% asian, 94% white, 2% AI/AN, 16% Hispanic	9%

In addition to assessing public and community perceptions of DAC on its own, we sought to understand how participation in design, implementation, and project management and oversight, as well as community benefits might affect overall acceptance of or opposition to DAC projects. To this end, focus groups assessed knowledge and perceptions of one common tool for benefit sharing: community benefit agreements (CBAs). CBAs are legally binding contracts negotiated between project developers and a group of community representatives that lay out financial and other benefits a community will receive over the course of the project (van Wijk et al., 2021).

Focus groups were conducted aimed at achieving thematic saturation, the point past which no new themes emerge in group interviews (Hancock et al., 2016), and sought to understand place-based perceptions of prospective DAC projects. The national survey complemented this by measuring existing knowledge of DAC and levels of support for prospective projects within respondents' communities, nearby, or in the United States once respondents had been provided information about the technology. Combining these approaches allowed us to both validate and complicate our national findings while generating additional hypotheses on how individuals may independently and collectively understand and perceive DAC.

Focus groups and the national survey were both granted approval by the Stanford University Institutional Review Board (IRB).

I. Focus groups

Deliberative focus groups have been used across a range of industrial projects to understand public perceptions in greater detail than other social science research methods like surveys typically provide (Gough et al., 2014; Wibeck et al., 2017; Shackley et al., 2004; Williams et al., 2021). With their smaller sample size relative to survey research, focus groups are not intended to be representative of the public at large, rather they uncover "complex personal experiences, beliefs, perceptions and attitudes of the participants through a moderated interaction" (Nyumba et al., 2018). Qualitative research through deliberative focus groups allowed us to generate hypotheses and validate findings from the national survey on which aspects of DAC might be important in predicting community acceptance, as well as understand more intimately the kinds of local concerns that might arise in a project planning process. We followed the focus groups with a quantitative national survey to shed insights on national and regional trends in public preferences for DAC deployment.

Focus group participants were recruited using regional market research recruitment firms with the objective of securing focus groups as representative of the community as possible across age, gender, income, and political affiliation. Given suggestions of DAC's potential role for just transition opportunities for heavy industry (Batres et al., 2021; Sovacool et al., 2022), we attempted to oversample from these workforces in our recruitment screener. All participants were 18 years of age or older. To encourage engagement in discussions, we opted to keep each focus group relatively small, aiming for four to six participants per group with three to four groups per site. Overall, each site had between 14 and 20 participants.

The day of the focus groups, participants were asked to fill out anonymous pre-focus group surveys that assessed prior knowledge of CDR, DAC, community benefit agreements (CBAs), and related concepts (see *Appendix 1*). Before breaking into smaller focus groups, all participants were given the same presentation, which provided background information on CDR, DAC, CBAs, and related concepts (see *Appendix 1*). We iterated on our presentation draft with experts to make it as informative, neutral, and balanced as possible, providing technical information alongside potential project benefits and risks. To address potential conflation between DAC and/or CDR with CCS, we provided a short description of the concepts' similarities and differences.

Previous research indicates that presenting climate change-related topics in locally relevant terms can increase engagement (Scannell & Gifford, 2011; Nisbet, 2009). More recently, research has shown that political polarization in the United States often leads self-identified Republicans to indicate lower levels of support for policies under a "climate change" frame as opposed to one of "extreme weather," whereas self-identified Democrats demonstrated higher favorability (Carman et al., 2022). Therefore, while the informational presentation remained identical in most respects across sites, slides providing context on CDR and why we had convened a focus group in their community were tailored to local political leanings: Bakersfield, CA, and Houston, TX, presentations included mention of climate change, whereas those for Beaver County, PA, and Rock Springs, WY, did not.

Each group had a facilitator from the research team whose job was to ask clarifying questions, refocus conversation, and take notes. Each focus group had audio and visual recording to supplement facilitator notes. Each group was provided with a list of potential features of a DAC project, including energy and heat sources, project owner, and community benefits. Participants were also provided high-level discussion questions and guided to consider the best case scenario for a DAC project, reflect on how they, as individuals, might feel about it and how they thought their community might feel about it, and then work backward to consider less-than-ideal scenarios and how those might impact their support of or opposition to a project. At the end of the discussion, a representative from each focus group was asked to present takeaways to the larger group. This provided the research team with an additional check on their assessments of the focus group discussions and allowed for transparency among groups on their discussions.

After completion of the focus groups, recordings were transcribed maintaining participant anonymity and qualitatively coded (Saldaña, 2021) using the NVivo software for analysis. Some codes were determined deductively (a priori) based on the discussion questions participants were given—namely, environmental concerns and opportunities, and economic concerns and opportunities. The third code group, stakeholder trust and community engagement, was analyzed using a combination of a priori and inductive (emergent) codes: community engagement, about which participants were asked directly, and stakeholder trust, which emerged while coding transcripts.

II. National survey

National survey respondents (N = 1,195) were first asked for basic demographic information, employment and household union status, political identification, and concern about extreme weather, air and water pollution, and climate change. Respondents were then asked how much they had heard about DAC. Those who selected “don’t know” were pushed to consider their level of support or opposition. Participants were then presented with a description of DAC, paired with a visual representation to aid conceptual understanding. Respondents were also provided short descriptions of possible attributes of DAC: source of project funding, project developer and owner, energy source, levels of community involvement in project siting and implementation, CO_2 storage and transportation mechanism, share of project costs reinvested into the community, and potential job benefit commitments (Table 2). Respondents were provided definitions for geothermal energy and CO_2 storage mechanisms, as these terms are lesser known.

Table 2
Possible DAC project components.

Funding source	Developer & owner	Energy source	Community involvement in project	Carbon dioxide storage & transportation	Project costs reinvested in community	Jobs
Economy-wide tax	National government	New or expanded fossil fuel energy	No consultation	Used for enhanced oil recovery on-site (extracting oil while potentially storing some carbon dioxide)	None	No local jobs guaranteed
Tax on polluting industries	State or local government	New or expanded nuclear energy	Written comments accepted	Stored underground on-site in depleted oil and gas wells (injecting into empty wells)	1%	Short-term local jobs guaranteed for construction without unionization
Closing tax loopholes for polluting industries	Cooperatively owned by community members and community orgs.	New or expanded wind/solar energy	Workshops held to collect feedback	Stored underground on-site using mineralization (injecting underground to turn carbon dioxide into rock)	5%	Short-term local jobs guaranteed for construction with unionization
Private funds	Fossil fuel company	New or expanded geothermal energy	An elected community advisory board has voting power over project decisions	Transported out of community by CO_2 pipeline to be stored elsewhere	10%	Long-term local jobs guaranteed without unionization
Income tax on the wealthiest Americans	Direct air capture company	Existing electricity grid energy	Community members have direct voting power over decisions	Transported out of community by trucks or rail to be stored elsewhere	20%	Long-term local jobs guaranteed with unionization

When asking for preferences, we used a four-point Likert scale (“strongly support”, “somewhat support”, “somewhat oppose”, “strongly oppose”, “don’t know”) (Revilla et al., 2014). Participants were recruited via web panel platforms, which use online advertisements, text messages, and in-app prompts. Recruited participants were provided with a link directing them to the Qualtrics survey. To make the sample nationally representative, it was weighted using census data. To assess EJ and JT specifically, included questions about perceived need

for jobs in respondents' communities, history of household union membership, and relative importance of addressing climate change as opposed to preserving existing workforces. Zip codes were collected and used to link responses to EJ indicators downloaded from the U.S. Environmental Protection Agency EJSCREEN tool (EPA, 2022).

Results

I. Focus groups

Focus group conversations ranged widely but fell into three categories: (1) environmental concerns and opportunities, (2) economic concerns and opportunities, and (3) stakeholder trust and community engagement. Woven into these categories were health concerns, which often provided rationale for other concerns. Given the cross-cutting nature of health concerns, it is discussed throughout. 61% of participants reported having heard of DAC prior to the focus group. Participants self-reported increased knowledge of CDR (p-value = 2.713e-13) and DAC (p-value < 2.2e-16) following the focus group as compared with before it. When asked to reflect on their perceptions of DAC overall following a presentation, participants indicated a high likelihood of considering projects in their communities (Fig. 1).

Environmental concerns

Environmental concerns emphasized potential local impacts. In particular, participants across sites identified air pollution, CO_2 transportation and storage risks, and strain on local infrastructural during construction as concerns. The potential for increased traffic to transport raw materials to the project site(s) was identified across all focus groups, focused primarily on truck traffic. All focus group locations had undergone major industrial construction recently enough that many participants remembered those impacts and used these examples to substantiate worries about increased air pollution. As one Texas participant expressed: "We dealt with power plants years ago, … benzene and lead now, different stuff." Participants across sites additionally expressed apprehension that the DAC facility might itself produce air pollution. Participants in Wyoming identified the area's communities as especially concerned about local wildlife. As many noted that hunting and outdoor recreation are culturally important, they

described conservation as a substantial consideration: “[Y]ou know, as soon as you start talking about solar fields and stuff like that, you're all of a sudden now impeding upon open space, you're impeding upon the things [like] hunting grounds, sage grouse population, the environmental impacts of wildlife, migratory corridors.”

Although participants expressed concerns about environmental risks across the DAC process chain, discussion concentrated primarily on CO_2 transport and storage components and less on capture and energy production stages—findings that corroborate those of Arning et al. (2021) for carbon capture, utilization, and storage. The possibility of groundwater contamination in injection and storage stages was raised in the California, Texas, and Pennsylvania focus groups. In addition to groundwater contamination, participants in California highlighted the region’s ongoing water shortage and existing water-intensive industries, especially commercial agriculture; any technology configuration that had large freshwater requirements would raise concerns.

Across all sites, the possibility of CO_2 leaking during transportation, injection, or from its storage reservoir were sources of worry—especially if there might be associated health impacts, which many participants asked about. One Bakersfield participant raised the example of a CO_2 pipeline rupture in Satartia, Mississippi, which forced roughly 200 residents to evacuate the town and some to seek medical attention. Pipeline-related concerns were also prominent in the Pennsylvania focus groups, where the community’s recent experience with the fracking boom led them to mistrust

pipelines and other infrastructure evocative of natural gas production and transportation.

Where storage was concerned, many participants returned to mineralization as the “safest” option, with similar reasoning used to support CO_2 utilization for long-lived materials. As one participant said, “carbon dioxide is injected into the ground, where it chemically reacts to become rock…okay, that sounds like it's the safest way to go.” Another noted: “[I]f it's in liquid or gas form underground, it will leak up into and overtake our water table. It's inevitable,” showcasing risk perceptions of geologic storage options shared by many. Participants also indicated concern that spent oil and gas wells might fill up over time if developers relied on them for storage.

Finally, for many participants concerned about climate change, questions about the moral hazard of CDR more broadly were raised. The possibility that DAC might allow companies to continue pollutive practices while greenwashing them to the public was raised across all focus groups. In the words of one participant, “[companies are] not going to really reduce the overall carbon emissions. It's just going to be redistributed to other companies [who] have enough money to pay for the credit.” One Wyoming focus group participant emphasized the energy-intensity of a practice with benefits that were difficult to grasp: “We are using high energy intensity to take elusive CO2 out of the atmosphere to feed a business model that seems to be just like…it’s smoke and mirrors. It's not something tangible that we need.” Others worried that DAC might be a front for fossil fuels to sustain themselves without contributing real environmental and climate benefits. This was of particular concern in the scenarios where the DAC facility were to be

powered by fossil fuels: “[I]t makes no sense to have this thing run by fossil fuels when it's supposed to clean the air and then companies are gonna go pay them for this carbon offsets scheme that's been going,” one participant said.

Environmental Opportunities

Although environmental concerns were primarily local, the environmental opportunities participants identified were largely global, with only a few potential local environmental benefits. At the global scale, many participants identified climate change as a growing threat and reasoned that DAC was likely an important part of the solution set. Many participants spoke in favorable terms about the opportunities DAC could present to “undo” climate-warming pollution. Many of the California participants cited the state’s increasingly devastating wildfire seasons and expressed beliefs that not enough was being done to curb climate effects like these. A few participants expressed hope that a DAC facility in their community could be their contribution to addressing the climate crisis. As one California participant said: “I feel this is something that is long overdue. We really need to think about the air or we won't have an Earth inhabited by us.” Sentiments like these were shared across Texas and Pennsylvania sites. California participants described increasingly long and widespread wildfire seasons in the state, which they attributed to climate change, the possibility of addressing the underlying problem was appealing. In the Pennsylvania focus group, where views on anthropogenic climate change were more split, a few participants urged that DAC be presented with more of a climate frame while others pushed back on climate change being a relevant issue for the area. In Wyoming, climate change was more contentious – both whether the climate was changing and whether it was caused by humans – with a few participants urging that a climate change frame not be used to discuss DAC, but rather one of economic diversification. Wyoming, despite its low unemployment rate, has experienced less-than-stable economic conditions given its strong economic reliance on fossil fuels, which experience boom-and-bust cycles (Campbell, 2021).

At the local scale, many participants mistakenly assumed that, if DAC were cleaning up one form of air pollution, it might be able to address other forms of air pollution as well. When presented with the information that current DAC technologies were unlikely to be effective tools in reducing criteria and hazardous air pollutants, which directly impact human health, many asked whether the technology might be adapted to tackle co-pollutants. Many thought this would make the technology more acceptable or even desirable to their community: “[A]nother thing that I think would…help alleviate a lot of fears, especially when it comes to… increased particulate pollution from dust and whatnot, if there would be a way to, I don't know, like, incorporate, not just a CO_2 filter. But if we can incorporate something like, you know, other types of filters as well”.

Economic concerns

Participants often asked about the economic model and feasibility of DAC. They wondered how any company could make money off of DAC. Moreover, some participants wondered if taxpayer money would be used to

build DAC facilities and, when told that Congress had already authorized funds (taxpayer dollars) to build DAC facilities, were curious about whether communities would be responsible for future infrastructure. Some participants brought up recent infrastructure projects in their communities funded by tax dollars and for which communities later became financially responsible. Others raised the concern that large corporations would be the primary economic beneficiaries and that the community itself would not reap the benefits. Overall, participants wondered who would benefit economically and how local economic benefits would be guaranteed.

Participants recognized the ability of a DAC facility to create jobs, but questioned whether the quality or quantity of jobs promised would be delivered. In Pennsylvania, one participant pointed out that a recently built Shell ethane cracker plant in the area had promised more local jobs than actually delivered:

[T]hey over promise on jobs. We just [saw] that with the cracker plant, just down the street here, promising all these jobs. Well, now all these people are moving out. They've driven our rents up and everything. So there's a lot of negative impact and things like that. Since this is, you know, pre-planning, I'd love for them to be more honest with how many jobs are going to be local jobs because I'd say 97% of the jobs that were at that cracker plant are from out of town.

In Texas, one participant expressed skepticism that a job in a DAC facility would be of an equivalent quality to a refinery job in the oil and gas industry, citing high wages and levels of unionization in the latter. Jobs presented by a DAC hub would have to be of the same, if not higher, quality to attract an experienced workforce. Indeed, a number of participants were skeptical that companies would deliver quality jobs, as measured by wages and opportunities for worker bargaining power (whether as part of a union or in direct negotiations). Labor benefits were the most commonly cited opportunities that a DAC Hub might present communities, whether because of a lack of awareness of other potential benefits or a true reflection of participant interest.

Considering local resources and infrastructure, some participants asked if DAC would further strain local infrastructure. In California, participants recognized that waste processing facilities were already in need of improvements and located in low-income communities and communities of color, questioning whether the burden of waste and/or other pollution from DAC would fall on the same communities. In the Pennsylvania, Texas, and California focus groups, participants additionally expressed worries about increased traffic and its impacts on commutes, as well as local road infrastructure. Their communities had already seen industrial activity increase air pollution and congestion, making commutes longer and more difficult. Finally, recognition of DAC's intensive energy requirements led some to worry that powering DAC using existing energy resources might raise energy costs for ratepayers. At the very least, participants reasoned, a DAC hub should not worsen the community's economic wellbeing, especially through something as important as energy costs.

Economic opportunities

Across focus groups, some participants discussed the possibility of a community-owned or co-owned DAC facility. While many had a difficult time imagining what such an economic model might look like, the opportunity for community benefit as well as community influence in decision-making was a source of

excitement. Particularly in California, participants suggested that a community-owned DAC facility could provide real benefits to a community in which Chevron and Aera oil and gas companies otherwise dominate local politics. In addition to offering workers jobs outside of those companies, lessening the municipality's economic reliance on these industries could transfer political power to the public as well. The need to decrease the amount of power fossil fuel companies and other pollutive industries wield in local politics was also raised in Texas and Pennsylvania, thus linking political stability with economic choice. Finally, while some viewed DAC development as a threat to residential energy costs, others saw it as an opportunity to expand energy infrastructure and sustainability. One California participant noted: "And if we allocate space for a solar farm that is used for, to fuel this place, any excess would benefit us directly…we can reduce our electric bill."

Stakeholder trust and community engagement

Many participants brought up stakeholder trust in discussions about DAC hub governance: overseeing project construction and operation, with particular focus on decision-making around hazard prevention and risk monitoring. When asked to consider who should develop, own, and operate DAC, divergent views emerged. Trust in local government was generally low, with several references to local corruption; however, there was also a desire for public participation in and oversight of a potential DAC facility. Participants in California raised the idea of state government involvement, although there were mixed views, as some pointed out that the state had not always effectively enforced environmental regulations in the surrounding area. Across focus group sites, participants asked how developers would be held accountable for project safety and efficacy, and many doubted that sufficient enforcement mechanisms would exist.

To fill potential gaps in project safety and equity, many participants expressed interest in direct community oversight. Such involvement would both make projects fairer – allowing community members decision-making power in the planning and implementation of a project that might affect them – as well as safer, placing a check on private interests. As one Pennsylvania participant said: "If you took the direct air company, and a group of community [members], and they did it together as equals, I think they would have the knowledge on how to do it. And then the community would give input from the people." In addition to wanting checks on the physical safety of operations, including monitoring systems for potential leaks, seismic activity, and other risks, many participants also identified a need to guard against social and labor risks. Many saw unions as an entity that could support this need, while others were either ambivalent toward or even mistrustful of unions, worrying about economic barriers to union participation. One California FG participant worried that a unionized workforce would mean that "there has to be more people, and a lot of money that would have gone to employees is going to go to the union instead. But if you prefer not being with a union, there's a risk that if the jobs are more difficult or harder than you thought, and there is no one who will fight for them, their pay and all that".

When asked who would be a trusted actor to carry out the DAC's construction, many participants stressed the importance of an experienced developer. While community oversight was important, there was a recognition of the role companies would play in building the facility. As a participant in Pennsylvania said, "I don't think you can gather a group of [a] community's people and expect them to know what to do for direct air capture… nobody's gonna be knowledgeable enough to lead this, to build it. You got to have somebody from a company

that knows what they're talking about." Most participants expressed preferences for working with companies that could demonstrate experience, but there was disagreement on what kinds of companies would best satisfy that requirement. Many thought that dedicated DAC companies would be the obvious choice. The possibility of fossil fuel companies playing a role was also discussed, with many participants identifying oil and gas as having the most experience with subsurface activity. Whether fossil fuel companies could be trusted even for non-extractive practices was far from unanimous, however, with other participants emphasizing fossil fuel companies' track records of pollution and lack of transparency.

II. National survey

In total, 2,197 participants were recruited as survey respondents; those who did not complete the survey, failed the attention check, or were in the fastest 5% of respondents from the beginning of the survey to the end (suggesting low engagement with survey content) were excluded from the sample of responses analyzed. Given the complexity of the topic, respondents were asked a comprehension check question; those who failed the comprehension check were also excluded, leaving a final sample size of 1,195 individuals. Using standard rake weighting, responses were weighted to represent national demographics recorded in the American Community Survey across sex, race, ethnicity, education level, age group, and region of the United States (U.S. Census Bureau, 2021).

When considering SLO, especially through EJ and JT lenses, it is important to consider diversity of opinion as well as exposure to topics. Beyond all else, our national survey shows that only a small share of Americans have interacted with the topic of DAC. Indeed, 71% of respondents reported having heard "nothing at all" about DAC before participating in the survey. Men, those identifying with a major party (as opposed to independents and apolitical respondents), those in households making more than $200,000 per year, and non-white respondents were significantly more likely to have heard of DAC prior to the survey. Among these, a majority self-reported to "somewhat support" or "strongly support" DAC being built in their community, near their community, or in the United States rather than "somewhat oppose" or "strongly oppose" (Fig. 2). This aligns with Satterfield et al. (2023)'s findings, who surveyed U.S. and Canadian publics located near a proposed DAC project in the Pacific Northwest and found 58% support and 13% opposition among survey-takers.

Given prior knowledge of DAC, most survey respondents learned about the technology through the survey. After being provided a description of DAC and its project components (funding, ownership, energy and heat source, community involvement in decision-making, CO2 transportation and storage, community benefits, and labor commitments) along with several images of what DAC might look like in communities (Kapila, 2022), all survey respondents were asked to provide their own overall impressions of DAC as well as to speculate on how their community might perceive DAC. Respondents who reported being "not very concerned" or "somewhat concerned" about air and water pollution or "not at all concerned" about climate change were significantly less likely to approve of DAC in the US. Similarly, those who reported being "somewhat concerned" about air and water pollution and those who were "not at all concerned" about climate change were significantly less likely to approve of DAC in their community. People living in small towns were significantly less likely to support DAC in their communities. Democrats were significantly more likely than non-Democrats to support the construction of DAC in their communities or in the U.S. in general, while Republicans were significantly less likely than non-Republicans to support DAC in their communities or in general. When examining race alone, Black, white, Hispanic, and those identifying as "other race" were statistically more likely to not support DAC in

their communities, and Black and Hispanic demographics were more likely not to support DAC in the U.S. Men were statistically likely to support DAC in their communities, and young people (18–35) showed support for DAC in the U.S.

While a greater number of respondents indicated that they would “strongly support” or “somewhat support” DAC in their community as opposed to “somewhat oppose” or “strongly oppose,” there was greater overall support for DAC when sited nebulously “in the U.S.” than in respondents’ own communities (Fig. 3), which aligns with research conducted on carbon capture and storage and suggests that “not-in-my-backyard” sentiments may be at work (Pianta et al., 2021).

When disaggregated by household income, however, lower (<$52,000) and middle ($52,000-$156,000) income brackets were significantly associated with support for DAC being constructed in their communities whereas the upper income bracket (>$156,000) was significantly more likely to oppose DAC in its communities. This was particularly true of wealthy Republicans and Independents; wealthy Democrats tended to support DAC in their communities. Beliefs about one’s community also had an influence on support for DAC being sited locally. Those who believed there was “large” need for jobs in their communities tended to support DAC being sited in their communities, whereas those who believed there was “little to no need” for jobs tended not to support it, suggesting that respondents may have associated DAC with job opportunities. In addition to considering differences between socio-political (broad) and community (local) SLO indicators across groups, we also investigated trends at the individual level and found that middle-aged people (36–60) showed increased support for DAC in their communities as opposed to in the U.S. in general, while young people (18–35) showed decreased support. Those with their bachelor’s, high school diploma, and less than a high school diploma showed increased support moving from general to local support, while Republicans showed decreased support for DAC in their communities as opposed to in the U.S.

As is well-cited in the EJ literature, Black and Hispanic people, especially those in the lowest income bracket, were significantly more likely to live in zip codes with at least one environmental justice indicator, as defined by the Environmental Protection Agency’s EJSCREEN tool, and white people were significantly less likely. When examining preferences for DAC being sited in one’s community, there was a significant negative relationship between support and living in a zip code in the top 5% of at least one type of air pollution (PM2.5, ozone, diesel particulate matter, air toxins with cancer risks, air toxins with respiratory risks, or traffic proximity) or one type of physical risk (lead paint, superfund proximity, risk management program site proximity, hazardous waste proximity, underground storage tanks, or wastewater discharge), which EJSCREEN uses to identify environmental injustices. Despite lower levels of support in EJ zip codes overall, those living in EJ communities who also identified their communities as needing jobs tended to support local DAC siting. This was also true more broadly: those who thought their communities needed jobs were significantly more likely to support local DAC projects.

Discussion And Conclusion

This study provides one of the first mixed methods analyses of community perceptions of DAC in the United States. Although broad public support will be useful for advancing policies that enable DAC deployment and scaling, such as the 2021 Infrastructure Investments and Jobs Act and 2022 Inflation Reduction Act,

community acceptance and buy-in will be instrumental in achieving SLO for specific projects. Combining data from a national survey with focus groups provides insight both on broad reactions of the national public to potential DAC projects as well as how communities might consider DAC's realization, including risks and opportunities. Our work illustrates that perceptions gleaned from place-based qualitative research locally can provide context-specific understanding.

Although most focus groups identified aspects of DAC deployment that might appeal to their community, much of their emphasis was on potential hazards, aligning with psychological research that points to heightened risk perceptions of hazards seen as unknown, unfairly distributed, or with the potential for sudden and catastrophic consequences (Wilson et al., 2019; Siegrist & Árvai, 2020). Risk perceptions are often heightened when considering new technologies, which may mean that the benefits delivered to a community would need to be more substantial to garner support than for a project that is better understood by the public and thus seen as less risky. This may be especially so in communities that have had bad experiences with industrial projects, as perceptions are often influenced by recent experiences with project developers and the government institutions charged with accountability (Malone et al., 2010). When considering potential risks, focus-group participants expressed concerns that DAC might cause or worsen air or water pollution, or cause other health or environmental harms. Many also worried that, despite substantial up-front federal incentives, funds would dry up and leave local taxpayers with the bill—if not directly, then through maintenance costs for supporting infrastructure such as roads, waste treatment, and other public goods.

Despite the concerns raised by focus group participants, a majority believed that, under the right conditions, their communities might support DAC development. Indeed, many identified potential benefits, including for their communities' existing industries and workforces. Questions remained, however, about whether and how the conditions for DAC development might materialize, with attention by many to the equity across planning, construction, and operation phases. Skepticism over equity usually cited personal or community experiences with heavy industries, especially the fossil fuel industry, which has a well-documented history of environmental injustice (Boyce & Pastor, 2013; Schlosberg & Collins, 2014). In some cases, those negative experiences led participants to draw a line: if led by a fossil fuel company, a DAC project was not to be trusted. Regional variability in project preferences did occur, however: In Wyoming, for example, having a fossil fuel company lead the project was largely seen as an asset given general favorability toward the industry as a whole, especially where employment was concerned.

Focus group participants preferred projects with substantive community engagement and investment, ideally beginning in early project stages, as well as projects owned cooperatively by community members and organizations. Indeed, most focus group participants expressed greater interest in projects that had some degree of community ownership and oversight, with all groups concluding that cooperative decision making would be more likely to yield successful outcomes than unilateral decision making by developers. Several focus groups began to envision what full community ownership might look like but lacked concrete examples of community infrastructure ownership models. Future research is necessary to elucidate what such a model might look like for large-scale CDR like DAC—for example, through analysis of similar ownership models for analogous technologies. This is especially important given recent calls for centering communities in DAC development (e.g. Batres et al., 2020) and the dearth of publicly owned DAC projects. As governance models for CDR develop on national and international stages (Schenuit et al., 2021; Honeggar et al., 2022; O'Beirne et

al., 2020; Lezaun et al., 2021), democratic governance structures that can address moral hazards of CDR broadly and DAC more specifically will be important. In particular, transparent monitoring, reporting, and verification may be necessary contributors to earning public trust.

Many participants expressed increased likelihood of support for DAC projects powered by wind, solar, or geothermal energy as compared with fossil fuel energy. Where nuclear energy sources already existed (Pennsylvania and Wyoming sites), there were additionally suggestions that these could power DAC. The exception to the preference for renewable energy was Wyoming: focus group participants, who expressed considerable skepticism toward renewable energy, indicating potential regional variability. Perceptions toward transportation also varied across focus groups: participants in Beaver County, Pennsylvania, and Bakersfield, California, expressed concern about the possibility of CO2 pipelines, whereas levels of concern were lower in Houston, Texas, and low to non-existent in Sweetwater County, Wyoming. Mineralization was seen as the least risky storage pathway, although focus group participants also raised the possibility of CO2 utilization. Previous research has highlighted consumer interest in utilization, especially for construction materials such as cement or concrete and insulation materials, indicating it may be a “win-win” pathway where feasible (van Heek et al., 2017; Arning et al., 2021).

Community members’ overall openness to accepting DAC infrastructure build-out provides nuance to a national discussion that assumes not-in-my-backyard (NIMBY) sentiments among communities in reaction to climate infrastructure. However, our national survey provided important context to this overall finding: while lower and middle household income brackets tended to favor DAC in their communities, the uppermost income bracket tended to oppose. JT and EJ literatures point to the need for large-scale infrastructure to take into account workforce and community needs, especially in communities with cumulative environmental burdens. While it is important for policies like IIJA and IRA to require that developers provide benefits to local communities, it may also be important to investigate policy and legal structures for requiring wealthy communities to assume their fair share of climate infrastructure burdens.

We did not find blanket endorsement of DAC construction in the lower- and middle-income communities where we conducted focus groups; however, a process for implementation premised on strong labor commitments, tangible community benefits, and early and active engagement with community stakeholders seemed to hold promise for many. It may be that self-reported levels of support ahead of projects and actual levels of support during and after project completion differ, but we found it encouraging that our mixed-methods, national and local results indicated similar preferences. These findings align with those of Bergquist et al. (2020), which show that linking climate policies to economic and social issues increases public support. Our results indicate that providing communities with tangible economic and social benefits increases socio-political (large-scale) as well as community (local-scale) support. Further, projects could aim to serve restorative justice ends, helping to repair the harms that frontline communities have faced and build much needed trust. One manifestation of this vision, which came up across focus groups, was community oversight and ownership of projects. Realizing this will require true public ownership models need to be developed, however, as participants often could not imagine what that might look like in practice.

Our results have various applications. First, they demonstrate the importance of community labor and economic benefits, as well as ongoing community engagement, to encourage support for DAC in host

communities. Second, they show that, though secondary to social and economic considerations, technological aspects of DAC can be important to informing SLO. Given DAC's relatively early stages of research, development, and deployment, an opportunity may exist to shape the technological features of the technology in ways that can improve its likelihood of achieving SLO in communities. As found in Cox et al. (2020), for example, some focus group participants mistakenly assumed DAC could remove other forms of air pollution, and others asked whether this was a possibility, indicating that tangible benefits like these might help convince their neighbors to approve of such a project. It is possible that, if DAC were able to address co-pollutants, the technology as a whole might be seen more favorably. Many participants also identified DAC's high energy inputs and expressed concern about what those would mean for energy security, reliability, and costs. Improvements in DAC efficiency and the ability to power DAC down in periods of exceptional grid demand (e.g., peak hours or during heatwaves) may help allay community concerns. Concerns about grid disruptions may also be addressed through co-location of renewable energy such as a solar park with the promise of providing stable energy price to local inhabitants. How DAC is presented to communities, and who the messenger is, may also be important in determining future public and community engagement and acceptance, but remains understudied. As a Wyoming participant said, "...if you're gonna sell [DAC hubs] as the green lifesaver to the Earth, Wyoming's gonna say, 'Kiss our butts,' because we got our green earth and outdoors. But if you're going to sell it as jobs, you might get it." The message, messenger, and the trust that each garners will be important to local SLO, perhaps particularly so in JT and EJ contexts.

Our research elucidates pre-conditions communities may need for DAC deployment to earn acceptance, and potentially even support. In particular, SLO founded in EJ and JT principles is likely to be responsive to levels of community engagement and benefits, with particular attention to past industrial harms to host communities. While DAC may provide opportunities for a just transition in communities currently reliant on carbon-intensive industries like fossil fuels, work is needed to engage communities early and in an ongoing manner in project decision-making. Models for how best to engage communities, and how policy can encourage community self-determination in and even ownership of projects will be important to DAC's success. To date, discussions of DAC's deployment have mostly been relegated to the private sector. However, mixed-sector stakeholder collaborations may be increasingly important to the success of DAC. Policies that provide public financing for projects such as the U.S. Infrastructure Investment and Jobs Act should especially prioritize pathways for community engagement, leadership, and ownership with particular attention to EJ and JT needs in low-income, fenceline, and communities of color, while also considering how policies can encourage fair-share adoption of climate infrastructure in wealthy communities.

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Figures

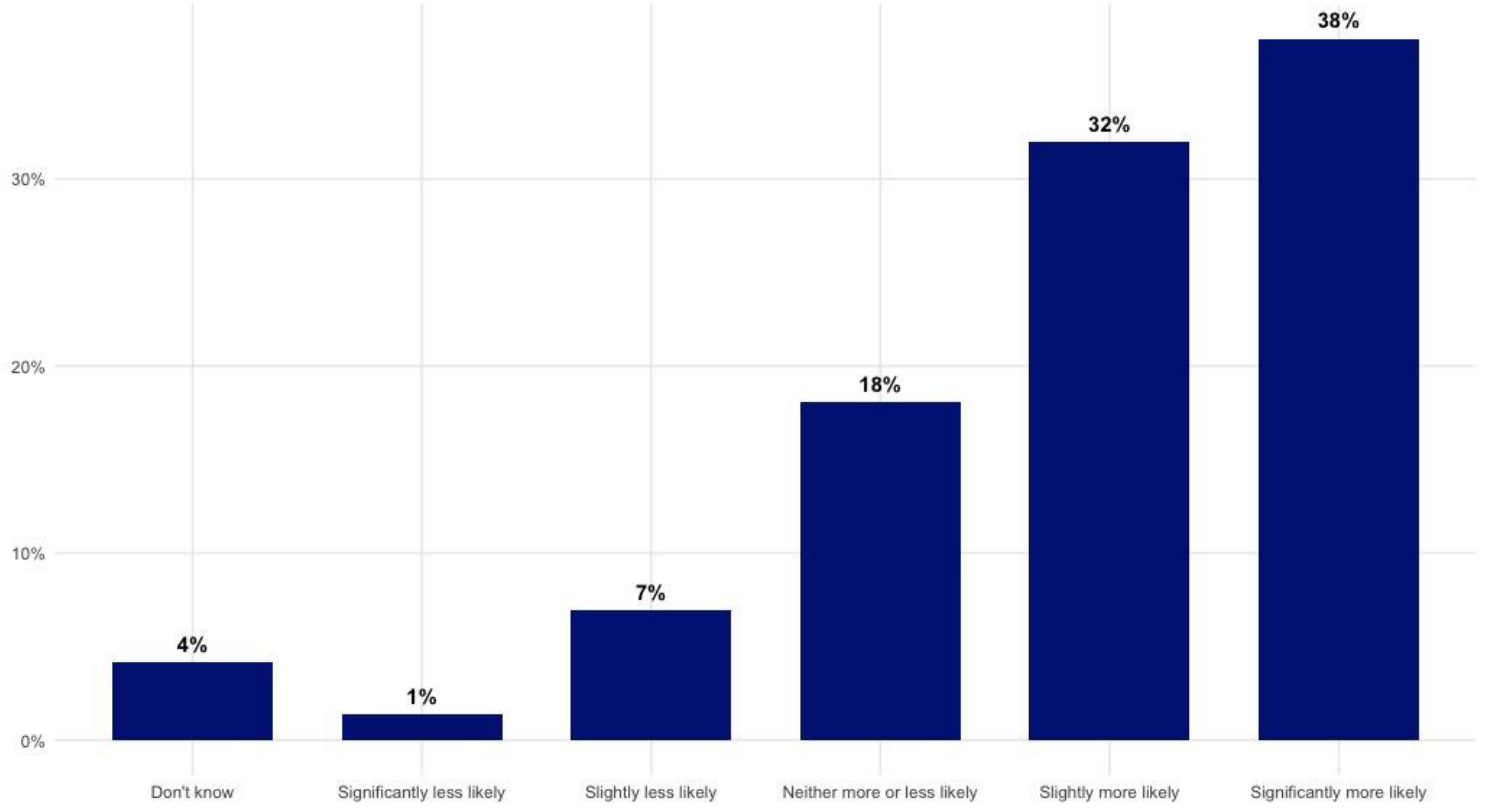

Figure 1

Focus group participant responses to the question, "After learning more about direct air capture at the beginning of the workshop, are you likely or unlikely to consider having a direct air capture hub in your community in general?"

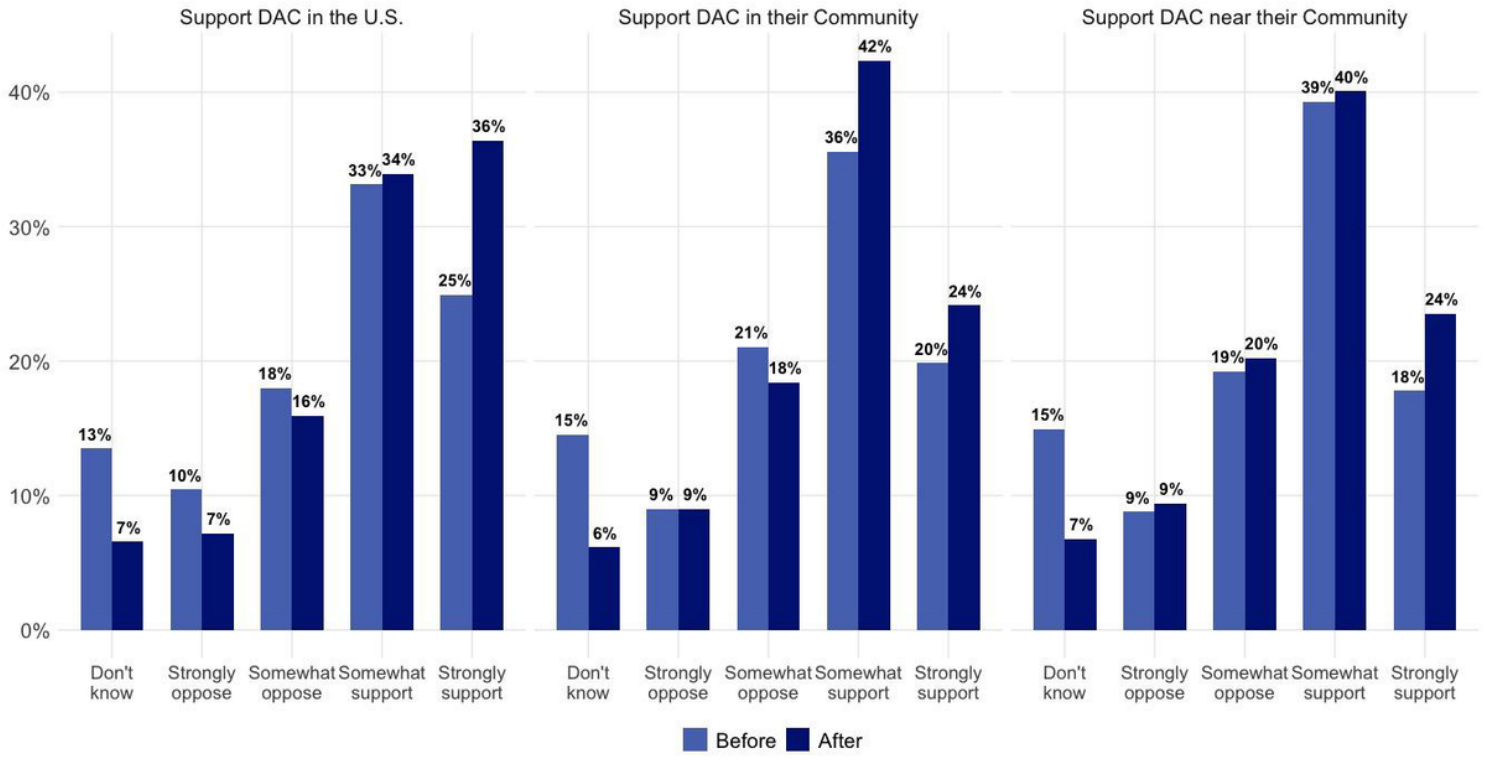

Figure 2

Levels of support or opposition toward DAC in (a) their community, (b) near their community, (c) in the United States pre- and post-survey among respondents who indicated having heard "only a little," "some," or "a lot" about DAC before taking the survey. Light blue indicates perception before taking the survey, while dark blue indicates perceptions at the end of the survey.

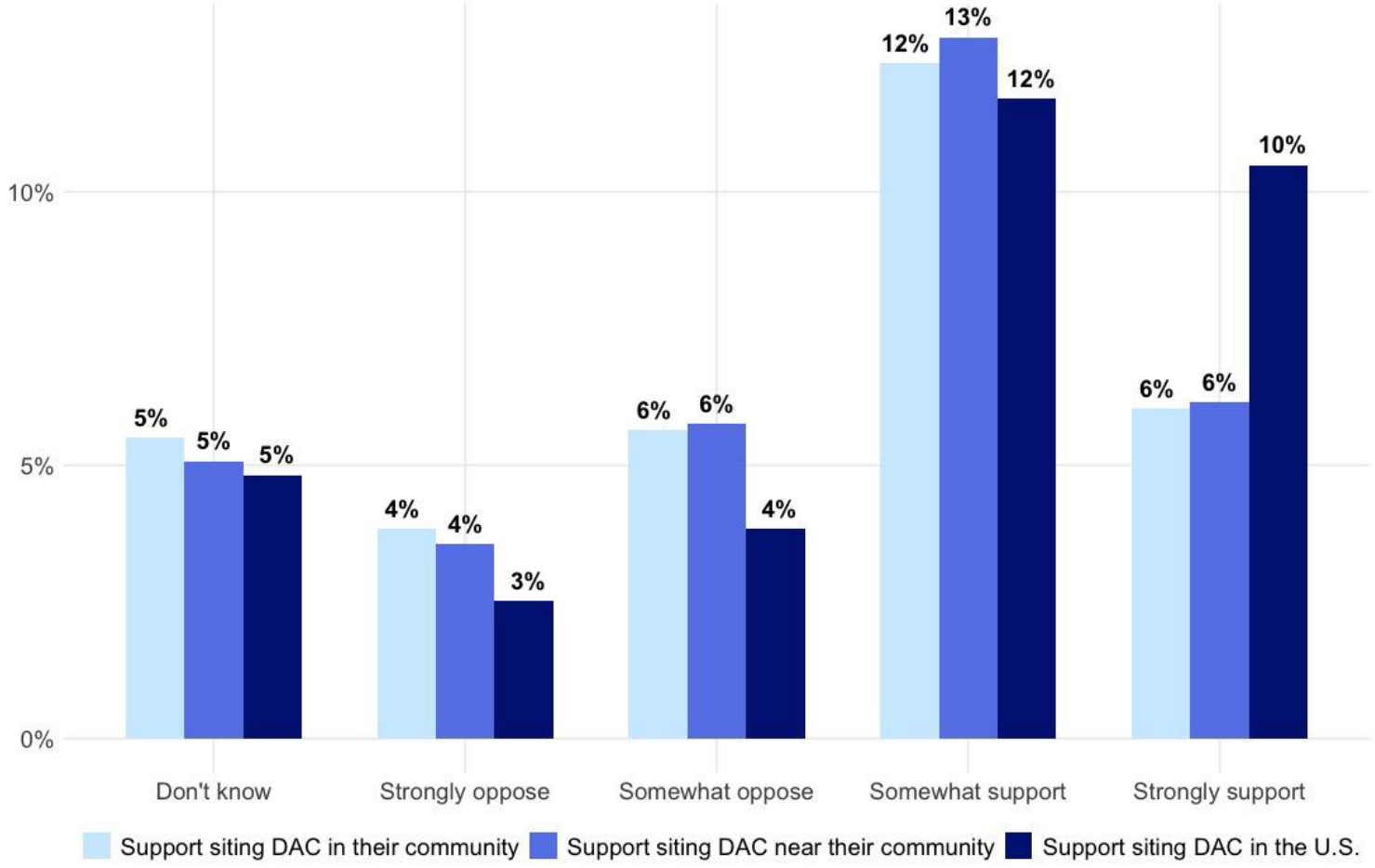

Figure 3

Levels of support or opposition to DAC among all survey participants in their community (light blue), near their community (medium blue), and in the United States (dark blue).

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementaryInformation.docx
- dacsurveycleaning.txt
- dacanalysis.txt
- finaldacvisualizations.txt

- ZIPTRACT122021.csv
- RUCA2010zipcode.csv
- EJSCREENFullwithASCNMIGUVITracts.csv
- psampusb.csv