CHAPTER 9

Energy Equity and Environmental Justice Impacts

SUMMARY

Rapidly scaling CO_2 removal to the billion-tonne scale by 2050 has the potential to stimulate changes in energy equity and environmental justice (EEEJ) across the United States. The net positivity of these changes, however, is dependent on purposeful design, siting, engagement, and management of CO_2-removal projects. For this chapter, we evaluated potential impacts (positive and negative) of different CO_2-removal methods and synthesized data relevant to these trade-offs that practitioners can use to make informed decisions. The positive impacts we evaluated include opportunities for restorative justice in communities inequitably burdened with air- and water-pollution issues and recognition opportunities for counties experiencing steep employment declines. Negative impacts included potential air and water impacts from transportation and construction, as well as land-ownership inequities, which could yield unintended socioeconomic consequences. How county residents perceive EEEJ trade-offs for each CO_2-removal method may be shaped by residents' past experiences. Examples of relevant past experiences might include historical or ongoing pollution, projects over-promising jobs, land-ownership disparities, declining industries that are integral to a county's identity, and inequitable public-health impacts.

To combine these interdisciplinary trade-offs into one metric for future studies to build upon, we constructed an "EEEJ Index" for each CO_2-removal method. Further, we classified CO_2 removal methods as either "protective" or "collaborative" (**Figure 9-1**), aiming to (1) align CO_2-removal project development with the counties most likely to experience co-benefits (high EEEJ Index values), (2) protect the most vulnerable US counties from pollution, and (3) prioritize early adoption in counties that need jobs and have the bandwidth to collaborate with project developers. We also used the Center for Disease Control's (CDC's) Social Vulnerability Index (SVI) [1] to identify counties with potentially differing degrees of bandwidth for collaboration or capacity to respond to emergencies, should any arise.

We then combined the EEEJ indices and SVI to prioritize well-understood, ecological CO_2-removal methods with high environmental co-benefits, such as forest and soil management, in highly vulnerable counties whose residents may be less equipped to protect themselves from pollution impacts (e.g., access to air and water filtration). We also prioritized CO_2-removal methods with high socioeconomic potential in the least vulnerable US counties with an abundance of skilled, underemployed workforces and a healthy ecosystem of diverse, small businesses.

CHAPTER SCOPE

This chapter reviews socioeconomic and environmental trade-offs for CO_2 removal methods. We synthesize peer-reviewed literature on the implications for energy equity and environmental justice (EEEJ) for each CO_2 removal method, considering factors such as the following:

- Pollution exposure
- Underemployed skilled workforces
- Land and business ownership

We calculate EEEJ index values for each US county, based on opportunities for potential co-benefits or negative impacts. We compare these EEEJ Indices to the Center for Disease Control's (CDC's) Social Vulnerability Index (SVI) to provide context to each county's potential to evaluate and/or respond to proposed projects and their effects.

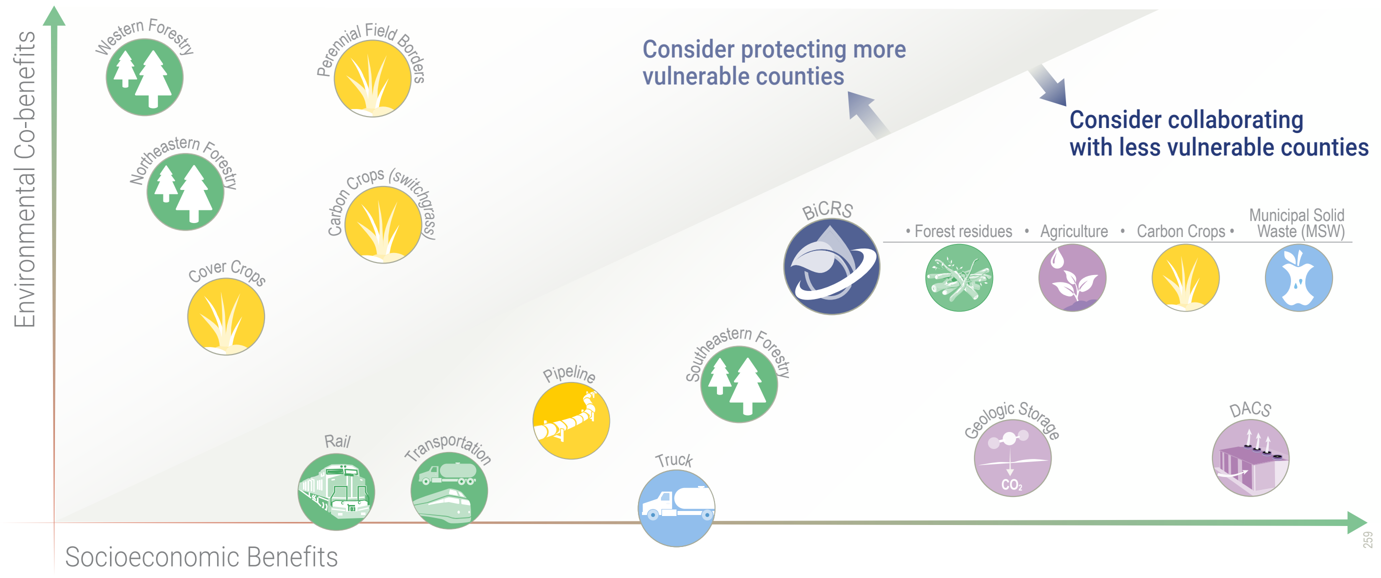


Figure 9-1. *Qualitative graph depicting* CO_2*-removal methods plotted based on their likelihood for having environmental and/or socioeconomic co-benefits.* CO_2*-removal methods that may be well suited for highly vulnerable counties are labeled as "protective"* CO_2*-removal methods and those that may be better suited for engaging less vulnerable counties as early adopters are identified as "collaborative"* CO_2*-removal methods.*

We hypothesized that these counties have the greatest local capacity for engagement as early adopters of less prevalent CO_2-removal methods, such as geologic carbon storage, biomass carbon removal and storage (BiCRS), and direct air capture with storage (DACS). Of note, we found, in nearly all cases, that the EEEJ indices we constructed in this report did not correlate with SVI, which suggests that our EEEJ indices do not bias toward vulnerable counties (**Appendix 9; Figure A9-1**).

The results from this chapter point to localized opportunities for specific CO_2-removal approaches. Furthermore, combining these two indices (our EEEJ index and SVI) with the CO_2-removal capacity and cost data presented in other chapters of this report can help identify counties that have both high CO_2-removal potential and a high likelihood for realization of co-benefits. We also hope to inspire subcounty-resolution analyses in the future since individual projects will inherently have subcounty impacts to consider. Further, we intend that our CO_2-removal-pathway-specific county-resolution EEEJ indices serve as a foundational work-in-progress for future research to build upon, rather than prescriptive, static values. Also, while our results can be used as a tool to help optimize equity amongst CO_2-removal projects on a big-picture scale, they should not replace on-the-ground relationship-building and co-creation efforts.

Key Findings

- In this report's cost-optimized scenario of 1 billion tonnes of CO_2 removal per year, CO_2 removal can create >440,000 long-term jobs, more than twice what the coal industry has lost since 1990, predominantly in BiCRS and DACS sectors (Figure 9-35).
- With respect to suitable land availability, land for BiCRS and DACS is equally available in disadvantaged and non-disadvantaged communities (±10%) (**Figure 9-2**). Optimizing DACS-facility placement for capacity and costs did not bias siting toward disadvantaged communities in this report's analysis (Figure 9-2).
- Two highly vulnerable counties in Oregon (Josephine and Jackson) have the greatest opportunity for wildfire-prevention-based CO_2 removal with maximal EEEJ co-benefit opportunities, followed by Trinity County in California and Idaho County in Idaho (Figures 9-17 and 9-19).
- CO_2 removal via cover cropping is the largest (total and per hectare) and most affordable ($/tonne CO_2) soil-based CO_2-removal management approach. Southern Georgia, eastern Tennessee, and Colusa County in CA are notable for equitable and environmentally just soil-based

CO_2-removal opportunities due to high SVI and EEEJ index values in highly vulnerable communities with diverse farm operatorship (Figures 9-22 and 9-26-235).

- An abundance of counties have affordable geologic carbon-storage opportunities across the United States; therefore, price does not need to be the sole deterministic factor—there is ample room for simultaneously prioritizing a county's social vulnerability and potential for impactful co-benefits (Figures 9-31 and 9-32).
- Some BiCRS wastes may include unconstrained per- and polyfluoroalkyl substances (PFAS; "forever chemicals"), which are carcinogenic at even low concentrations. It is imperative that BiCRS feedstocks be tested for PFAS to ensure appropriate use of conversion methods that destroy PFAS (Figure 9-34).
- Wet-waste-based BiCRS projects (anaerobic digestion (HD) and high-temperature liquefaction (HTL) need to carefully consider inequitable pollution burdens that may result from confined animal feeding operations (CAFO). This issue is of particular concern in highly vulnerable counties, which may lack advocacy power and secondary protective measures (e.g. in-home water filtration). Enforceable management plans that minimize air emissions and dilute manure will be critical to environmentally just scale-up of this BiCRS method (Figure 9-42b).
- Dry-waste-based BiCRS provides value for the carbon content of forest residue biomass and generates market incentives for forest thinning, which could increase the practice's prevalence. This may ultimately reduce air pollution for vulnerable communities with high wildfire probability or those that are downwind from susceptible forests.
- Wyoming stands out for its abundance of counties (e.g., Sweetwater and Campbell) that are suitable for early engagement (low SVI) in geologic carbon storage and DACS, with affordable costs for both (Figures 9-32 and 9-44).

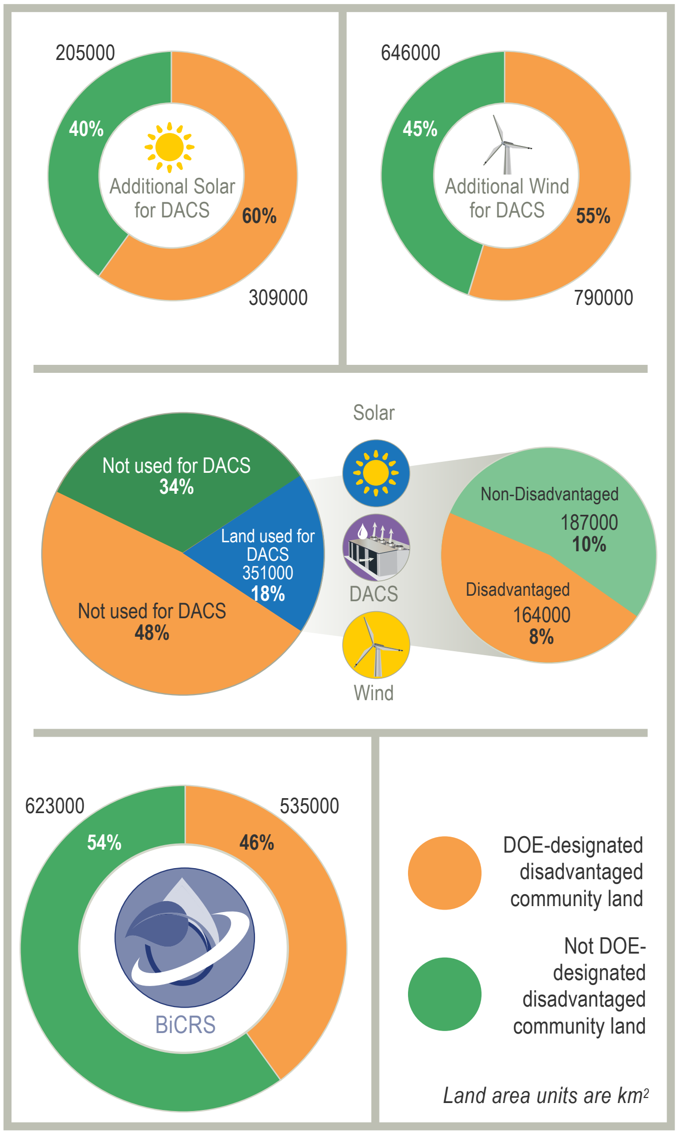


Figure 9-2. *Diagram of land area suitable for deploying solar and wind energy that is additional beyond the National Renewable Energy Laboratory's (NREL's) 2035 model for what is needed for decarbonization. Suitable land areas are divided into "disadvantaged" and "non-disadvantaged" based on census tract-resolution data available in DOE's Justice40 Mapping Tool. For greater detail on the definition of suitable land and Sankey diagrams, refer to* ***Chapter 8*** **– Cross-Cutting**. *Calculations show that, from a capacity perspective, there is no intrinsic bias that would site DAC or BiCRS facilities in disadvantaged communities. Therefore, if we observe biases in future siting as these industries grow, this would be caused by variables other than solely cost or capacity.*

Introduction

We take it as a given that CO_2 removal must not compete with nationwide decarbonization; decarbonizing US energy, transportation, and industrial sectors will reduce air pollution nationwide, with outsized reductions for communities of color and high poverty, which currently bear disproportionate exposure (e.g. [7-9]). The emissions reductions from decarbonization will result in health benefits valued at ~$200 billion per year [10]. *Any diverted efforts toward decarbonization goals are contrary to a key principle of environmental justice: "all people deserve the same degree of protection from environmental health hazards, regardless of race, color, or income"* [11]. Even with this deep decarbonization, however, the United States will need CO_2 removal to counteract residual emissions from hard-to-abate sectors (e.g., agriculture) and environmental feedbacks (e.g., permafrost thawing) (**Chapter 1 – Introduction**). Furthermore, when these sectors are decarbonized, residual air and water pollution issues will persist, alongside job losses in traditional energy communities, both of which necessitate mitigation. Without purposefully counteracting the economic transition challenges associated with decarbonization, traditional energy communities may be put at risk of economic and public health crises [12-14].

In this chapter, we first introduce concepts foundational to the Department of Energy's (DOE's) EEEJ goals [15], such as reducing inequitable energy, job loss, and pollution burdens. We review baseline conditions and trade-offs relevant to each CO_2-removal method, through socioeconomic and environmental lenses, and discuss case studies. Then, we synthesize the results of each CO_2-removal method's trade-off analysis and relevant county-resolution data into an interdisciplinary EEEJ index [16-18]. For our EEEJ Index, values closer to 1 have maximal opportunity for co-benefits for a given CO_2-removal method, while values closer to 0 are less likely to experience co-benefits. These indices are compared with county-resolution, nationwide datasets from this report (e.g., tonnes of CO_2-removal capacity and $/tonne CO_2) and the CDC's SVI [1] to assess which counties might represent a win-win-win scenario for the climate, local residents, and CO_2-removal practitioners. The CDC constructed the SVI from 16 US Census variables (e.g., high poverty, low percentage of vehicle access, crowded households) (**Figure 9-3**); it is used to refer to the potential negative effects on counties caused by external stresses on human health (Box 9-3). The CDC's SVI represents the degree to which counties exhibit certain social conditions that may affect their ability to prevent human suffering and financial loss in the event of a disaster (e.g., disease outbreak or a chemical spill). Incorporating the CDC's SVI into our analyses permits decision makers to optimize ecological CO_2 removal with outsized pollution abatement potential in communities that likely need additional support or, conversely, to use caution with perceived first-of-its-kind CO_2-removal methods when they are proposed in communities that disproportionately lack the resources to respond to unforeseen events. With responsible scale-up and by keeping EEEJ principles at the forefront, CO_2 removal can become a tool for restorative environmental justice, climate resilience, long-term employment, and enhancing public health, all while combatting climate change.

Energy Equity

In the energy sector, justice considerations play a pivotal role in ensuring equitable access to renewable, clean-energy resources and addressing energy-burden disparities. Energy equity refers to who has access to sustainable, non-polluting energy sources and the potential impact on marginalized communities. It recognizes that disadvantaged groups often

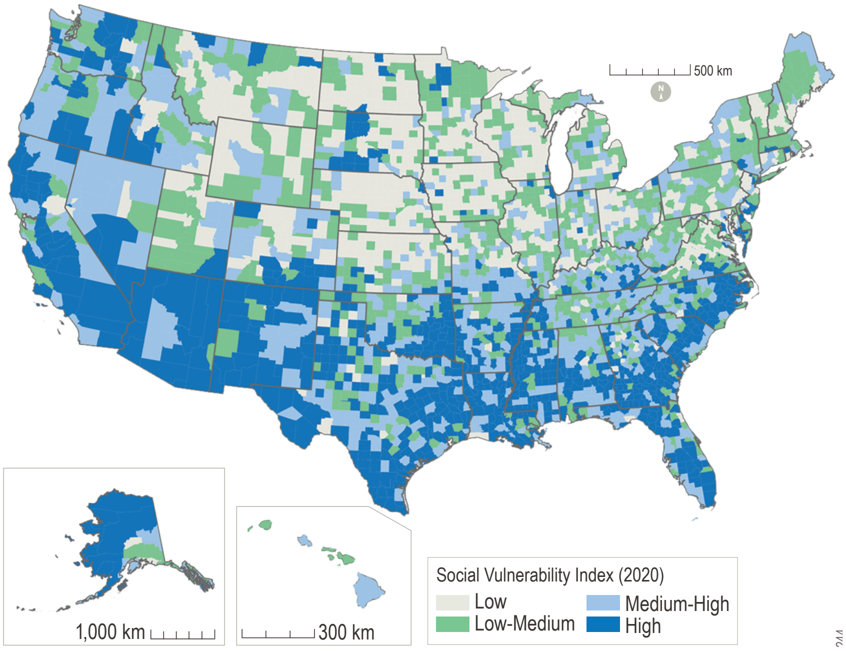


Figure 9-3. *The CDC's county-resolution 'social vulnerability index' (SVI) is constructed from 16 U.S. census variables and refers to the potential negative effects on communities caused by external stresses on human health. Examples of these variables include: population below 150% poverty, civilians with disabilities, racial and ethnic minority status, and households without vehicle access.*

face barriers to adopting renewable-energy technologies, perpetuating environmental and economic inequalities. A clear example of this energy inequity can be found in tax records for who is taking advantage of residential tax credits for solar-energy installation and electric vehicles (EVs), where the top quintile for incomes have claimed 60% and 90% of tax credits, respectively [19]. With renewable-energy programs as an example, the CO_2-removal industry could purposefully conduct equity-enhanced outreach (Box 9-2) to members of disadvantaged groups when potential benefits are available from CO_2-removal projects (e.g., land leases, jobs, and new financing programs). Energy reliability is another crucial aspect in the energy sector that intersects with justice considerations. Some CO_2-removal methods require renewable energy, adding to the broader for decarbonized power decarbonized power. For these methods (e.g. BiCRS and DACS), we directly model the necessity of additional renewable energy and purposeful avoidance of lands slated for economically optimized renewable energy deployment for the grid [20] (**Chapters 6 – BiCRS, 7 – DACS,** and **8 – Cross-Cutting**).

Beyond reliability, energy burden is a concern for communities where CO_2 removal is being proposed. Energy burden refers to the portion of household income spent on energy costs (including electricity, transportation, cooling, and heating). Energy burden disproportionately affects low-income families, who often spend a higher percentage of their income on energy expenses, leaving less money available for other essential needs. High energy burdens (up to 30%–40% in the United States) are correlated with minority and linguistic isolation status, which indicates an interdisciplinary, systemic problem beyond solely income inequities [21]. Concerns over the competition between CO_2 removal efforts and decarbonization for affordable renewable energy in counties with high energy burdens for residents reinforces the necessity for CO_2 removal to avoid competing with affordable renewable energy access. Amidst the ongoing decarbonization trends in the United States, these energy justice variables, within the context of equity and environmental justice principles, are gaining increasing emphasis and are highlighted as a topic to address in DOE's Community Benefits Plans for CO_2-removal project proposals.

In the context of DOE's EEEJ goals, equity refers to the principle of fairness and impartiality in ensuring that all individuals and communities, regardless of their background or economic status, have equal access to benefits and opportunities within the energy sector [15]. DOE is committed to addressing historical disparities and promoting social justice by creating a level playing field and breaking down barriers that hinder equitable participation in energy-related decision-making processes and resource distribution. By focusing on energy equity, DOE aims to bridge the energy gap and alleviate the disproportionate burdens that certain communities face when it comes to energy costs and accessibility. This approach seeks to foster a more inclusive and equitable energy landscape, where everyone can share in the advantages of sustainable energy practices and advancements, including CO_2 removal.

Environmental Justice

Environmental justice is the fair treatment of all people in the context of environmental issues, regardless of race, ethnicity, or socioeconomic status [11]. Environmental justice encompasses several interrelated dimensions, including procedural justice, distributive justice, recognition justice, and restorative justice.

Procedural justice refers to the fair involvement of all individuals in decision-making processes related to environmental concerns, ensuring that marginalized communities have a voice in shaping policies and projects that impact their lives. A review by Schlosberg & Collins (2014) [22] highlights the importance of procedural justice—with specific examples of citizen advocates from different neighborhoods/boroughs—in effective adaptation planning for climate-change resilience, disaster response, and rebuilding plans.

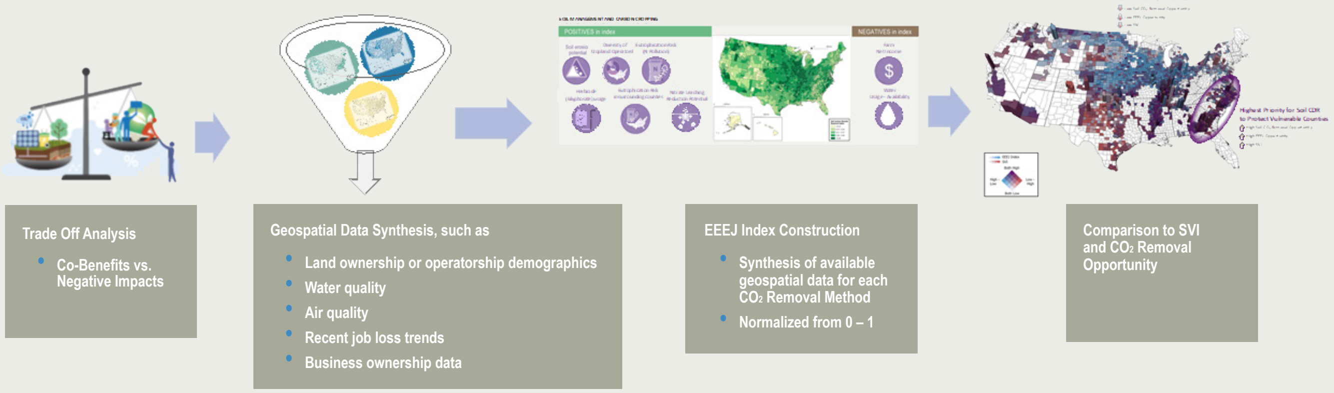
Distributive justice focuses on equitable distribution of environmental burdens and benefits, aiming to prevent vulnerable populations, who inequitably lack secondary protective measures (e.g. in-home air and water filtration), from bearing a disproportionate share of pollution and environmental hazards. For example, siting of CO_2-removal methods with an industrial presence, such as BiCRS and DACS facilities, may have distributive justice implications due to the overlap with fossil fuel communities, who bear disproportionate pollution burdens [7]. To assess whether BiCRS or DACS siting could have geophysical biases in the future, risking risking distributive injustices, we conducted we conducted a baseline assessment to answer the question "of the land area suitable for BiCRS and DACS, what percent is disadvantaged or not?" To establish this baseline, we calculated the relative abundance of viable land options for BiCRS and solar- or wind-powered DACS that are within DOE-recognized disadvantaged communities (Figure 9-2) [16].

Recognition justice focuses on identifying vulnerable groups who may be put at additional risk and recognizing past harms that they may have unduly experienced, then identifying ways for these recognized groups to be included most beneficially

BOX 9-1

Energy, Equity, and Environmental Justice (EEEJ) Index

We calculated each EEEJ Index from county-resolution variables relevant to an individual CO_2-removal method. To merge numerous socioeconomic and environmental variables into a single value that could be used for big-picture nationwide assessments, we normalized each variable's dataset (e.g., job loss trends at the county level) to a 0–1 scale before calculating an average from all the relevant variables. This average yielded the EEEJ Index value for every CO_2-removal method in each US county, where 1 represents a higher likelihood of a county experiencing co-benefits from a CO_2-removal method. This index provides an opportunity to compare with other federal indices (such as SVI; **Box 9-3**) and provide a more holistic context for people interested in CO_2 removal.



Trade Off Analysis
- Co-Benefits vs. Negative Impacts

Geospatial Data Synthesis, such as
- Land ownership or operatorship demographics
- Water quality
- Air quality
- Recent job loss trends
- Business ownership data

EEEJ Index Construction
- Synthesis of available geospatial data for each CO_2 Removal Method
- Normalized from 0 – 1

Comparison to SVI and CO_2 Removal Opportunity

Flowchart describing how we constructed our EEEJ Index for each CO_2-removal approach analyzed in this report. Trade-off table variables (with county-level data) were sourced from peer-reviewed literature or federal monitoring agencies (e.g., the Environmental Protection Agency (EPA)). We normalized data to a 0–1 scale, then calculated an average. Values closer to 1 represent counties likely to experience co-benefits and values closer to 0 represent counties less likely to experience co-benefits or that may experience negative impacts.

in planning processes. In interviews with Appalachian coal communities, who have already been hit hard by the energy transition and are expected to continue to suffer from related challenges, Carley et al., (2018) [23] found, in many cases, acceptance that an energy transition away from coal was occurring. However, frustration centered around the abrupt nature of job losses and the lack of recognition that the community's suffering received; yet the interviewees also held positive views on budding collaborations between different sectors (e.g., research, workforce, government) and the notion of recently unemployed populations designing the community's next phase and cultural identity.

Finally, ***restorative justice*** seeks to, in this context, address past environmental injustices by providing remedies and redress for affected communities. Hazrati & Heffron [24] reviewed literature relevant to restorative justice in the low-carbon energy transition and used case studies from the oil and gas industry, such as contaminated lands from spills, to show that the three tools of greatest use in achieving restorative justice are environmental impact assessments, energy financial-reserve obligations, and social license to operate. While these three tools are useful, additional studies point out that especially disadvantaged community members simply may not have the time, resources, or expertise to engage in these restorative justice tools, which suggests that funded capacity building in communities where CO_2 removal may be proposed could help increase procedural and restorative justice opportunities.

Understanding and addressing all four environmental justice dimensions in the buildout of CO_2 removal will be important in fostering a more equitable and sustainable future for all counties involved.

In this chapter, we analyze the socioeconomic and environmental trade-offs for each CO_2-removal method, reference relevant case studies, and synthesize variables of interest/concern into EEEJ Indices for each method. We present these EEEJ Indices for each CO_2-removal method in county-level resolution maps for consistency with the overall report, which we hope will allow policymakers to engage with and prioritize counties with outsized potential for co-benefits and minimal risks more efficiently. Furthermore, we compare these indices to SVI to assess any correlations, which would indicate that our EEEJ Indices bias toward inequitable siting. In some cases, such as western-forest thinning for wildfire prevention, some may opt to prioritize counties that have high EEEJ Index and SVI values as a means of protecting the most vulnerable US populations—who would be least equipped to respond—from damaging wildfires. In other cases, especially for CO_2-removal methods that are still perceived as first-of-their-kind, some may opt to focus outreach efforts on counties with high EEEJ and low SVI index values, as those communities may have the interest and capacity to engage in project planning as early technology adopters. To use these indices responsibly, however, project developers and other decision-makers should consider them as initial, big-picture overviews for the nation and recognize that all projects will inevitably come down to subcounty-level decisions, contexts, and communities with differing priorities; these indices are not a substitute for community engagement [25]. Discrete co-benefits and potential negative-impact mitigation and avoidance methods could be negotiated in advance of a project and include an enforceable framework (e.g., a community benefit agreement) to ensure benefits are realized and negative impacts are minimized.

The following sections individually review socioeconomic and environmental trade-offs for each CO_2-removal method analyzed in this report. We present data, when available, and refer to the EEEJ trade-off tables from the chapters covering individual CO_2-removal methods.

Forests

Forest management has substantial cultural significance (particularly for indigenous peoples), encompassing biodiversity, sustainability, and cultural heritage. Tribal nations visibly contribute to the diversity of woodland ownership in the United States, and recognizing their sovereign right to manage their forests is a key guardrail to any forestry-based CO_2-removal methods or recommendations discussed in this chapter (**Figure 9-4** [26]). As we consider three distinct forest-management scenarios from an EEEJ perspective, it becomes evident that impediments to realizing potential co-benefits and balancing concerns surrounding different

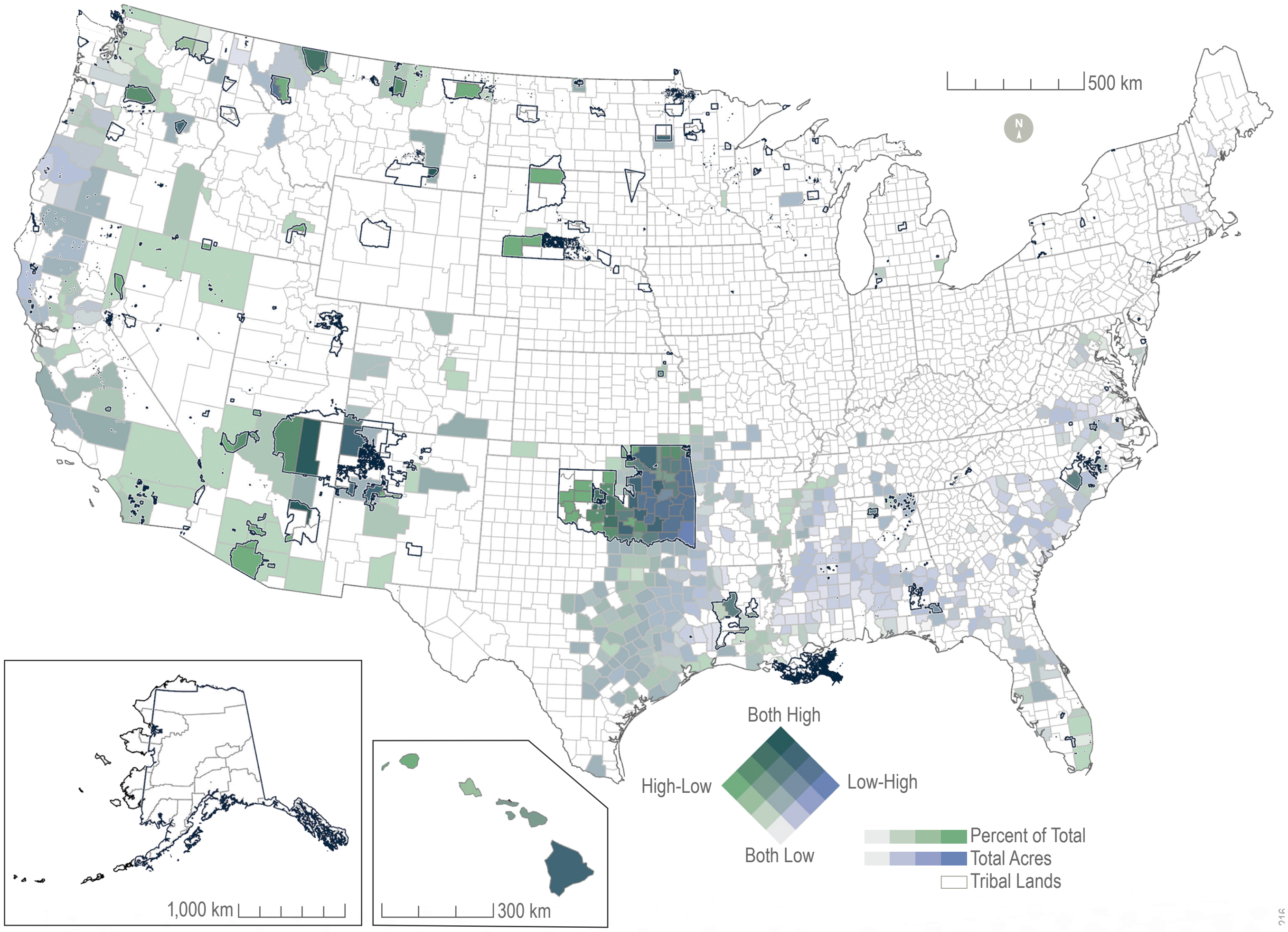


Figure 9-4. *Bivariate map of non-white woodland operator acreage (blue scale) and percentage of total woodland area non-white operatorship represents (green scale). Data are derived from the US Department of Agriculture (USDA) National Agriculture Statistics Service (NASS) 2017 Census [26].*

forest-management methods are multifaceted (**Chapter 2 – Forests**). In the Northeast region, the concept of forest-stand age and species diversification emerges as a potential solution to address disturbances caused by pests and windstorms, while simultaneously creating job opportunities in a declining forestry and logging industry. Meanwhile, in the Southeast region, reforestation efforts focused on pine plantations aim to not only restore degraded land but also to boost local economies and enhance biodiversity. Lastly, in western areas, forest-thinning initiatives are driven by the urgent need to reduce wildfire risks, which in turn could improve air quality and safeguard vulnerable communities. In contrast to the potential co-benefits that forest-based CO_2 removal may yield, several risks exist if forest-management increases are undertaken without first decarbonizing the United States economy, such as increasing diesel-derived air pollution (e.g., fine particulate air pollution (PM2.5); **Figure 9-5**) and noise pollution from equipment usage in the logging and transportation processes [27, 28]. *Premature deaths from trucking emissions are included in all EEEJ analyses in this report to balance the potential negative impacts that increasing any transportation may have on counties already overburdened by traffic-induced air-quality issues.* Conversion to EVs and electric equipment (e.g., chain saws) avoids air-pollution issues, decreases noise pollution and physical demands on workers, increases worker safety, and leads to a less intrusive forest-management experience—a key benefit for both public forest users and private forest owners, who highly value the privacy role that forests play [27-31]. By exploring these scenarios, we can begin to appreciate the importance of managing our forests holistically as a nation, considering both socioeconomic and environmental factors, and striving for sustainable solutions that benefit both ecosystems and communities.

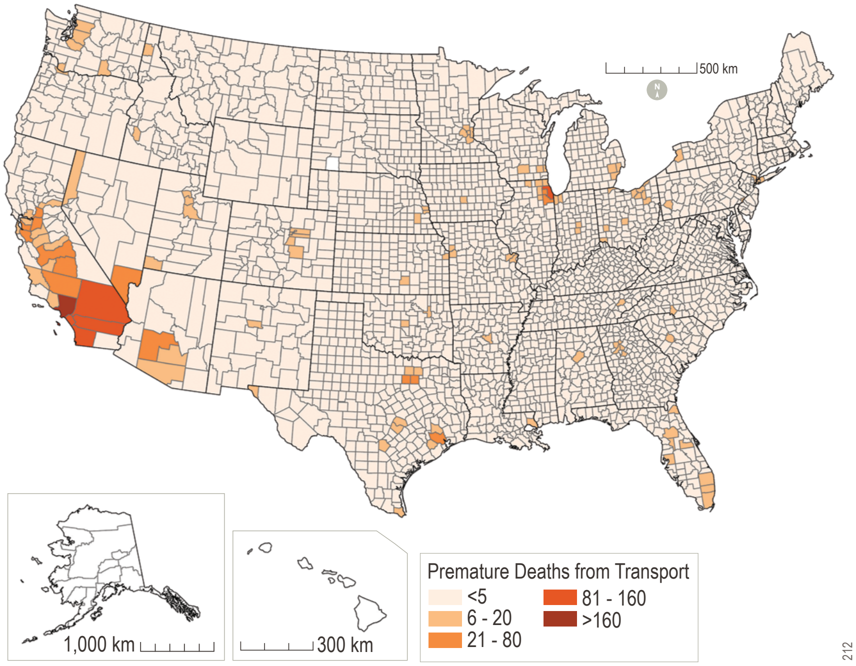


Figure 9-5. *Premature deaths that would be avoided by decarbonizing the trucking and freight sector by placing a cost on the carbon emissions. Data from Pan et al., (2019) [28].*

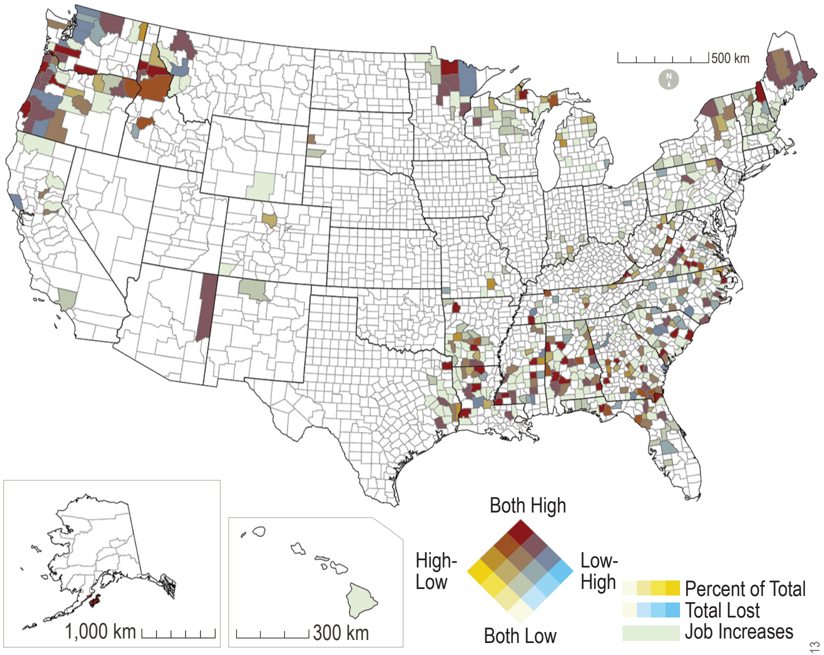


Figure 9-6. *Bivariate map of average annual job loss trends (where linear declining trends had an R2 > 0.4) in the forestry & logging sector (NAICS 113) between 2015 - 2022 (blue scale) and the percentage of total county jobs (in 2015) that those annual job losses represent (yellow scale).*

Northeastern Stand Diversification

Socioeconomic Impacts

The impacts that increased forest management may have on northeastern US communities is wide-ranging, from reemploying skilled workforces that recently lost their jobs (**Figure 9-6**; NAICS 113) to increasing energy

BOX 9-2

Equity Enhanced Outreach

Equity-enhanced outreach refers to an approach or strategy that is designed to improve fairness, justice, and inclusivity in outreach efforts. This may involve ensuring that outreach initiatives or programs intentionally consider and address disparities and inequities in access or participation. For CO_2-removal projects, it could encompass efforts to reach and engage diverse populations, considering factors such as socioeconomic status, gender, race, ethnicity, or other characteristics of the people and/or businesses being included.

independence in rural communities and instigating discussions regarding the role of ethical implications of land ownership in forest management-based CO_2-removal discussions. The forest and logging industry in the northeastern United States has experienced recent employment losses with outsized impacts on job inventory in rural counties, such as southern Maine and northern New York (Figure 9-6; [32]). These losses are predominantly due to reduced demand for timber and increasing operating costs [33], but socioeconomic dynamics are also at play, including reduced numbers of young workers interested in pursuing a career in logging [34]. Valuing the carbon-removal-and-storage benefits that forest management can yield may address some of the difficult economics of timber operations in the northeast. However, the declining workforce may present a challenge to scaling forest management for CO_2 removal as quickly as it needs to be scaled to realize climate benefits. To address this issue, the job quality of forestry and logging could be increased to attract new employees. Specifically, reducing the physically demanding nature, improving working conditions (including safety), and increasing compensation with benefits have been shown to be top priorities for workforce bolstering [34]. These recommendations are consistent with current federal guidance around a just transition of the energy sector to low-carbon options and its goals to increase both job quality and quantity in rural America through decarbonization [35, 36].

In addition to job-inventory increases, forest management in the Northeast United States may increase the supply of local wood pellets for rural communities—a renewable source of winter heating for 8%–17% of residents in the northeast [37]. While wood pellet heating is not considered a long-term energy solution, particularly with the decreasing costs and increasing prevalence of renewable-energy microgrids worldwide [38], it is an affordable, reliable and locally sourced heat option for rural northeasterners in the interim that could become even more affordable with increased forest management [37].

Most forests in the northeastern United States are privately held by families, corporations, or timber-investment management organizations [39]. This private ownership has the benefit of allowing quick action, relative to the bureaucracy that governs public forests, so there is potential for immediate climate-relevant action if a forest-management practice is decided upon. According to the most recent US Department of Agriculture (USDA) Census of Agriculture (2017) [26], aside from two counties (Androscoggin, ME and Worcester, MA), there are no records of non-white woodland operators in the northeast. However, the information in the census is only as representative as the people responding and previous research shows that non-white family forest operators are more likely to own smaller parcels and less likely to engage with federal programs [40]. As such, there is reason to believe that under-reporting could have occurred and that there are some non-white woodland operators or family forest owners in the northeast who remain unaccounted for. However, this result is consistent with the US national average, where 95% of forestlands are white-owned [40]. *Policymakers, project developers, and other decision-makers could undertake equity-enhanced outreach to give owners of smaller parcels, especially those operated by minoritized practitioners, an equitable chance to engage early in these income-generating processes for forestry-based CO_2 removal.* Large landowners will undoubtedly yield the greatest forest-management opportunities, but direct economic incentives for small landholders could have an outsized positive economic impact on historically marginalized communities if outreach is optimized for socioeconomic equity. Another example of an optimization strategy that targets equity is the prioritization of public forestlands for CO_2 removal, which can perpetuate the open-space resource they represent for residents. An exemplary area of the Northeast region that has an anomalous abundance of public forestland is upstate New York, where the state owns much of the woodland. This positions upstate New York to be a potential leader for early adoption of stand diversification in public northeastern forests.

Environmental Impacts

Increasing forest management in the northeastern United States provides opportunity to increase biodiversity in forests that currently have minimal tree diversity. Increasing biodiversity of tree species has been shown to instigate ripple effects that increase the ecosystem services of a forest, such as abundance and diversity of animals—a net benefit for recreational hunters [41]. Increasing opportunities for recreational hunting through increased forest management also provides opportunity for increased funding for conservation and restoration projects through permit revenue [42]. Furthermore, by making tree-species and-age diversity a priority, we decrease the risk of pest invasions and windstorm susceptibility, which should help preserve forests for future generations to enjoy [43, 44].

Reforestation and Afforestation with Southeastern Pine Plantations

Socioeconomic Impacts

Reforesting marginal and vacant lands with pine plantations has the potential to instigate socioeconomic changes in the southeast, such as increasing participation of minority (non-white) forest owners in forest-management programs and creating direct and indirect jobs in rural counties to support the expanded industry, thus potentially re-employing skilled workforces that recently lost their jobs. The forest and logging industry in the southeastern United States has experienced a regional decline but with individual counties experiencing gains or losses differently (**Figure 9-7**; [32]). All southeastern states (except Kentucky) have been experiencing job-loss trends from the forestry and logging sector (Figure 9-7; [32]). Relative to the total job inventory for each southeastern state, the four states that experienced the greatest employment losses from the decline in forestry and logging are Louisiana, Alabama, Mississippi, and West Virginia (Figure 9-7; [32]). These job losses are predominantly due to reduced demand for timber and increasing operating costs, but there have also been demographic shifts, specifically aging workforce and business owners, that are impacting this decline [33, 45, 46]. Interviews with young logging business owners of diverse demographics in Georgia and Florida have indicated that start-up costs, networking, and skilled labor are their biggest challenges [46].

Of the three forestry-based CO_2-removal methods examined in this chapter, the southeastern pine reforestation and logging scenario has the greatest potential to increase economic opportunities across diverse demographics due to the relative prevalence of minority-owned woodlands in the southeast (Figure 9-4 above) and the abundance of small, local- and minority-owned businesses capable of supporting the industry, both directly and indirectly ([47]; **Figures 9-8** and **9-9**; data from US Census Bureau [48]). This opportunity, however, may be more successful if it is (1) led locally by the communities that may be impacted by the increased commercial activity and (2) balanced with future land needs for community priorities. Furthermore, to make this opportunity a reality, encouraging forest owners of diverse backgrounds to become skilled leaders in the logging business, promoting logging business opportunities more broadly, and emphasizing the benefits of getting an interdisciplinary education in business and forestry industries could increase participation in the industry more broadly across the southeast and diversify forest/logging business

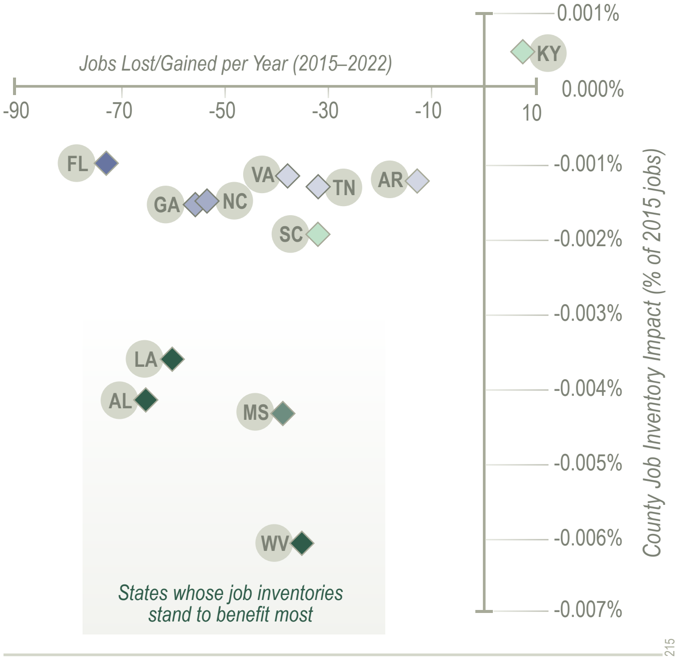


Figure 9-7. *Average annual employment trends in the forestry and logging sector (NAICS 113) in the southeastern United States. Data from the Bureau of Labor and Statistics, 2015–2022 [32]. States with outsized annual losses and a greater dependence on jobs in this sector (represented by the y-axis values) are highlighted for clarity.*

ownership. Conducting equity-enhanced outreach to diverse woodland and business owners is important because minority forest owners have historically had lower participation rates in forest-management programs—including timber harvesting—relative to their white peers, and this lower participation rate has been attributed to a lack of outreach to bring awareness of programs [40]. By not participating, however, the land may yield low to no economic returns and cause owners to sell off their forested lands to avoid negative financial consequences [40].

Equity-enhanced outreach and network building between woodland owners, logging businesses, and underemployed workforces could help pivot the southeastern United States' declining logging industry into a nation-leading minority-led and -operated forestry-based CO_2-removal hub. Given that the loblolly pine industry currently generates 110,000 jobs and ~$30 billion for the southeast United States' economy ([2] references therein), there is reason to believe that its expansion could instigate meaningful economic growth, if designed and carried out thoughtfully.

Valuing the carbon-removal benefits of increased forest management may address some of the difficult economics of timber operations in the southeastern United States, but addressing other factors contributing to the declining workforce may also help scale forest management-based CO_2 removal. Specifically, reducing the physically demanding nature, improving working conditions (including safety), and increasing compensation with benefits, as well as workforce-training program development, may restrengthen this workforce [29, 34]. These recommendations are consistent with current federal guidance around the just transition of the traditional energy sector to low-carbon options and its goals to increase both job quality and quantity in rural America through decarbonization [35, 36]

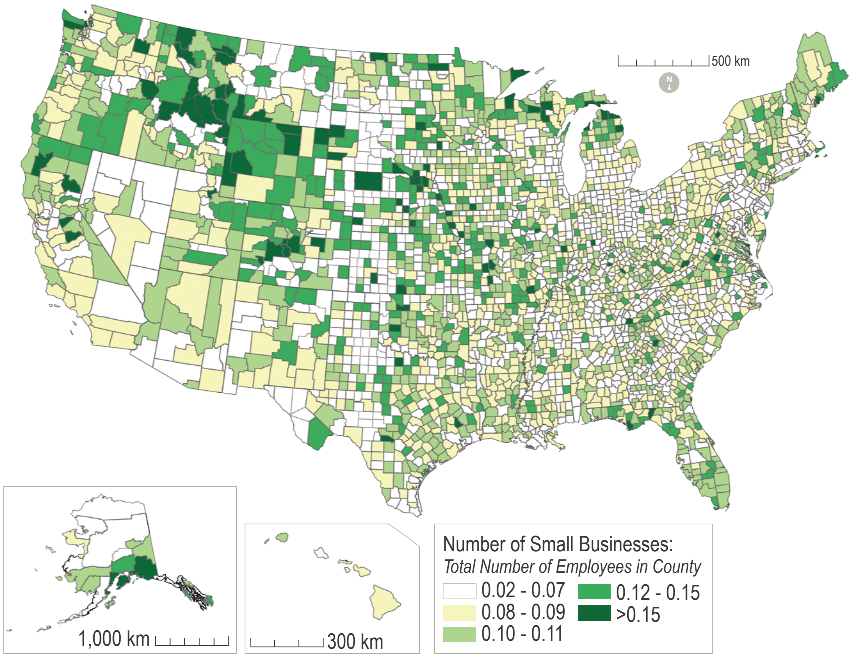


Figure 9-8. *Ratio of people employed by small (<100 employees) businesses to the total number of employed persons in the county according to the 2012 US Census Bureau's survey of US businesses [48].*

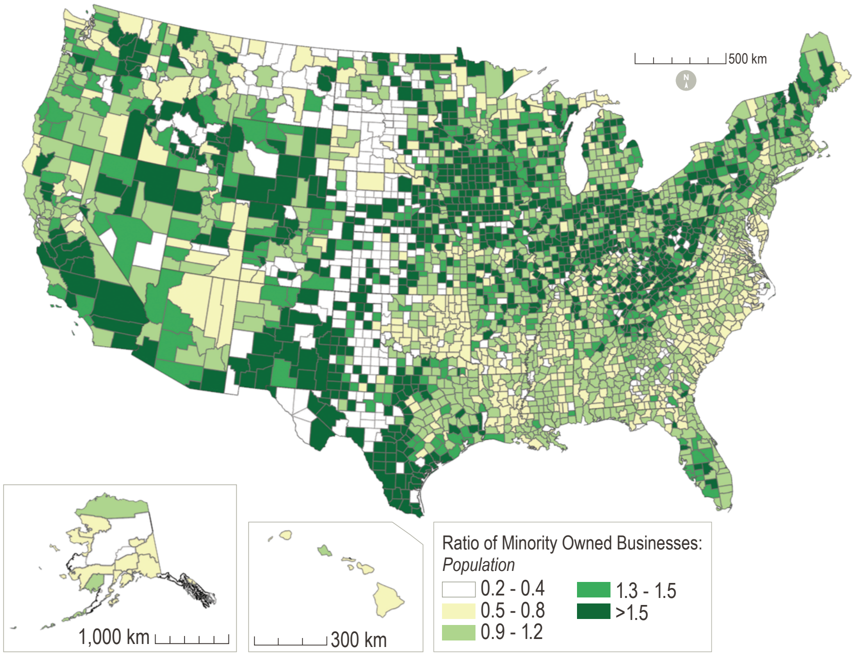


Figure 9-9. *Ratio of the percentage of businesses owned by minorities to the percentage of minority populations in each county according to 2012 US Census Bureau Business Survey data [48].*

Environmental Impacts

The baseline state of the land selected for reforestation with loblolly pine in the southeast is critical not only to its carbon negativity, but also to its environmental impacts. By exclusively reforesting vacant land in the erosion-prone southeast with pine (**Figure 9-10**, [49] based on 30 m resolution output from POLARIS model [50]), we would expect soil erosion to decline and wildlife abundance and biodiversity to increase [51]. In contrast to northeastern- and western-forest management, southeastern pine reforestation would necessitate the application of fertilizer to increase tree growth for economic viability, which has the potential to increase nutrients (e.g., nitrogen and phosphorus) in local waters. Increasing nutrient concentrations can impair water quality in a manner that poses both ecological and human-health risks [52]. Some examples of management practices that minimize these risks include avoiding regions with already impaired waters (**Figure 9-11**; [53]) or implementing the practice of 'stream management zones' (borders >15 m in width around working forests) to buffer streams from fertilizer application [54] and timing fertilizer application to avoid rain events—a typical best-management practice already being applied in the timber industry.

Fire Resilience Treatment of Western Dry Forests in the Wildland Urban Interface

Socioeconomic Impacts

Over the past five decades, the United States has employed a policy of extreme wildfire suppression, without conducting the necessary thinning to avoid such fires in the future [55]. As a result of this decades-long policy and climatic changes, large wildfires are occurring more frequently, incurring massive socioeconomic costs for counties, both locally and within smoke plumes. For example, it is estimated that California's wildfires in 2018 resulted in $28 billion in capital costs, $32 billion in health costs, and $89 billion in indirect losses [56]. Of these costs, 31% were outside of California [56]. The monetary costs, however, are not the only measure of local and out-of-state costs that

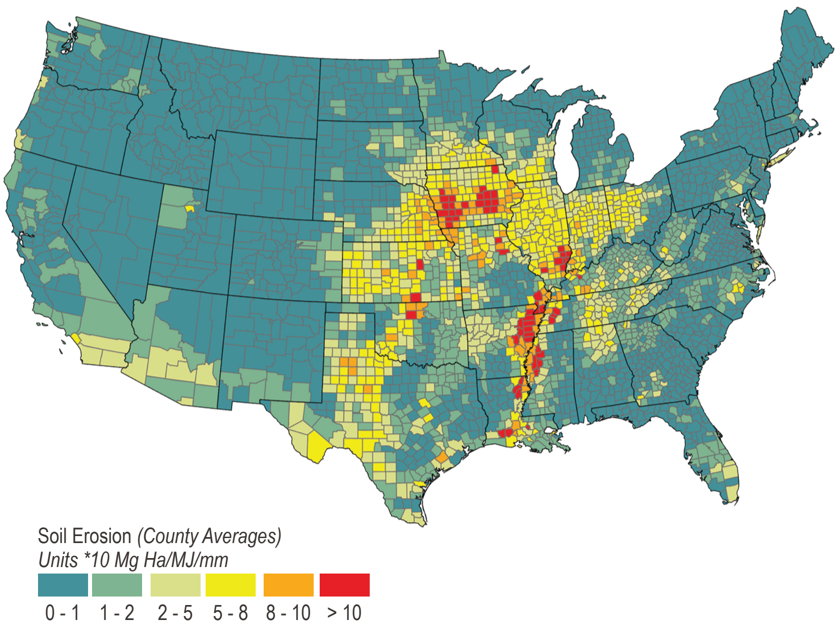


Figure 9-10. *Soil erodibility index constructed from data translated to county averages from figure S7(B) in Shojaeezadeh et al., 2022 [49] submitted (preprint), based on the POLARIS model.*

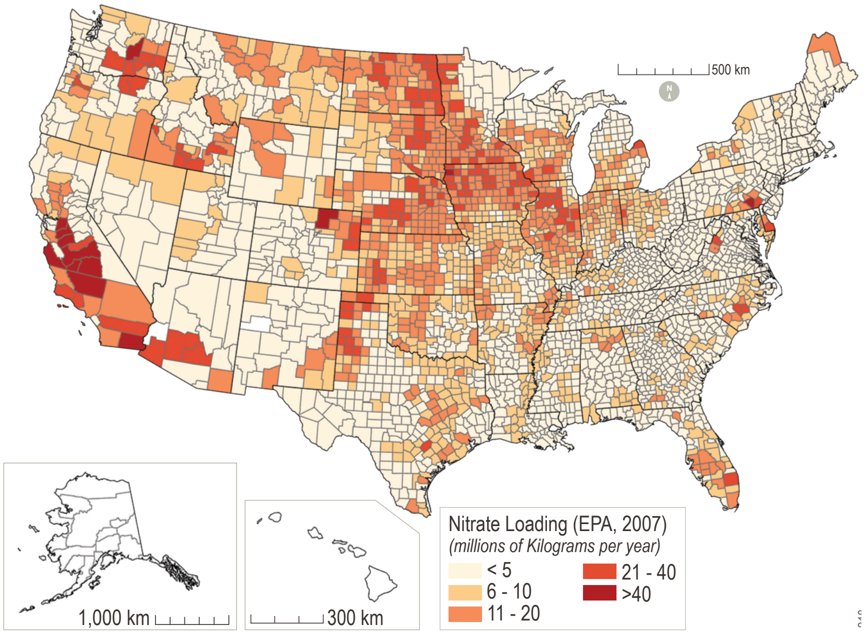


Figure 9-11. *Nitrate loading from fertilizer and manure from the EPA (2007) [53]; high nitrate values indicates that caution should be used when beginning forestry* CO_2 *removal that depends on fertilizer, due to increasing risks for eutrophication and subsequent fish kills.*

western forest fires incur. One study calculated that, from 2006–2016, wildfire smoke and its PM2.5 contributed to an estimated 1000 deaths per year in the United States, and due to the “smoke-wave” effect, it disproportionately contributed to the premature deaths of Black and Hispanic individuals in the contiguous United States and hospitalization of Native Alaskans and rural residents in Alaska with adverse health impacts (**Figure 9-12**; [57-59]).

While this report only directly investigates the carbon emissions abatement and storage potential for western forests in the contiguous United States, the US Forest Service (USFS) recently published high-resolution burn probability maps for all 50 states that depict high burn probability in central Alaska and Pacific Northwest with forecasted climatic changes, both states with outsized indigenous populations (**Figure 9-13**; [60]). *To avoid the socioeconomic, human health, and premature death tolls that will result for rural Americans, especially those from historically disadvantaged backgrounds, from increasingly more frequent and intense wildfires, swift and widespread management is in the public’s best interest.*

In part due to the broadly experienced and advertised impacts of devastating wildfires, public perception around forest management, whether that be by thinning or indigenous fire practices, is overwhelmingly positive, so there is reason to believe that public support for this widespread management will be nearly unanimous in the western United States [61]. Tackling such an immediately pressing socioeconomic and public-health crisis, however, requires a large, skilled workforce willing to work in remote conditions. Re-employing recently laid-off employees from the forestry and logging sector may be an efficient method for mobilizing this workforce (Figure 9-6). However, aside from select counties (e.g., Idaho and Clearwater counties in Idaho), there is geospatial disagreement between counties with the highest burn probability and those with the largest underemployed workforces (Figures 9-6 and 9-13). The best example of this geospatial disagreement is perhaps Oregon, which has experienced the greatest

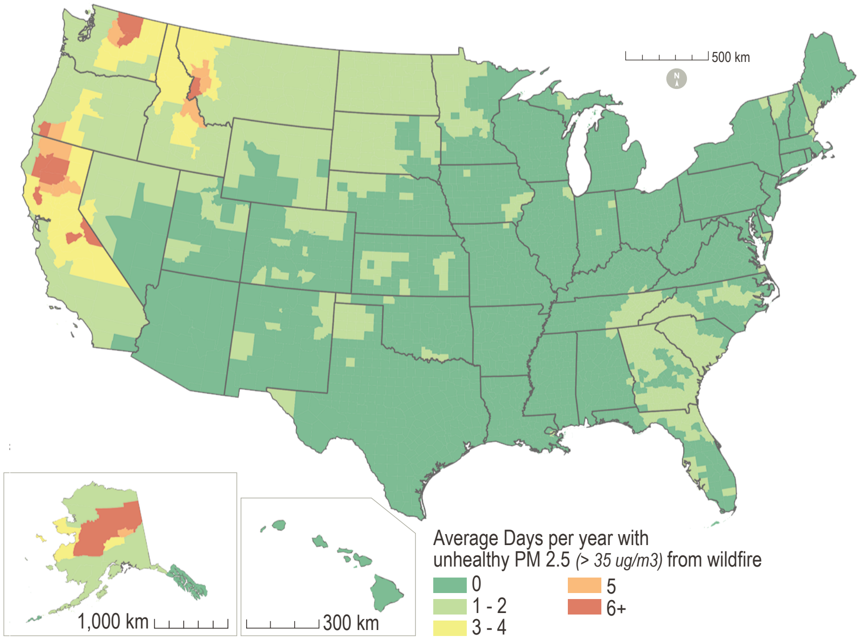


Figure 9-12. *Average days per year with unhealthy PM2.5 (>35 µg m-3) from wildfire-derived smoke, averaged by county in Ma et al., 2023 [57] and Chen et al., 2023 [59].*

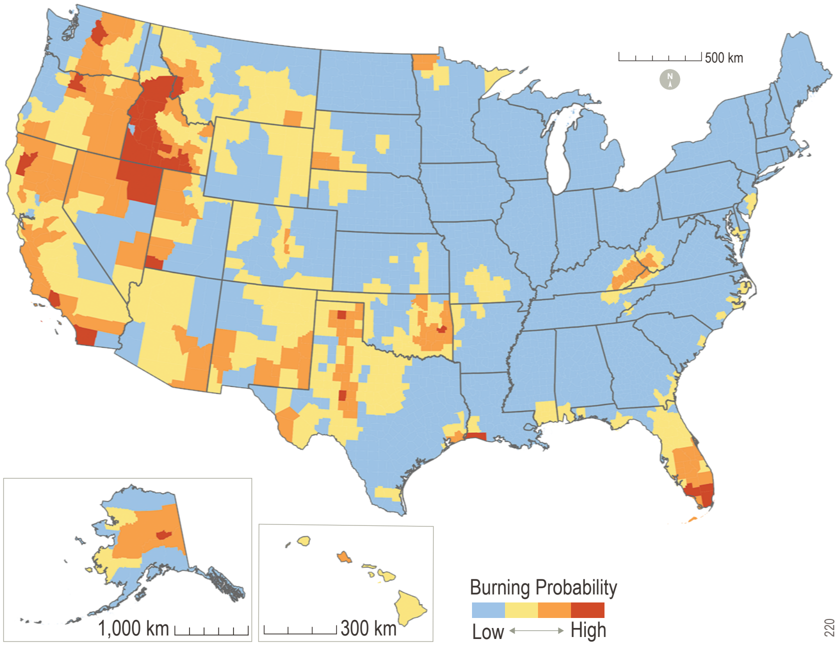


Figure 9-13. *Burn probability by 2050; modeling data from Short et al., 2016 [60].*

decline in state job inventory, by percent, from forestry and logging job losses (**Figure 9-14** [32]), but these losses are concentrated along the coastal counties, which have low burn probability, especially compared to eastern Oregon (Figure 9-13). Similarly, Kodiak Island on the south coast of Alaska has recently experienced declines in forestry and logging jobs, but the highest burn probabilities are all predicted in central Alaska (Figures 9-6 and 9-13). This geospatial incongruity suggests that either new workforces will need to be recruited and trained in counties where burn probability is high or compensation that reflects the necessary travel and/or relocation requirements needs to be enticing enough for underemployed, skilled workforces to re-engage with the forestry and logging industry in counties that are likely not their home. Counties that embark on increased forest management stand to benefit as well, since previous research has shown that, at least in California, 1.15 indirect jobs are created for every direct hire in forest management [62].

Figure 9-14. *Average annual employment trends in the Forestry and Logging sector in the southeastern United States. Data from the Bureau of Labor and Statistics, 2015–2022 [32]. States with outsized annual losses and a greater dependence on those sector jobs (represented by the y-axis values) are highlighted for clarity.*

Forest thinning for wildfire management may also benefit from recognizing and collaborating with sovereign tribal nations, whose cultural burning practices have been demonstrated to diversify forests and make them less prone to catastrophic wildfires. The forest-management techniques of tribal nations, villages, and communities already often include a combination of prescriptive fire and woody biomass collection and, in some cases—such as with the tribes of the Klamath-Siskiyou region—have been shown to reduce the risk of high-intensity fires (e.g., [63-65]). Further, combining indigenous forest-management expertise with financial resources and technological innovation has been shown to yield some innovative solutions to both wildfire risk and decarbonized, reliable, and affordable energy production. An example of such a collaboration is that between Fort Yukon Gwitchyaa Zhee Corporation and DOE's Tribal Energy Program to develop an integrated biomass energy program for Fort Yukon that replaced an antiquated diesel power plant in one of Alaska's regions with abundant excess biomass and high burn probability. Through this program, an in-village, for-profit wood harvest and delivery business was created to support a heat and power system that utilizes wood energy [66]. A complementary funder of programs such as these for repurposing excess woody biomass is the USFS annual Wood Products and Wood Energy program, which funded $43 million in projects earlier this year across the United States [67]. Through innovative programs like these, which can maximize the co-benefits of excess wood harvesting in fire-prone regions, there is the potential to address a public-health and climate-change threat crisis while decarbonizing the US economy.

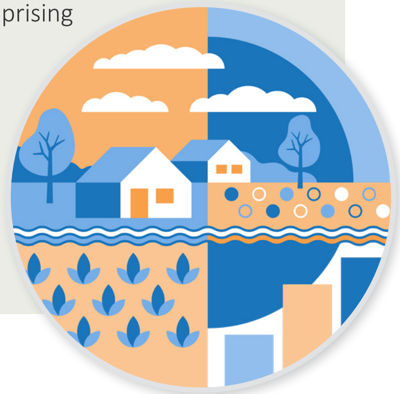
Environmental Impacts

Beyond the physical protection of people and infrastructure and the pollution-abatement potential relevant to human health (e.g., PM2.5 from wildfire smoke), additional environmental co-benefits can be realized from thinning, and for some environmental scenarios, extra care may be beneficial for avoiding unintended consequences. By thinning western forests in drought-prone or pest-prone areas, the water or disease stresses on remaining trees can be lessened, leading to more resilient forest stands and protecting public open spaces [68]. Forest managers may employ tailored management practices on soils prone to erosion (e.g., steep slopes) that minimize risks of increased short-term runoff or landslides. Best practices regarding biomass removal versus prescribed burning are often decided based on the potential to minimize negative air-quality impacts from prescribed fire smoke.

BOX 9-3

Social Vunerability Index

In this chapter, we use the Center for Disease Control (CDC)'s Social Vulnerability Index (SVI) to represent a county's capacity to engage in procedural justice, as well as context for distributive justice assessments. Then, we constructed our EEEJ indices to represent recognition and restorative justice opportunities. The SVI is a multidimensional tool that evaluates the resilience of communities in the face of external threats and emergencies. Comprising 16 variables across 4 thematic areas—socioeconomic status, household composition and disability, minority status and language, and housing and transportation—the SVI provides a comprehensive understanding of a community's vulnerability. By considering factors such as poverty, education, housing quality, and access to transportation, the SVI aims to identify counties that may be disproportionately affected during disasters or public health emergencies, helping to guide targeted interventions and resource allocation to enhance community resilience.



Forests Summary

We have created a first-of-its-kind EEEJ-optimization index that merges geospatial data on variables relevant to forest management in the northeast, southeast, and west into a single value. We used this index to identify counties that could maximally benefit from these three forest-management techniques for CO_2 removal, while also removing/storing maximal amounts of carbon. Values closer to 1 indicate an outsized opportunity for co-benefits, and values closer to 0 indicate increased likelihood for challenges that will require extra consideration (**Figures 9-15, 9-16,** and **9-17**; methods detailed in the Appendix). The interdisciplinary nature of potential co-benefits, challenges, and considerations required to avoid negative impacts make such analysis difficult, but we regard this effort as an important starting point.

In this report, we regard increasing forest management in the northeast and west as a protective CO_2 removal method; it is generally well understood and publicly supported with numerous opportunities for environmental co-benefits. To leverage forest management for CO_2 removal as a tool for restorative environmental justice, prioritizing its implementation in the most vulnerable counties of the United States could be advisable. To facilitate the identification of top priority counties within both case studies, we constructed

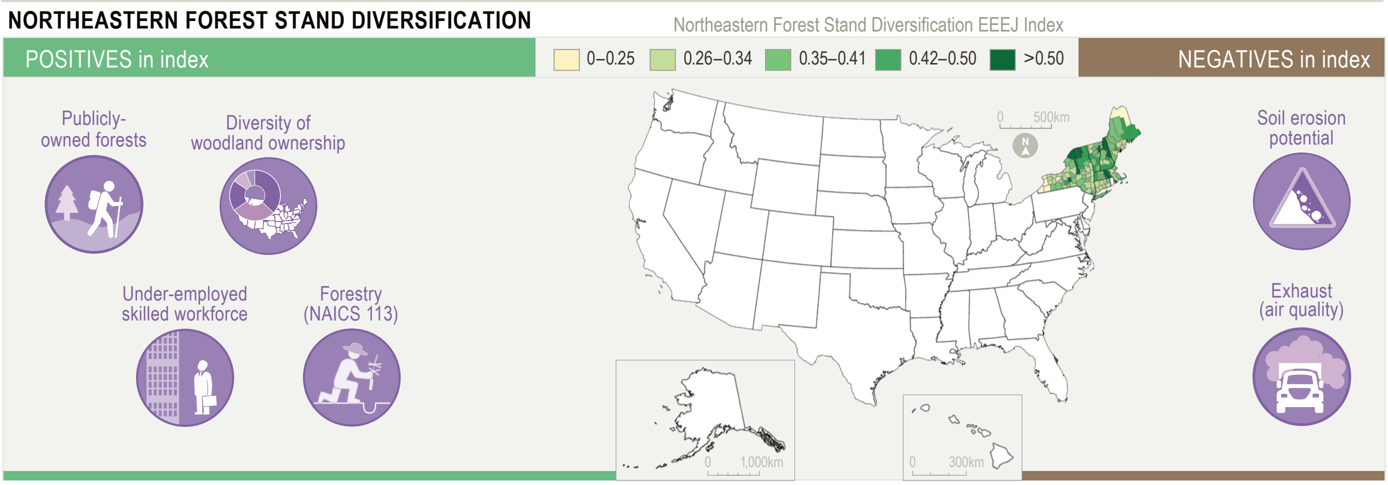


Figure 9-15. *Geographic representation of EEEJ Index values with illustrative positives and negatives in the index. Darker green represents counties with minimal risks and the highest opportunity for co-benefits, such as protecting publicly benefitting forests, while also investing in a diversity of woodland owners. Refer to Table 706 (**Chapter 2 – Forests**) for greater detail and references.*

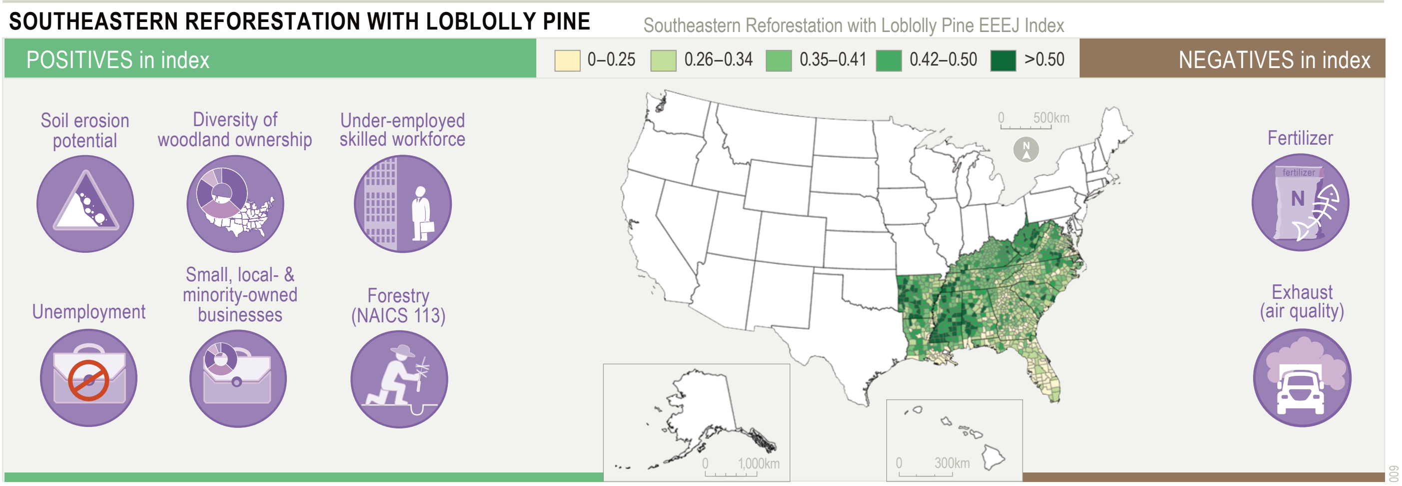


Figure 9-16. *Geographic representation of EEEJ Index values with illustrative positives and negatives in the index. Darker green represents counties with minimal risks and the highest opportunity for co-benefits, such as reemploying residents (especially those with forestry experience) and reducing soil erosion, while also uplifting small, local- and minority-owned businesses. Refer to Table 706 (Chapter 2 – Forests) for greater detail and references.*

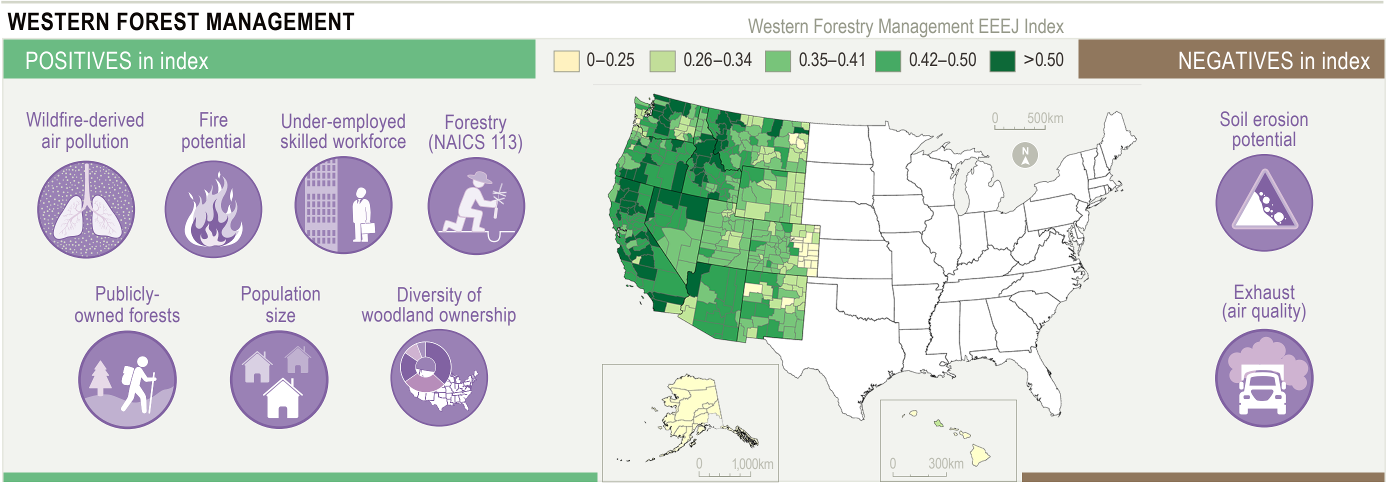


Figure 9-17. *Geographic representation of EEEJ Index values with illustrative positives and negatives in the index. Darker green represents counties with minimal risks and the highest opportunity for co-benefits, such as reducing risks to people and property, while also investing in a diversity of woodland owners. Refer to* **Table 7-6** (***Chapter 2 – Forests***) *for greater detail and references.*

3-dimensional maps that compare our EEEJ index values to SVI [69], as well as CO_2 removal potential data from this report (**Chapter 2 – Forestry**) (**Figures 9-18** and **9-19**). In contrast, we categorize afforestation and reforestation of loblolly pine in the southeastern United States as a collaborative CO_2 removal method. Pine forestation for timber may be well understood by some, but its co-benefits are predominantly socioeconomic in nature and, thus, may benefit from early, collaborative planning that ensures these co-benefits are distributed fairly across southeastern residents. To leverage Loblolly pine forestation as a tool for distributive justice, prioritizing its early adoption in counties that are less vulnerable may be advisable to ensure that there is adequate social infrastructure and bandwidth to engage in project development. To facilitate the identification of potential early adopters, we constructed a 3-dimensional map that compares our EEEJ index values to SVI [69], as well as CO_2 removal potential data from this report (**Chapter 2 – Forestry**) (**Figure 9-20**).

The forest-management scenarios of diversification, pine-plantations, and forest thinning for wildfire risk reduction demonstrate the range of potential EEEJ considerations that could be used to shape sustainable land-management practices. By reforesting erosion-prone southeastern lands with Loblolly pine, we can mitigate soil erosion and promote economic sustainability in rural southeastern counties that have a track record of effectively uplifting small, local- and

BOX 9-4

NAICS

The North American Industry Classification System (NAICS) is a standardized system used to classify businesses and industries in North America. It assigns a unique numerical code to each industry, facilitating consistent data collection and analysis across the United States, Canada, and Mexico.

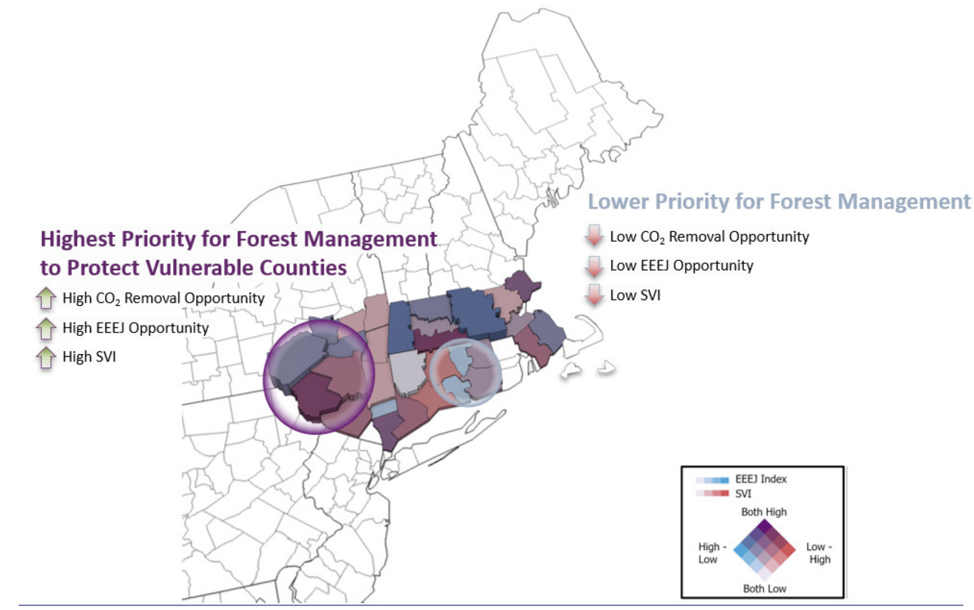


Figure 9-18. *Map of the CDC's Social Vulnerability Index (SVI) (red axis) and the EEEJ Index (blue axis) for increased forest management in the northeast. The height of the counties represents the number of forest acres in each county available for increased management, which we use as a proxy for the available CO_2 removal potential (see Chapter 2 – Forests for details). The map is annotated to reflect our premise that increased forest management to decrease risk of forest disturbances (e.g. wind storm damage) a protective CO_2 removal method. Therefore, we highlight highly vulnerable counties that are poised to especially benefit from this CO_2 removal practice as an example, as well as some less vulnerable counties, in contrast, that may be a lower priority.*

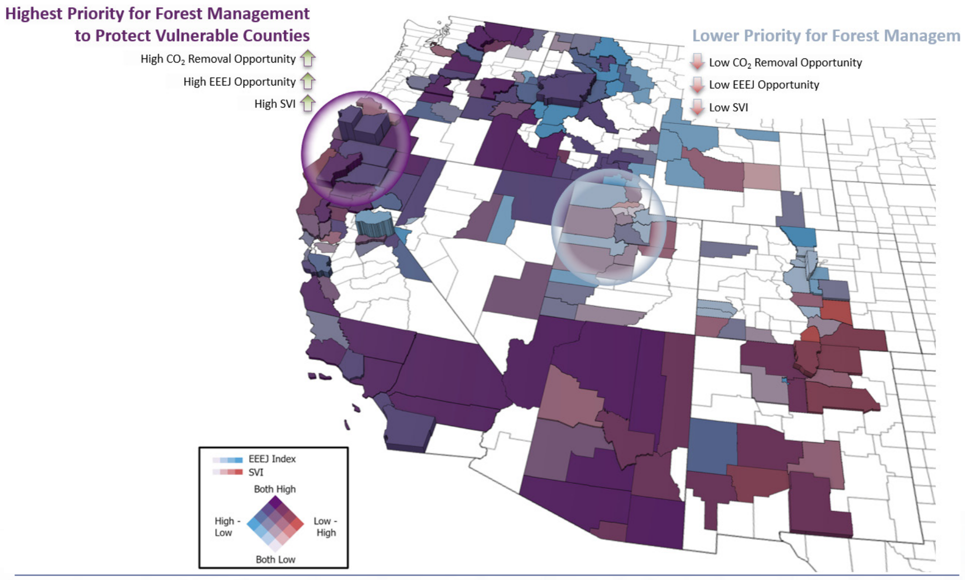


Figure 9-19. *Map of the CDC's Social Vulnerability Index (SVI) (red axis) and the EEEJ Index (blue axis), for increased forest management in the western US to reduce wildfire risk. The height of the counties represents the CO_2 removal potential (Chapter 2 – Forests). The map is annotated to reflect our premise that increased forest management is a protective CO_2 removal method. Therefore, we highlight some highly vulnerable counties that are poised to especially benefit from this CO_2 removal practice as an example, as well as some less vulnerable counties, in contrast, that may be a lower priority.*

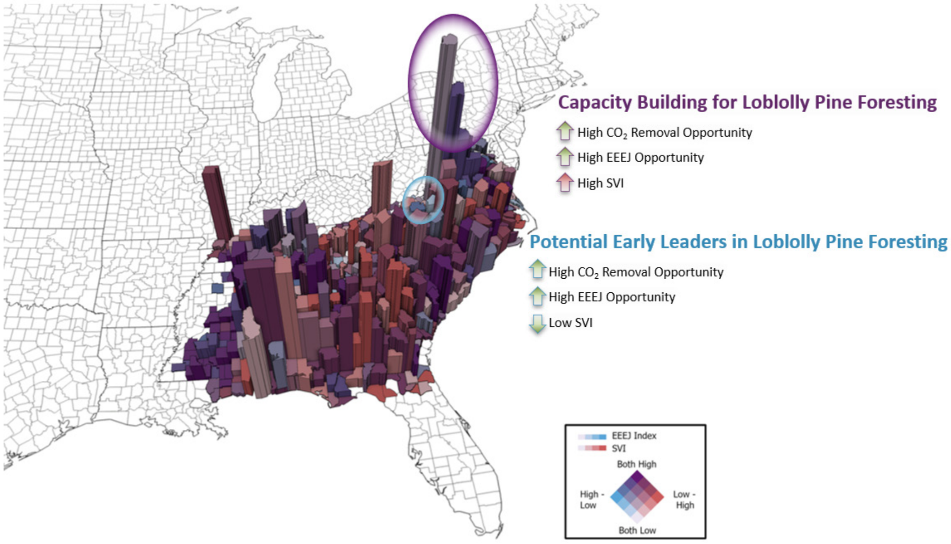


Figure 9-20. *Map of the CDC's Social Vulnerability Index (SVI) on the red axis and the EEEJ Index, calculated in this report, on the blue axis for Loblolly Pine reforestation or afforestation in the southeast. The height of the counties represents the available CO_2 removal potential (see Chapter 2 – Forests for details). The map is annotated to reflect our premise that Loblolly pine plantations are a collaborative CO_2 removal method. Therefore, we highlight some less vulnerable counties that may be equipped to collaborate on projects as early adopters, as well as some counties with high CO_2 removal opportunities, but high SVI, which suggests that they may benefit from some targeted capacity building around the topic and its trade-offs.*

minority-owned businesses. Additionally, focusing on equity-enhancing outreach to minority woodland operators nationwide ensures that the economic benefits of forest management are accessible to all. Reducing wildfire risk in the western United States not only improves air quality, particularly vital in the face of climate change, but also protects vulnerable communities and public spaces. These scenarios also have the potential to revitalize the forestry and logging sector, providing job opportunities in areas experiencing a decline in the industry. However, we must proceed with caution when it comes to transporting biomass; decarbonizing trucking or rail methods is vital to avoid exacerbating air-quality concerns for communities residing near major highways. Crucially, while forest management serves as a valuable CO_2-removal tool, we must respect the sovereign rights of tribal nations and communities to manage their forests independently, striking a balance between national objectives and local autonomy. By embracing an EEEJ and SVI-optimization perspective, we can foster sustainable forest-management practices that safeguard our environment, promote equity, and respect the diverse needs and rights of our nation's communities.

Soils

Working lands play a critical role in meeting our nation's food-security needs, while also providing longstanding economic, ecological, and social infrastructure for much of rural America. As we consider three distinct soil-management practices—cover cropping, carbon cropping, and perennial field borders—from socioeconomic and environmental perspectives, it becomes evident that realizing potential environmental co-benefits is hindered by perceived economic risks (**Chapter 3**). The co-benefits of soil-based CO_2 removal include (1) increased longevity and productivity of food-producing systems and communities by mitigating erosion, (2) creating habitat for wildlife, (3) improving water management, (4) enhancing biodiversity, and (5) reducing pollution. By conducting environmental-justice-optimized outreach to farmers in counties prone to nutrient pollution (Figure 9-11), high herbicide-application rates (**Figure 9-21;** [70]), high soil erodibility (Figure 9-10), and high social vulnerability, there is potential to decrease the environmental harms of industrial agriculture, while increasing soil-carbon storage. However, designers of a just soil-based conservation and CO_2-removal incentive structure must carefully consider how and to whom funds could be awarded.

Historically the US agricultural industry was built on injustice and inequity, including relying on enslaved farmworkers; white theft of land owned by indigenous, Black, and other people of color; and bank and crop-insurance discrimination against Black, indigenous, and farmers of color (e.g. [71]). These historic and ongoing injustices have resulted in an agricultural industry composed of more than 95% white (and majority male) land owners and 86% white land renters [72]. In contrast, more than 60% of farm laborers are people of color, the majority of whom are Hispanic [72]. To visualize the geospatial heterogeneity of minority-operated croplands in the United States, we used USDA census data from 2017 to quantify what percent and how many total acres of agricultural land was operated by non-white farmers (**Figure 9-22** on the following page; [68]). Outside of tribal nations, which represented an outsized portion of non-white operated acreage, the southeastern United States and O`ahu (Hawai`i) were some of the notable regions for simultaneously high total acreage and % of agricultural acreage (Figure 9-22). This heterogeneity of diverse farm operatorship is intended to help contextualize the issue that soil-based CO_2-removal incentives that award funds to all landowners without regard for nationwide inequities run the risk of flowing funds almost entirely to white men, further exacerbating existing structural inequalities and injustices. Instead, the *design of credit or incentive programs/policies could be crafted to support historically marginalized communities, including small, family-owned farms, which have greater diversity of ownership than larger, industrial farms*. In fact, beyond place-based outreach directly to demographically minoritized farm owners, a promising option to increase equitable participation in soil-carbon management practices is to target outreach to small, family-owned farms (gross annual income <$350,000, **Figure 9-23**; [73]). Upfront costs to implementing soil-carbon practices are especially detrimental to their participation, relative to large industrial farms, which is an equity issue because small, family-owned farms also have the greatest operator diversity of all USDA farm-size classes. This diversity in operatorship is observed in numerous categories, including gender (38% versus 24% were female), age (35% versus 23% were >65 years old), and race (5% versus 2% were non-white) [73]. Conducting equity-enhanced outreach in counties more likely to have small or financially struggling farms may also increase the likelihood of participation in soil-carbon practices if there is economic surety beyond tax rebates backing the implementation. Soil-based CO_2 removal has significant capacity for climate benefits with high restorative environmental justice potential and, crucially, can be implemented immediately. It is therefore critical to mitigate farmer risks, encourage adoption, and

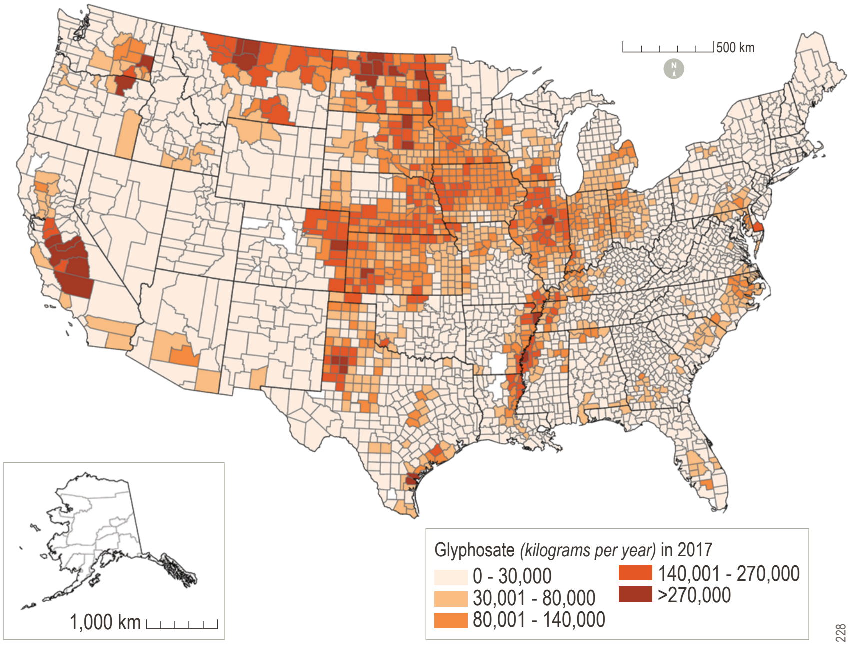


Figure 9-21. *Application rates of glyphosate (herbicide), organized by county [70].*

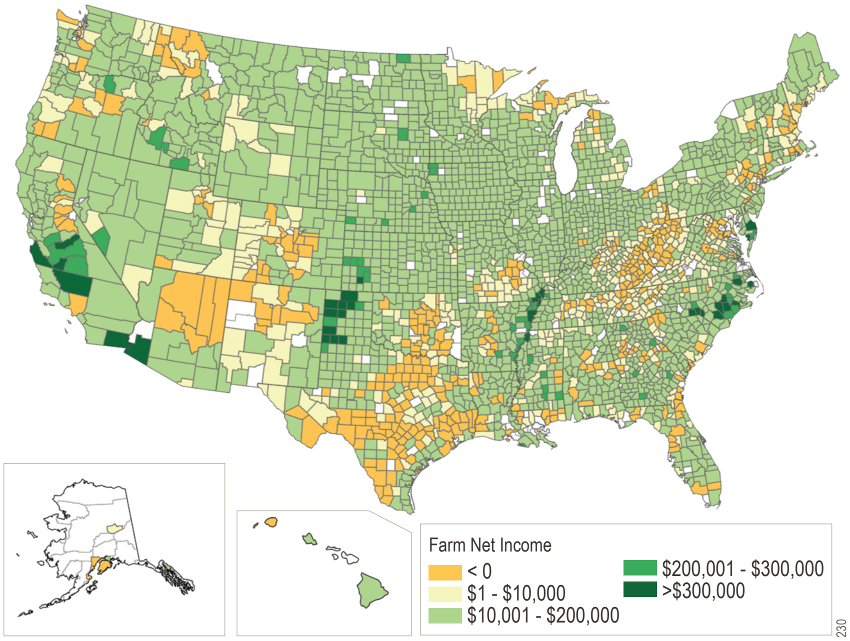


Figure 9-23. *County averages of farm net income [73]. Counties with lower net-income averages may be more likely to have small, family-owned farms or farms that are financially struggling.*

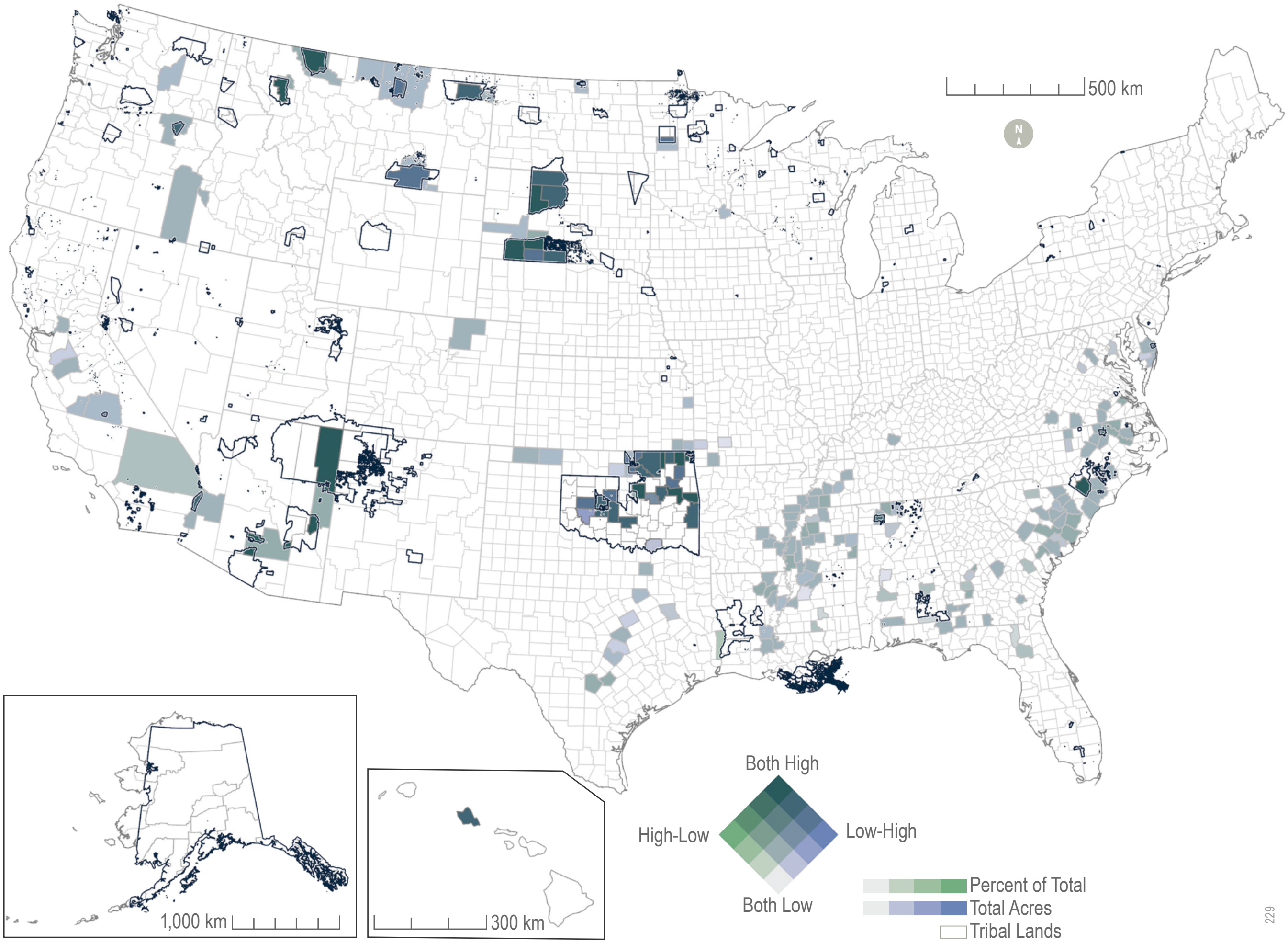


Figure 9-22. *Bivariate map of non-white cropland-operator acreage (blue scale) and percentage of total cropland area that non-white operatorship represents (green scale). Data are derived from the USDA NASSS 2017 Census [68]. Tribal nation boundaries are included to highlight lands of tribal sovereignty, which will supersede US federal soil-carbon policies.*

increase persistence in soil-based CO_2-removal practices, while maintaining a focus on both socioeconomic and environmental implications.

Cover Cropping

Socioeconomic Impacts

The socioeconomic impacts that cover cropping can have on a farm may include upfront costs for cover-crop seeds, decreased irrigation and herbicide costs, and income-stream diversification. This income stream diversification is derived from the sale of the cover crop directly. Methods for implementation can be tailored to maximize co-benefits of cover cropping to the individual farmer's needs. For example, if a farm is experiencing variable wet and dry weather year-over-year that is causing harmful soil-moisture swings for the primary crop, then cover cropping with a winter rye may be an ideal option since it has been shown to increase topsoil water storage by 10%–11% and plant-available water by 21%–22% with continuous annual planting [74]. However, if weed intrusion and consequential herbicide expenses are a pressing issue for a farm, then a farmer might opt for a high-biomass, wide-leaf morphology cover crop (e.g., buckwheat, pearl millet, or cereal rye) to quickly maximize weed suppression over the field (e.g. [75]). Farmers are almost always aware of the potential co-benefits and economic opportunities that cover cropping can yield; however, farmers regularly point to the upfront economic costs, paired with uncertainty in crop insurance and market forces, as preventing their participation (e.g., [76, 77]). In 2007, resultant from a survey of 3500 corn-belt farmers, the majority (56%) reported a willingness to cover crop, but only if cost-sharing were an option; from this survey, mean minimum economic assistance of $23 per acre was calculated [76]. In a farmer survey from 2019, the annual cost of cover cropping ranged from $15–$78 per acre, but the median cost was $37 per acre; in this survey, a mean minimum economic assistance of ~$28 was reported [78]. Based on the results of these combined surveys, an economic assistance between $20 – 30 per acre, or ~2/3 of the median price per acre, may increase cover cropping participation in the United States. Regardless of how cost sharing, incentives, or risk-mitigation structures are designed, reducing economic risk for farmers will likely yield an increased cover-crop adoption rate, benefitting US farming regions by increasing long-term resilience of food-producing lands for generations.

Environmental Impacts

Increasing adoption of cover-crop practices across the United States could result in a sizable reduction of both excess nutrient loading to local water resources and erosion (by wind or water), while also potentially reducing herbicide leaching, especially if herbicide application to terminate the cover crop is avoided. While nutrient runoff in small quantities can be beneficial for plant and aquatic life, too much (which is a chronic problem throughout much of the agricultural United States) can lead to algal blooms, collapsed fisheries, and negative human health for those who rely on local resources for drinking water (e.g., Wurtsbaugh et al., 2020 and references therein [79, 80]). This over-abundance of nutrients (nitrogen and phosphorous) in water bodies is referred to as eutrophication. For maximal nutrient-runoff mitigation co-benefits that combats eutrophication, it is recommended that sandier soils (e.g., ultisols, histosols, and inceptosols) be prioritized with carbon crops from the Brassicaceae and Poeceae families, which can decrease nitrate runoff by ~77% in corn-soy agricultural field trials [81]. Furthermore, this prioritization could result in maximal public health benefits, as high nitrate concentration (>10 mg/L) is deleterious to human health [82]. Reduction in soil erosion from cover cropping will also improve local water visibility and conserve productive croplands for future generations. Herbicide applications, however, are the environmental impact from cover cropping that is quite variable and up to a farmer's individual preference. Specifically, the decision to use herbicide to terminate the cover crop before spring planting, a common practice amongst midwestern farmers in the United States [83], could result in increased herbicide pollution in local waters. Herbicide pollution, such as that from glyphosate application for cover-crop termination, can have negative environmental and human-health implications if not managed carefully in a watershed [84]. To avoid this potential negative impact, programs for farmers could include recommendations or incentives for planting cover crops that reduce weed growth and for implementing alternative practices for cover-crop termination [75]. This decision would, ideally, be guided by geographic context for herbicide applications, currently prioritizing their reduction in counties already overburdened (Figure 9-21).

Carbon Cropping

Socioeconomic Impacts

Cropland retirement can be instigated by a variety of factors (e.g., water shortages, pest infestations, water quality concerns, economic forces, declining crop yields). However, converting croplands that would otherwise be retired into carbon-cropping farms offers vast potential for perpetuating farming in counties where it otherwise might not be viable, while also remediating environmental pollution concerns for local and downstream residents. Forecasting out to 2080, it is clear that some irrigated cropland will have to be retired due to over-drafting of groundwater supplies [85]. In many drought-prone states of the western United States (e.g., California), this is already occurring. Furthermore, farms on sub-prime agricultural land growing corn for ethanol production for passenger vehicles are facing an uncertain future as vehicle electrification becomes more popular (**Chapter 3 – Soils**). These environmental and economic headwinds may push cropland owners and farm operators to choose between leaving the land fallow/vacant (an economic loss), developing the land (an economic gain, but may conflict with farmland-owner ethos), or planting deep-rooted native grasses as a carbon crop (an economic substitute of uncertain magnitude). Assuming there is future economic value for purposeful carbon cropping on these lands, this last approach could maintain an income stream for farmers, while also maintaining the inherent value of open space. In counties where property and income taxes from farming operations compose a sizable portion of their tax base, this practice may be especially appealing for keeping public funding for local services. Areas ideal for carbon cropping include the Midwest, which has both white and tribal-nation-owned agricultural lands, and the southeast, which has a particularly high rate of Black-owned farms (Figure 9-22) [72]. This geospatial diversity of economically viable land presents an opportunity to potentially uplift all these communities if equity-enhanced outreach and collaboration is conducted with local farmland owners/operators.

Environmental Impacts

Nearly all the environmental impacts of carbon cropping in agricultural lands are positive, as it is essentially returning former grasslands to their original state, with a caveat of annual or less-than annual harvesting of only the above-ground biomass and, in some cases, reduced species diversity. Switching commercial agricultural fields to native perennials will reduce erosion (by wind and water) [86], increase biodiversity and wildlife abundance [87], and reduce nutrient, herbicide, and pesticide pollution to local waters [88]. The sole negative environmental impact would likely be air pollution emissions (e.g., $PM_{2.5}$) from off-road harvesting equipment, which can be avoided by opting for zero-emission vehicles/machinery. If the carbon negativity of the practice is being valued, then those external economic incentives for the net carbon negativity, including harvesting, would incentivize zero-emission vehicles in the first place. However, beyond the annual harvest, opting to transition some portion of the nation's least productive croplands in counties currently shouldering an inequitable water-pollution burden may also assist with agricultural resiliency amidst climatic changes, such as drought, that can increase eutrophication risks.

Perennial Field Borders

Socioeconomic Impacts

Compared to cover cropping and carbon cropping, perennial field borders may have the greatest potential for job creation due to upfront educational needs, design and implementation costs, and continued maintenance. Therefore, prioritizing this practice in regions where agricultural jobs are being lost could help re-employ some of the skilled, underemployed workforces locally (**Figure 9-24** [32]. Furthermore, prioritizing equity-enhanced outreach, such as to small, family-owned farms, may reduce the potential risk of these soil-carbon-practice benefits flowing disproportionately to large, industrial farms, whose ownership is less diverse than small, family-owned farms.

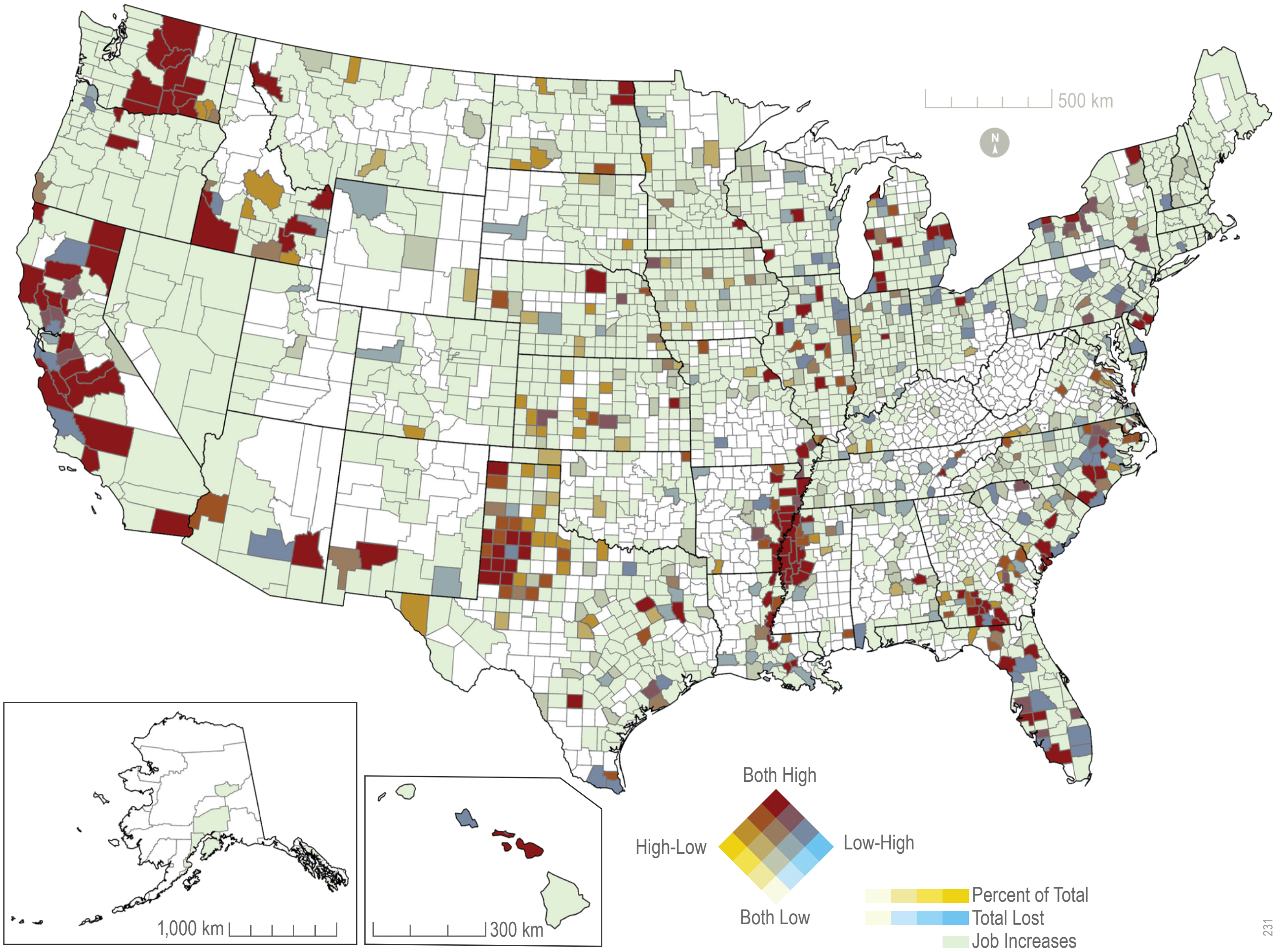


Figure 9-24. *Bivariate map of average annual job-loss trends (where linear declining trends had an R2 > 0.4) in the crop-production sector (NAICS Industry Code 111 – Cropland) between 2015 and 2022 (blue scale) and the percentage of total county jobs (in 2015) that those annual job losses represented (yellow scale). Data from US Bureau of Labor and Statistics [32].*

Environmental Impacts

Properly installed and maintained perennial field borders (often referred to as conservation buffers) are predominantly useful for reducing negative environmental impacts of large-scale agriculture on surrounding areas, in similar ways to the aforementioned cover cropping and carbon cropping practices. However, *a key benefit that perennial field borders have over the other practices is their outsized potential—due to purposeful design—to increase wildlife abundance and biodiversity* (e.g., [89]). More detailed case-study data from perennial border studies can be found in **Table 3-4, Chapter 3 – Soils.**

Soils Summary

We have created a first-of-its-kind EEEJ optimization index that merges geospatial data on variables relevant to soil-management techniques for CO_2 removal (e.g., nutrient loading, soil erodibility, diverse farm operatorship, farm net incomes, etc.) into a single index value to identify counties that could maximally benefit from these soil-management methods, while also removing/storing maximal amounts of carbon (**Figure 9-25**; methods detailed in **Appendix 9**). In this report, we regard these soil carbon management practices as protective CO_2 removal methods; they are generally well understood and publicly supported with numerous opportunities for environmental co-benefits. To leverage soil carbon management for CO_2 removal as a tool for restorative environmental justice, prioritizing its implementation in the most vulnerable counties of the United States could be advisable. To facilitate the identification of top priority counties within both case studies, we constructed a 3-dimensional map that compares our EEEJ index values to SVI [69], as well as CO_2 removal potential data from this report (**Chapter 3 – Soils**) (**Figure 9-26**).

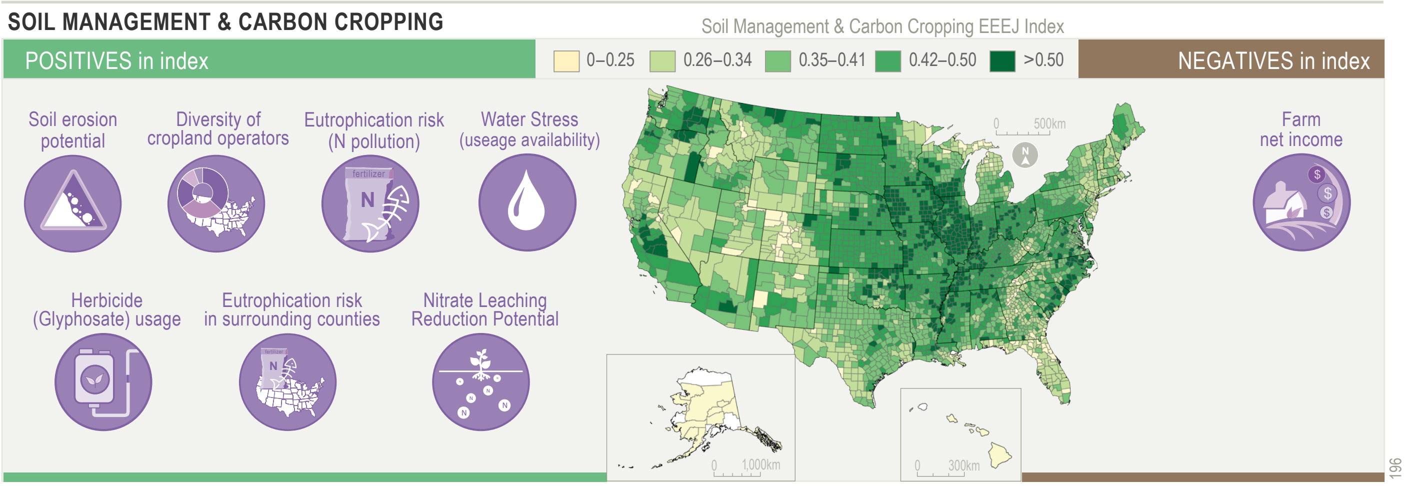


Figure 9-25. *Geographic representation of EEEJ Index values, with illustrative positives and negatives in the index. Darker green represents counties with minimal risks and the highest opportunity for co-benefits, such as reducing water pollution and soil erosion, while also investing in a diversity of woodland owners. Refer to Table 745 (**Chapter 3 – Soils**) for greater detail and references.*

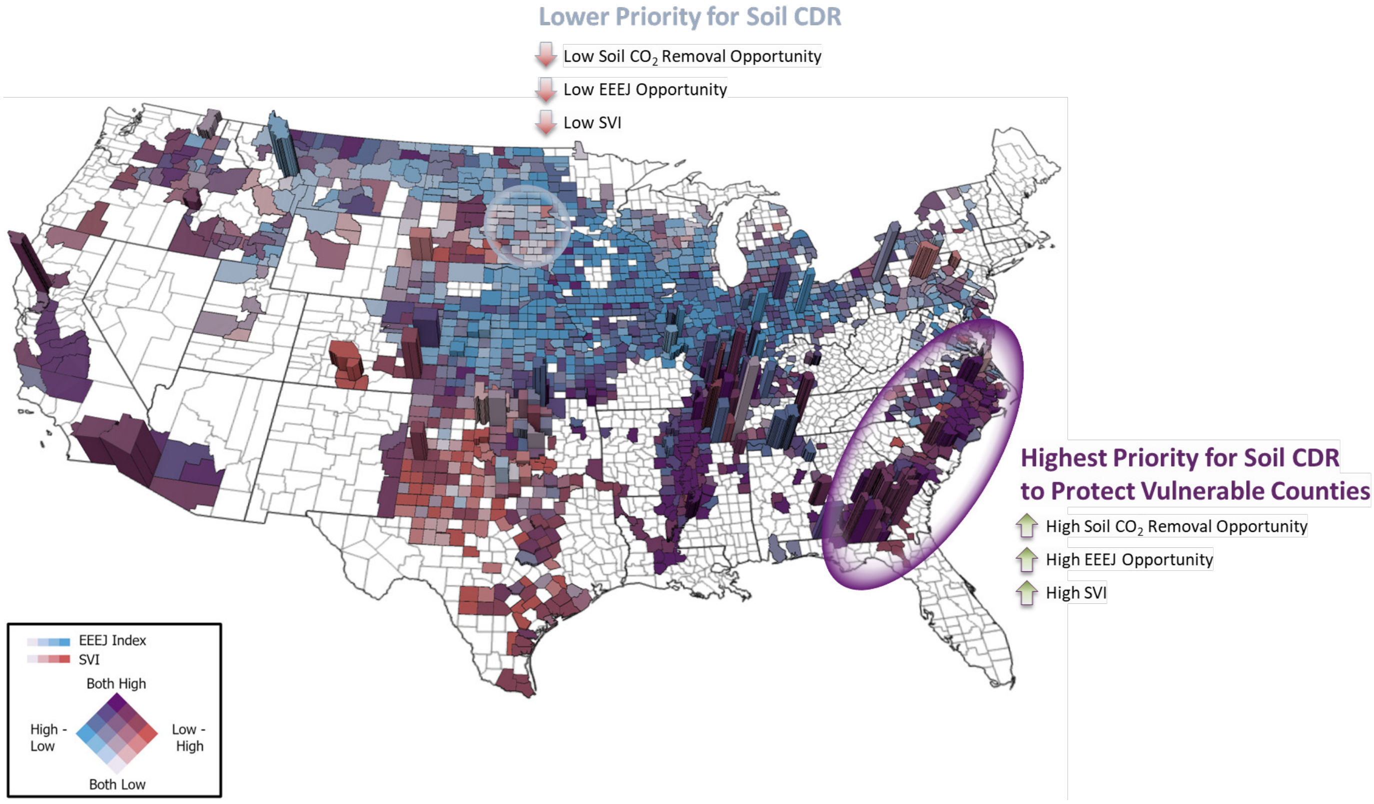


Figure 9-26. *Map of the CDC's Social Vulnerability Index (SVI) (red axis) and the EEEJ Index (blue axis) for soil carbon management practices in the United States. The height of the counties represents the cumulative CO_2 removal potential, per acre, by county in 2050 with all soil carbon practices (see Chapter 3 – Soils for details). The map is annotated to reflect our premise that soil carbon management is a collaborative CO_2 removal method. Therefore, we highlight some exemplary, highly vulnerable counties that are poised to especially benefit from this CO_2 removal practice, as well as some less vulnerable counties, in contrast, that may be a lower priority, since residents in these counties may have greater access to secondary protective measures, such as water filtration or nearby medical care.*

Geologic Carbon Storage

The rock formations and geologic basins suitable for geologic carbon storage overlap significantly with the rocks and basins from which oil, gas, and coal are produced. Energy communities, defined as communities associated with, predominantly, fossil-fuel-based energy production, consequently, also overlap with prime geology for carbon storage. This overlap is exemplified in **Figure 9-27**, which overlays geologic carbon storage injection sites atop White House-designated energy communities [90]. Energy communities have played and continue to play a critical role in our nation's prosperity, providing necessary energy for economic and societal benefits, but in some cases accompanied by environmental and human health impacts (Figure 9-27). Fossil-fuel production can create disproportionate pollution burdens for nearby communities, often impacting already disadvantaged populations [91-93]. At the same time, the transition away from carbon-intensive fossil fuels is resulting in job losses and decreases to state and local revenues from fossil-fuel-producing regions [49, 94]. Geologic storage may also take place in communities with no previous experience with energy or infrastructure projects. As we consider what a reimagined geologic carbon-storage industry could look like from an EEEJ perspective, it becomes evident that projects must go beyond "do no harm" to also provide early and ongoing opportunities for community engagement around designation and distribution of project benefits (**Chapter 4 – Geologic Storage**).

Socioeconomic Impacts

Geologic carbon-storage projects can have a wide range of potential co-benefits, including direct and indirect jobs; improved infrastructure; and new sources of revenue for landowners, state and local governments, and others. Care must be taken to ensure realization and equitable distribution of these benefits. Many regions around the United States have underemployed, skilled workforces with expertise applicable to geologic carbon storage; optimizing projects that reverse job-loss trends in regions especially dependent

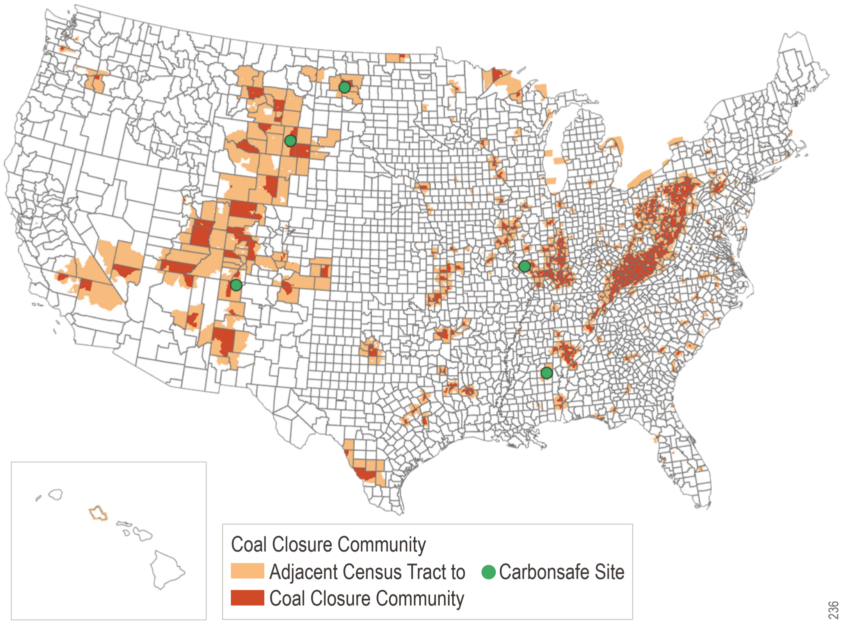


Figure 9-27. *White-House-designated energy communities, where coal mines/power plants have either closed (dark orange) or are adjacent to a closure (light orange). Tax incentives exist to recruit new businesses that create long-term quality jobs to these counties. Phase III sites for the DOE's Carbon Storage Assurance Facility Enterprise (CarbonSAFE) initiative are overlain to illustrate the geospatial similarities behind geologic carbon storage and traditional energy communities, such as coal.*

on traditional energy industries may have outsized economic benefits, especially with local hiring commitments and living-wage compensation (**Figure 9-28**) [4-6, 95-98]. DOE estimates that the cumulative employment needed to build out a 2 billion ton per year carbon-capture-and-storage economy by 2050 will range from about 390,000 to 1.8 million people across the full carbon-capture-and-storage supply chain [96]. In addition to direct and indirect jobs, local landowners can receive compensation for hosting geologic storage projects beneath their land [99]. However, as discussed previously in the forest and soils sections, land ownership is inequitably distributed in the United States. If optimizing for maximal equity in economic benefits flowing from geologic carbon-storage projects, then assessing what percentage of land in each county is publicly (versus privately) owned could help guide democratized pore-space opportunities, **(Box 9-6)** where revenues would be shared through lease agreements that benefit a tax base (e.g., federal, state, county, or tribal nation) (**Figure 9-29**; [100]). Geologic storage projects may necessitate development of new infrastructure that can be designed to maximally benefit the community, such as new roads, broadband internet access, water, or electricity infrastructure, which are currently not equally distributed in the United States (**Figure 9-30**). Counties and communities can negotiate with project developers regarding infrastructure build-out to identify points for improvement that have the greatest shared benefit, including an initial regional assessment of infrastructure deficiencies [101-104].

To ensure that all members of the community receive benefits, not just those who are directly involved with a project, communities may also negotiate with project developers for a broad community-benefit fund, with a designated portion of project revenue going to support projects or causes important to the community [105]. Another example of a potential wealth-building mechanism for the local county is equity-enhanced subcontracting, giving small, local, and minority-owned businesses bidding priority on subcontracts awarded that support the project. Counties across the United States have varying abundances of minority-owned business that could be uplifted through carbon-management projects involving geologic carbon storage (**Figures 9-8 and 9-9**). By working with counties that have a promising track record of supporting a healthy ecosystem of small, local- and diverse businesses, there may be greater opportunity for local wealth generation as a product of the storage project, especially in the construction phase. Some communities may also wish to publicly signal their commitment to carbon management and value being an early adopter and leader in geologic carbon storage [106].

Realization of these benefits, however, could be impeded by community hesitancy or distrust. Research shows that perceptions and acceptance of carbon-management projects are influenced by many factors, including past experiences with energy or infrastructure projects, whether positive or negative; the perceived balance of risks versus benefits; the perceived trustworthiness of project stakeholders; the perceived need for the facility; and many others [107, 108]. Although dozens of geologic CO_2-storage projects exist worldwide and have in some cases been operating for decades, few communities have direct experience with such projects. One national study [109], which surveyed 126 people, found consistent responses from participants saying they believed CO_2 stored in geologic reservoirs would leak out, eventually worsening climate change anyway.

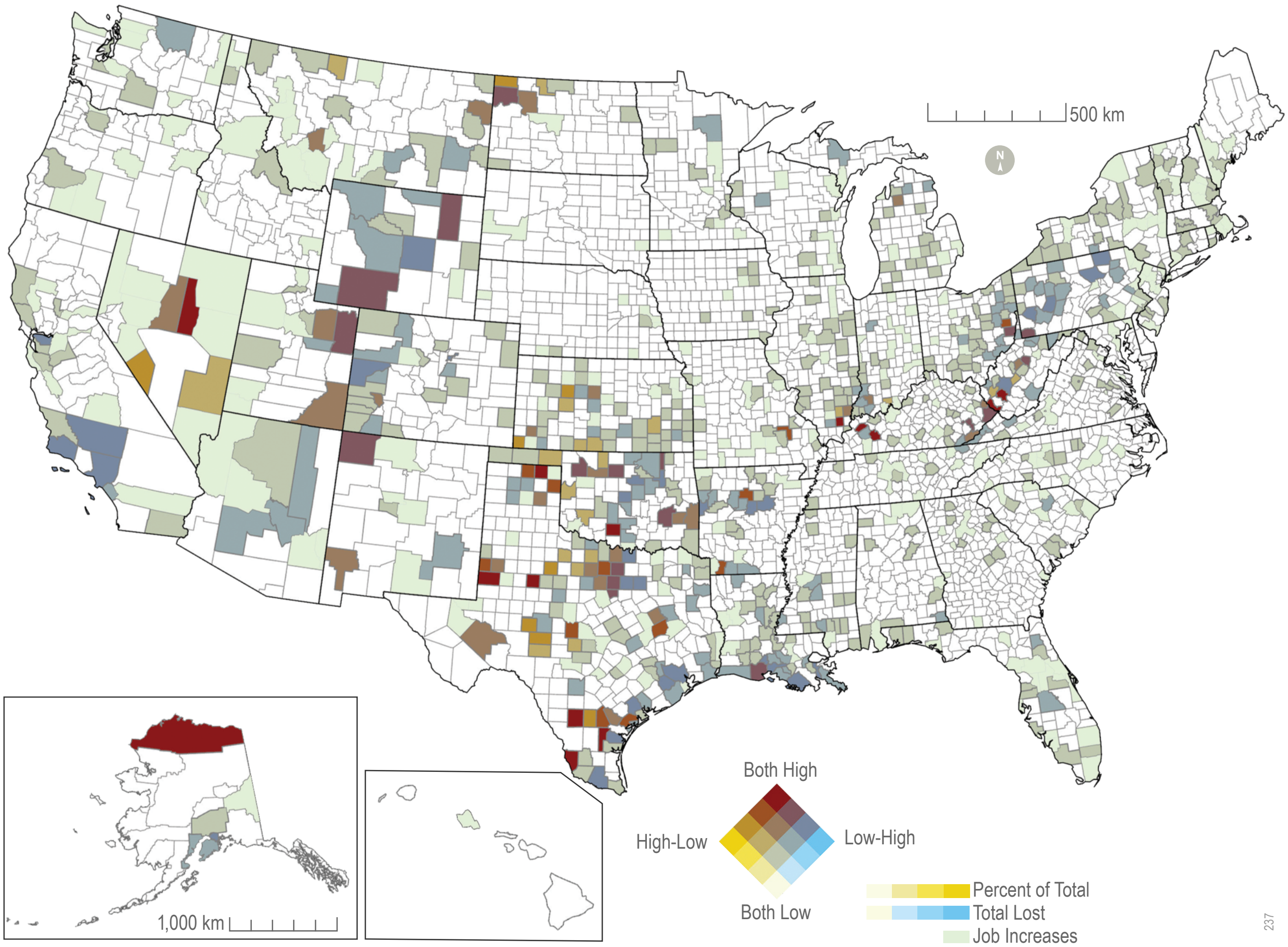


Figure 9-28. *Bivariate map of average annual job-loss trends (where linear declining trends had an R2 > 0.4) in the mining, oil, and gas sector, often dubbed the fossil-fuel sector (NAICS Industry Code 21 – Oil and Gas) between 2015–2022 (red scale) and the percentage of total county jobs (in 2015) that those annual job-loss trends represent (blue scale) [4-6, 95-98].*

BOX 9-5

Eutrophication

Eutrophication is the enrichment of a water body with nutrients, mainly nitrogen and phosphorus, leading to excessive growth of algae and aquatic plants. This process can result in oxygen depletion, negatively impacting the ecosystem by causing dead zones and harming aquatic life.

To counteract this prevalent belief, broad and accessible community engagement through trusted messengers may help build trust, reduce hesitancy around geologic storage projects, and ensure benefits are realized [101-104].

Environmental Impacts

Geologic carbon storage projects are a critical enabling technology for carbon capture and removal and are, therefore, an important component to avoiding some of the worst environmental impacts of climate change. Carbon storage projects may, however, have additional environmental impacts to account for and mitigate. The most consequential potential environmental impacts associated with storing CO_2 underground includes the possibility of mismanagement that causes CO_2 to leak out of the storage formation to the atmosphere or to protected underground sources of drinking water, as well as the potential for manmade earthquakes. Before CO_2 can be injected underground, stringent federal and state regulations require that project operators evaluate and address all these risks [110, 111]. This includes carefully and thoroughly evaluating the underground rocks for their ability to trap CO_2 and make sure it will remain in place, looking for and either fixing or avoiding pathways that could allow the CO_2 to escape to the surface or into drinking water, and assessing the history of earthquakes near the site and whether injecting CO_2 could trigger new earthquakes [112, 113]. A storage site cannot be used if federal and state authorities think these risks are too great. Laws and regulations also require storage sites to be closely monitored while injecting CO_2 and for years after injection stops to confirm that CO_2 is not leaking and that earthquakes are not occurring [114, 115]. If this monitoring indicates potential problems, steps must be taken to fix them, such as repairing or plugging faulty wells, decreasing the injection rate, or in extreme cases, shutting down the storage project or removing the CO_2 from storage. Note that, while we do have precautions in place, decades of research and real-world experience also confirm the durability of CO_2 storage at properly selected and operated sites [116-123].

Temporary environmental and human-health impacts may also be associated with activities to characterize the well site, drill injection and monitoring wells, operate and maintain facilities, and close the site at the completion of the project. Impacts may include, but are not limited to, noise and light pollution, increased vehicle traffic and associated air pollution and safety risks, dust or other air pollution associated with site clearing and construction, water use, and visual impacts. These activities are limited in both duration and frequency but may be reduced by conversion to EVs and electrified

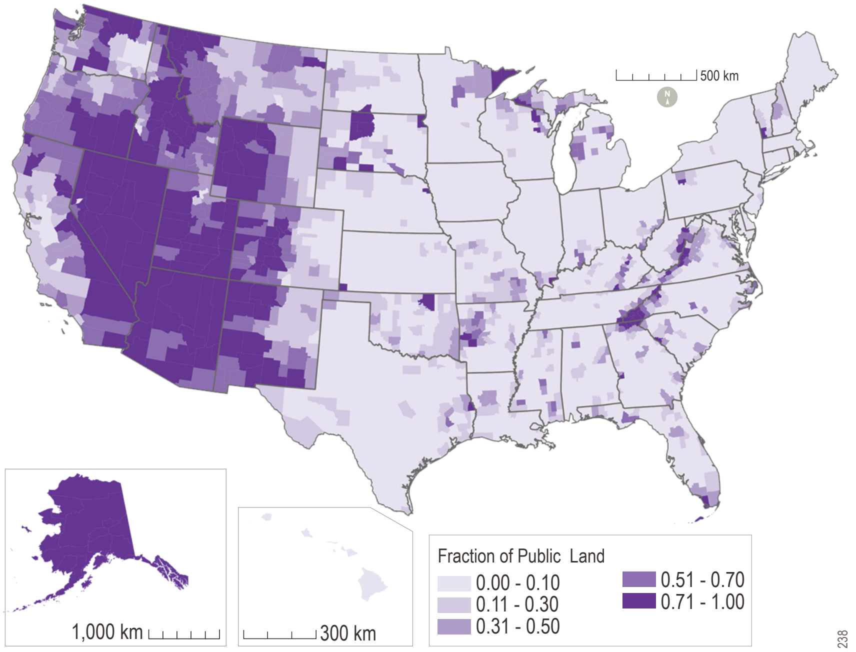


Figure 9-29. *Percentage of county land that is publicly owned; this includes federal, state, local, and tribal-government lands. Counties with high percentages of publicly owned land have greater potential for democratization of financial benefits from geologic carbon-storage revenues due to their direct applicability to public service funding. Data sourced from the Bureau of Land Management ([100]; last accessed: July 31, 2023).*

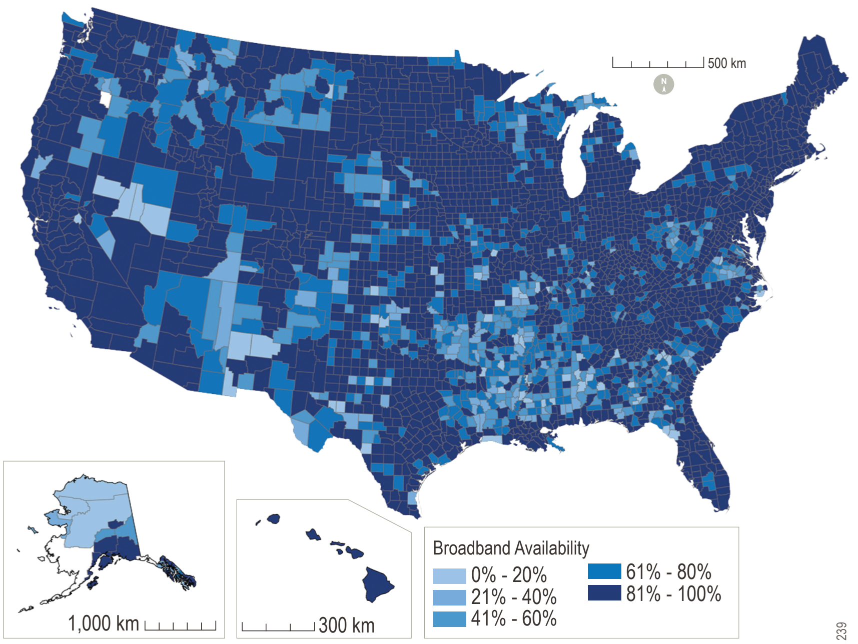


Figure 9-30. *Average broadband access, by county (data provided by Microsoft)*

BOX 9-6

Democratized Pore Space Opportunities

specifically highlights a commitment to ensuring that public agencies, as landowners with control over the subsurface pore space, play a pivotal role in the development of geologic carbon storage projects on public lands. This approach aims to guarantee that economic benefits are distributed fairly among the public, aligning with principles of equity and inclusive access to the opportunities presented by carbon storage initiatives

equipment (e.g., trucks, drill rigs, dump trucks), which decrease airborne contaminants (i.e., diesel fumes) and noise pollution for employees, as well as for nearby communities [28, 124, 125]. In the near-term, the construction phase will likely have negative air-pollution impacts due to the specialized and hard-to-decarbonize nature of some necessary machinery. However, project developers and community members can negotiate mitigation/avoidance measures, such as the usage of zero-emission vehicles, when available, or concurrent investment in environmental justice groups that engage in PM2.5-abating practices (e.g., air filter giveaways or urban tree planting). Beyond emissions, other mitigation measures to reduce construction impacts are common for projects, such as the use of light and sound barriers, practices to recycle water and use non-potable water where possible, practices to reduce emission of dust and other air pollutants associated with land clearing and road construction, and others. Project developers and communities may benefit from discussing and documenting such potential impacts before the project commences to integrate mitigation measures into a community benefits agreement [105]. As demonstrated in this study, the amount of underground storage space in the United States is vast. Much of that storage space is in remote areas where few or no people live, which could be prioritized for storage sites to eliminate any potential human impacts and avoid sensitive ecosystems.

Geologic Storage Summary

We have created a first-of-its-kind EEEJ optimization index that merges geospatial data on variables relevant to geologic storage projects into a single index value to identify counties that could maximally benefit from projects, while also storing maximal amounts of carbon affordably (**Figure 9-31**). In this report, we regard geologic carbon storage as a collaborative CO_2 storage method; it is not commonly known of in the public realm and its co-benefits are predominantly socioeconomic in nature; thus, projects may benefit from early, collaborative planning that ensures these co-benefits are distributed fairly for local residents. To leverage geologic carbon storage as a tool for distributive justice, as the country aims to decarbonize deeply without inequitably causing economic hardship to energy communities, prioritizing its early adoption in counties that are most likely to benefit but are also less vulnerable may be advisable to ensure that there is adequate social infrastructure and bandwidth to engage in project development. To facilitate the identification of potential early adopters, we constructed a 3-dimensional map that compares our EEEJ index values to SVI [69], as well as the affordability of CO_2 storage in each county with data from this report (**Chapter 3 – Storage**) (**Figure 9-32**). In this figure, we observe and annotate some groups of counties that may be poised for affordable geologic carbon storage, like the Gulf Coast and California Central Valley, but the counties are classified as 'highly vulnerable,' which may suggest that investing resources, time, and space to grow their own local expertise on geologic carbon storage could be beneficial. In contrast, the counties around the Montana-Wyoming-North Dakota nexus appear to be poised for high co-benefit opportunities, affordable geologic carbon storage, and their low social vulnerability score suggests that they may have greater social infrastructure, capacity, and bandwidth to collaborate with project developers to become early leaders in geologic carbon storage. By facilitating early adoption in counties that are poised to collaborate meaningfully on projects, the transparency and publicized track record for safety that they develop may ultimately increase public support for these projects and, by consequence, their development [126].

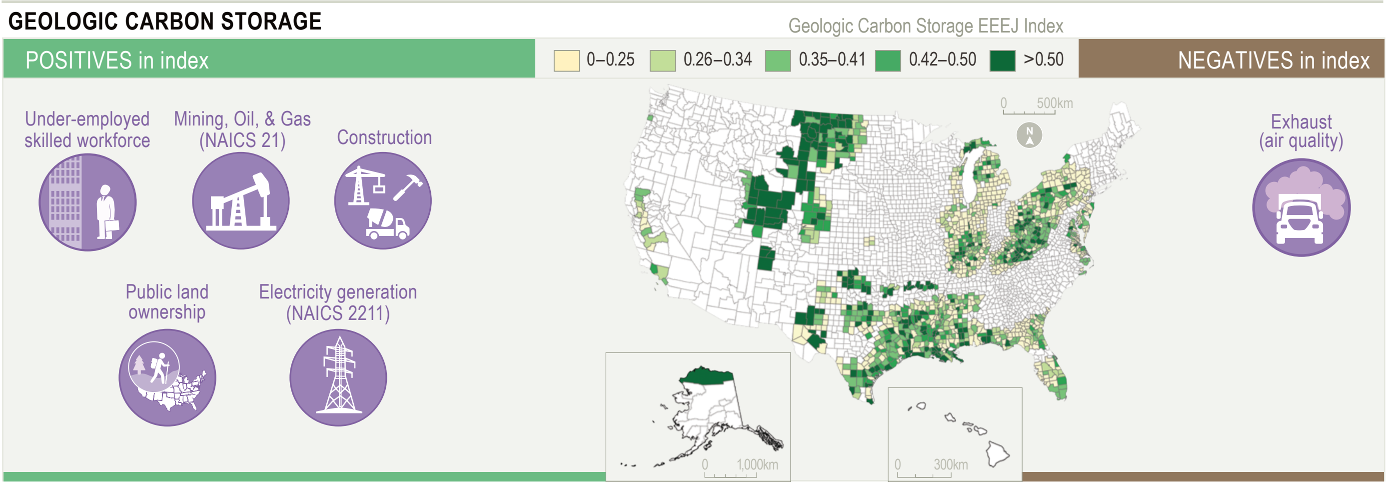


Figure 9-31. *Geographic representation of EEEJ Index values, with illustrative positives and negatives in the index. Darker green represents counties with minimal risks and the highest opportunity for co-benefits, such as reemploying skilled workforces that have been recently (in the past six years) laid off in counties with a higher likelihood of publicly-owned pore space suitable for geologic carbon storage. Refer to Table 277 (**Chapter 4 – Geologic Storage**) for greater detail and references.*

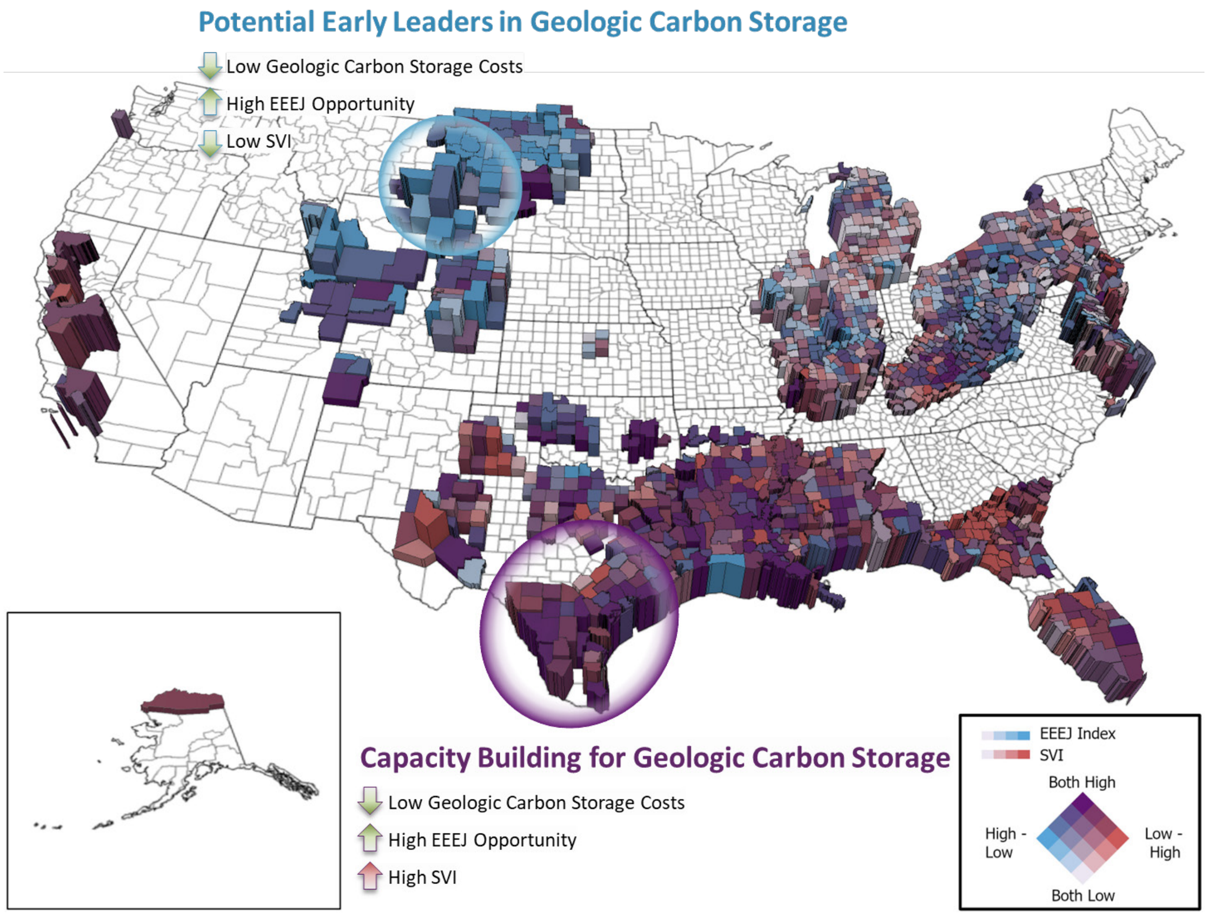


Figure 9-32. *Map of the CDC's Social Vulnerability Index (SVI) on the red axis and the EEEJ Index, calculated in this report, on the blue axis for geologic carbon storage in well-characterized and affordable subsurface basins. The height of the counties represents the tonne of CO_2 that can be stored per dollar (\$) (i.e. the inverse of \$/tonne). Taller counties, therefore, represent the cheapest geologic carbon storage costs. This map is annotated to reflect our premise that geologic carbon storage is a collaborative CO_2 storage method. Therefore, we highlight some less vulnerable counties that may be equipped to collaborate on projects as early adopters, as well as some counties with high CO_2 removal opportunities, but high SVI, which suggests that they may benefit from some targeted capacity building around the topic and its trade-offs.*

Biomass for Carbon Removal and Storage (BiCRS)

The feedstocks being diverted to BiCRS are wastes, with the exception of purpose-grown carbon crops (**Chapters 3 – Soils, Chapter 6 – BiCRS**). These waste streams are derived from working lands (e.g., agriculture and managed forests) and population centers (e.g., municipal solid waste (MSW) and point sources, like wastewater from treatment plants). Working lands and population centers compose the backbone of our nation's balanced economy, but it is important to recognize that—inherent to the repurposing of any waste stream—class, race, economic, and other biases, in part, dictate which communities are currently exposed to these waste streams and their associated pollution burdens (e.g. [127-129]). In contrast, however, there are also counties that have built up identities around some of these industries (e.g., crop and animal production) and whose county-wide economies are reliant on the related employment sectors [130]. In some cases, these counties have also innovated ways to mitigate pollution and maximize employment opportunities from these feedstock-generating industries (e.g., [131]). Therefore, as we consider these five BiCRS feedstocks: agricultural wastes, forest residues, manure, and MSW, we must also evaluate inequitable pollution burdens in today's baseline, as well as counties whose job inventories are especially reliant on the industries they represent. *If adopted and scaled responsibly, with these priorities at the forefront, BiCRS technologies have the potential to reduce pollution burdens and re-employ/retain employment for tens of thousands of Americans* [132, 133]. To analyze potential socioeconomic and environmental implications of BiCRS, we compared trade-offs relevant to the feedstocks separately from those relevant to the conversion processes (**Chapter 6 – BiCRS**). However, we first discuss two pressing issues: per- and polyfluoroalkyl substances (PFAS or forever chemicals) and issues affecting net carbon negativity of the BiCRS process.

Per- and Polyfluoroalkyl Substances (PFAS)

Considered one of the most pressing environmental issues of the 21st century, PFAS are toxic to human health, even with very minimal exposure [134]. PFAS were introduced to the environment through direct applications (e.g., the use of firefighting foams) or wastewater-treatment plants with subsequent biosolid applications, a practice recommended for farmers prior to their discovery of PFAS and its toxicity in ~2018 [135]. Once PFAS entered the environment, they became a public-health threat of unconstrained proportions [135]. PFAS are bioaccumulated from soils where biosolids have been applied, so they can be found in agricultural products, manures, MSW, and wastewater [135, 136].

Due to their anthropogenic origins and heterogeneous contamination across the United States (**Figure 9-33**; [137]), the only way to confirm their presence is to test BiCRS feedstock directly for them. If PFAS are detected in BiCRS feedstocks, *then the only conversion methods discussed in this report that are demonstrated to destroy 99% of the PFAS are thermochemical reactions >350 °C: pyrolysis, gasification, and hydrothermal liquefaction (HTL)* [136, 138, 139]. If the BiCRS feedstocks are converted using one of these methods, then the byproduct (e.g., ash or char) is thought to be safe for reapplication or landfilling. To scale up BiCRS safely and with restorative environmental justice at the forefront, widespread

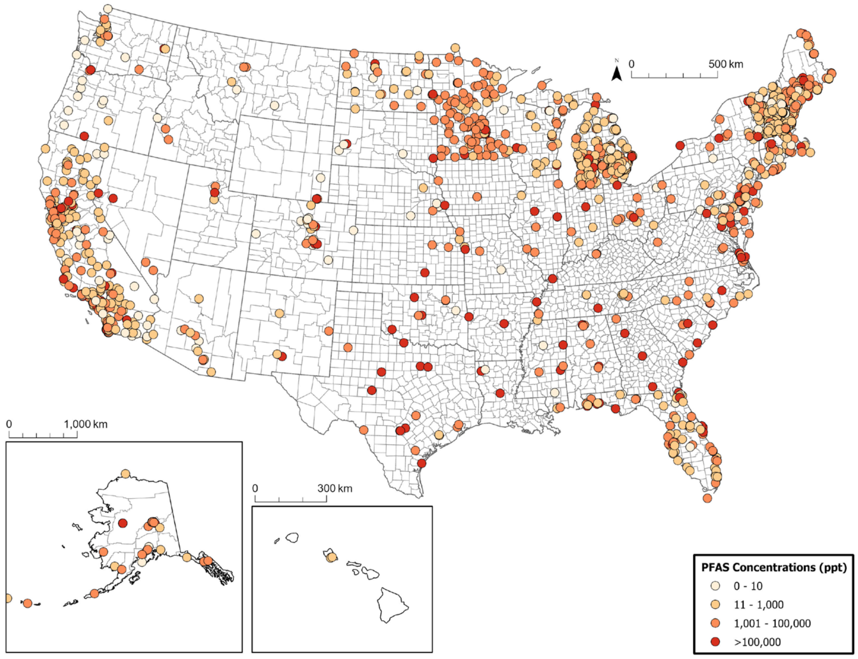


Figure 9-33. *Locations with per- and polyfluoroalkyl substances (PFAS) observed in drinking water (light blue) above EPA threshold, as well as additional sites of concern (purple and orange) for potential PFAS contamination. This map is not exhaustive due to not-yet-widespread testing. Data originally derived from EPA, but map sourced from the PFAS Project Lab and its partners, such as the Environmental Working Group [137]. The heterogeneity of PFAS data (occurring only in certain states) is because there has not historically been a nationwide PFAS monitoring program that monitors waters in the United States evenly. Future BiCRS projects may want to consult the most up-to-date PFAS-abundance maps as they are planning for the future.*

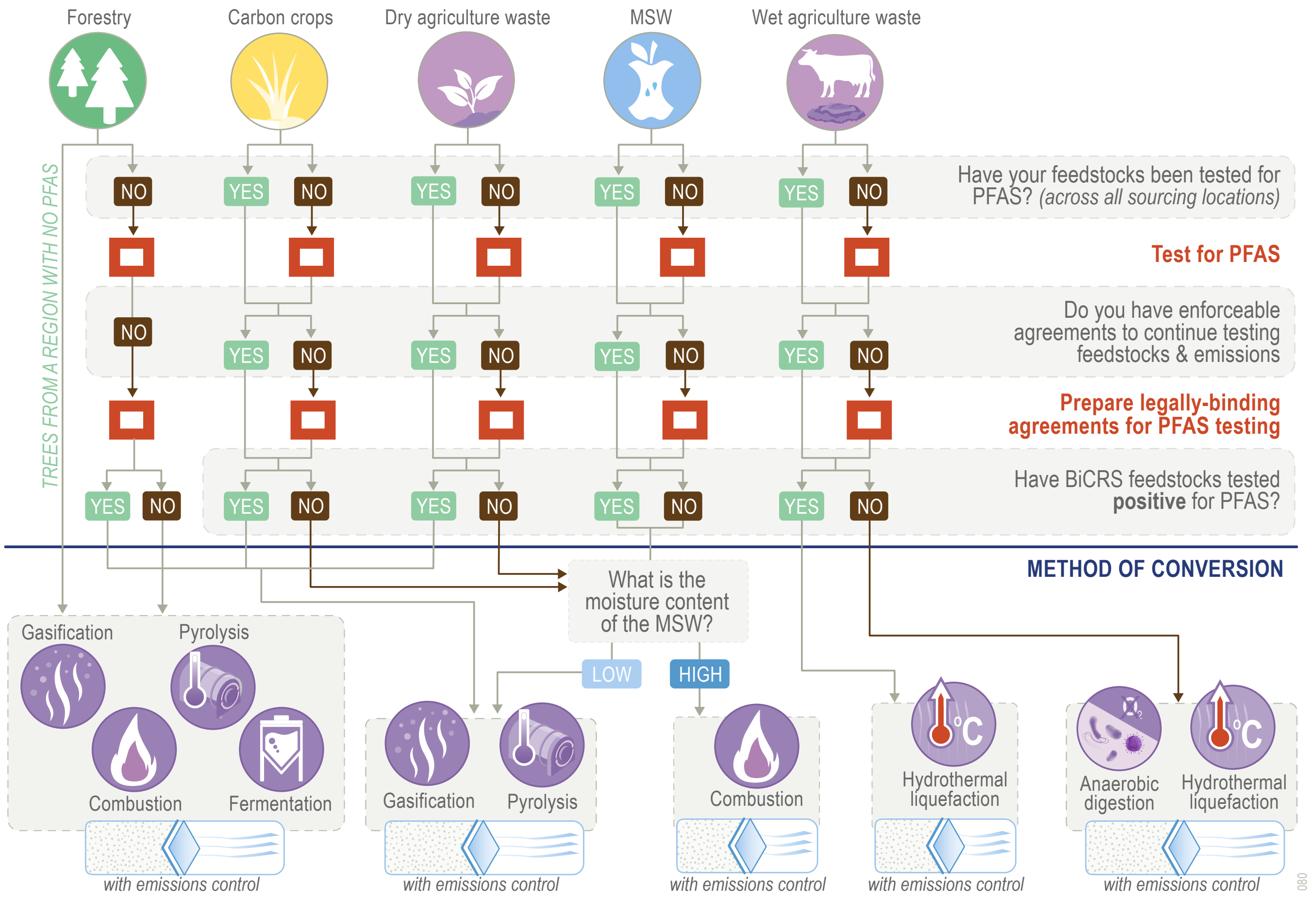


Figure 9-34. *Decision flowchart regarding responsible BiCRS considerations, which may help prevent the further spread of PFAS in the environment, while destroying some/all of the PFAS already accumulated in BiCRS feedstocks. PFAS = per- and polyfluoroalkyl substances.*

PFAS-contamination testing must be scaled up concurrently and dictate allowable BiCRS conversion processes. A flow diagram of this design is presented in **Figure 9-34**.

Net Carbon Negativity and Equity of BiCRS Processes

Another pressing issue that affects the net carbon negativity and equity of BiCRS processes is the not-yet-decarbonized nature of the preparation, collection, transportation, and holding of wastes pre-conversion. *Without first decarbonizing these steps—which currently emit diesel-derived air (e.g., PM2.5) and noise pollution—and mitigating non-*CO_2 *greenhouse gas (GHG) emissions that can serve as precursors for PM2.5 (e.g., nitrogen oxides (NOx) and sulfur oxides (SOx)), we forgo much of the potential restorative environmental justice opportunities that these waste-conversion technologies pose.* In addition to pollution concerns, the conversion to EVs and electrified equipment (e.g., trucks, drill rigs, dump trucks) increases worker safety through reduced exposure to atmospheric contaminants and noise, as well as leading to a less intrusive industrial experience overall—a key benefit for communities near the feedstock, transportation corridors, and conversion sites [28, 124, 125]. Furthermore, for each feedstock, we will discuss potential mitigation or optimization methods for abatement of non-CO_2 gas emissions. By critically analyzing each BiCRS feedstock and conversion method, we can appreciate the interconnectedness and importance of responsible waste management in a just decarbonization strategy, considering both socioeconomic and environmental factors to develop long-term solutions that benefit communities and ecosystems.

BiCRS Feedstocks

Woody Wastes: Agricultural Biomass and Forest Residues

Socioeconomic Impacts

At the point of feedstock collection from working lands, whether they are farms or forests, the socioeconomic impacts of diverting woody wastes (e.g., forest-thinning residues, orchard pruning, sugar cane stalks, etc.) to BiCRS is clear: *farmers, landowners, foresters, and agricultural/forested counties will directly, financially benefit from the sale of their wastes to companies that value it based on carbon content, which can be greater than its bioenergy value alone* ([140] **Chapter 6**). The current baseline end-uses for these working-land wastes are burning, composting, mulching, or landfilling, which represent zero, indirectly positive (through compost application), uncertain (water conservation versus chipping costs), or negative economic value, respectively, to farmers, ranchers, foresters, or landowners (hereafter referred to as practitioners). Giving practitioners the option to sell their waste to BiCRS facilities diversifies their revenue streams, making their businesses more resilient to climate change, economic, and/or other challenges.

Furthermore, in rural counties, where forestry-and-logging and crop-production jobs can represent an outsized portion of a county's job inventory, persistent job-loss trends can lead to underemployed, skilled workforces and/or reduced county solvency (Figures 9-14 and 9-24; BLS NAICS 111 and 113 [32]). Biomass-based energy facilities, while not a perfect analog for BiCRS, have been shown to create ~17.4 total jobs per $1 million of spending—11 (63%) of which are in the agricultural/forestry and transportation sectors—where the biomass would be sourced [3]. When BiCRS companies are considering counties where they will source their feedstocks, equity-enhanced outreach could be undertaken with data presented in **Chapters 2 – Forests** and **3 – Soils** (e.g., Figures 9-4, 9-22, and 9-23) to give small farms, especially those operated by minoritized practitioners, an equitable chance to engage early in these income-generating processes. Large farms will undoubtedly yield the greatest feedstock supply, but the purchase agreements for BiCRS-feedstock sourcing from small farmers could have positive impacts on historically marginalized communities if outreach is optimized for socioeconomic equity.

While much of the declining forestry-and-logging and crop-production job trends are due to economic forces, such as reduced/variable demand and higher operating costs (e.g., [33, 141]), background socioeconomic dynamics are also reducing the number of young workers interested in pursuing careers in these sectors (e.g., [34, 141]). Valuing the carbon in these woody wastes may address some of the difficult economics of timber and agricultural operations, but the declining workforce may present a challenge to scaling woody-biomass-based BiCRS for CO_2 removal as quickly as it needs to be scaled for climate impact. Increasing the job quality of forest and farm jobs may be beneficial for addressing this issue; specifically, reducing the physically demanding nature through mechanization, improving working condition (including safety and comfort), and increasing compensation with benefits are top priorities for workforce bolstering (e.g., [34, 141]). These recommendations are consistent with current federal guidance around the just transition to a deeply decarbonized economy and its goals to increase both job quality and quantity in rural America through decarbonization [35, 36]. Through creation of high-quality collection, storage, and transportation jobs resulting from implementation of woody-waste-based BiCRS, skilled workforces in the forestry, agricultural, and transportation sectors can be maintained and/or reemployed, thereby replenishing the backbone of economies in rural counties.

At the point of biomass conversion, where the BiCRS facilities would be, the county could expect ~6 long-term jobs per $1 million of investment by the project developer, largely in the facilities maintenance and operations sector (**Figure 9-35**) [3]. Previous studies have argued that traditional energy communities (e.g., coal communities) be given priority in deciding where BiCRS facilities will be, since these facilities use similar workforces to coal mines and power plants, which are most at-risk of economic losses and associated public-health crises from economy-wide decarbonization (e.g., [13, 133, 142]). One national study estimated that the preferential conversion of coal communities to biomass-based renewable-energy projects could retain ~40,000 jobs in the United States, particularly in coal communities, and create ~22,000 new jobs, with an outsized portion in the forestry sector [133]. Current policies around energy communities include tax incentives for new business development for just this reason [36] (Figure 9-27). Of critical importance in these coal-to-bioenergy transitions, however, is retention of job quality; many traditional energy jobs are unionized with livable wages, high-quality benefits, and recourse in case of injury; without maintaining these workforce characteristics and the energy-community identity with early buy-in before plant closures, it is uncertain how effective this type of transition may be (e.g., [23, 143] and references therein).

Environmental Impacts

While each practitioner decides how and when they want to dispose of their woody wastes, within the confines of local

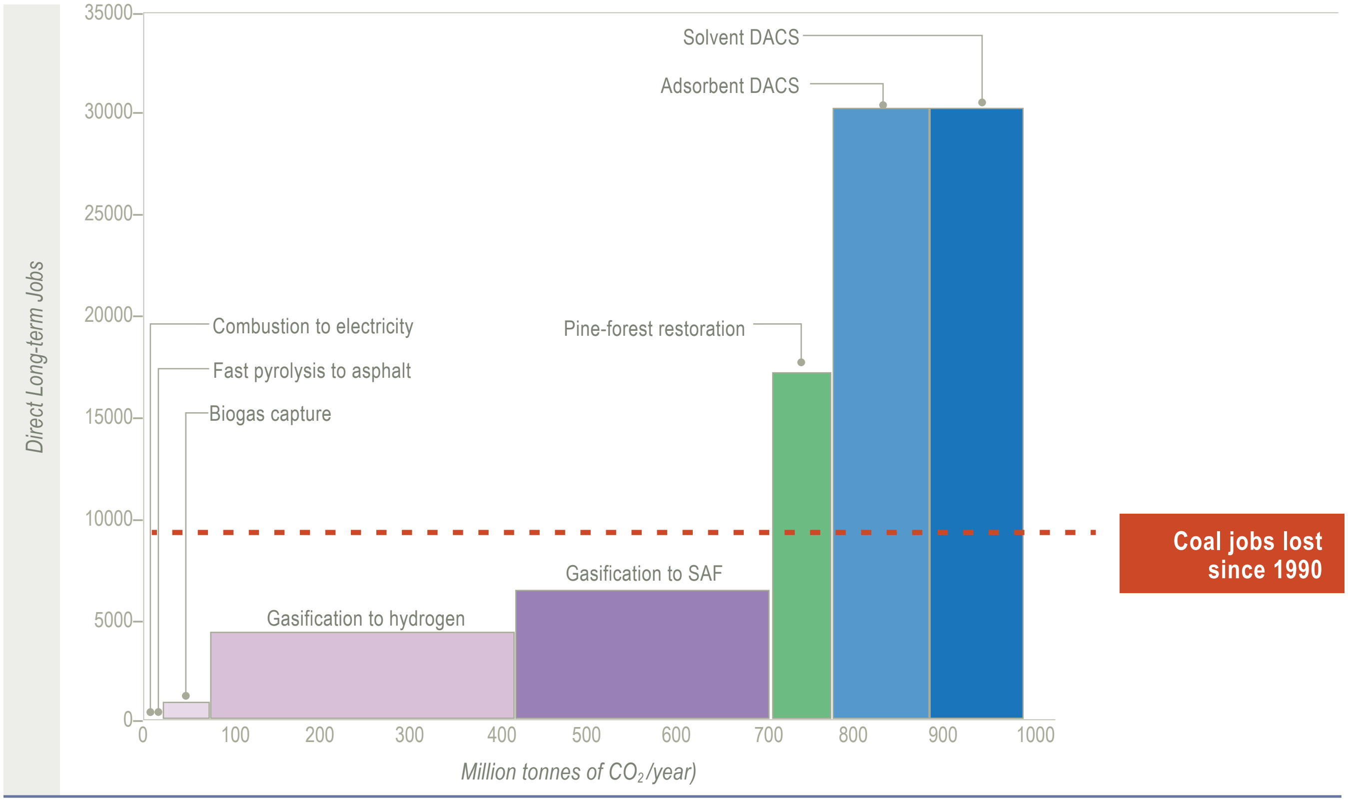


Figure 9-35. *Employment potential is shown based on linear estimates from the Southeast region's current Loblolly pine industry [2], biomass-energy-plant employment estimates [3], and DACS estimates from the Rhodium Group [4-6]. Coal-job losses since 1990 are provided for context. SAF = sustainable aviation fuels.*

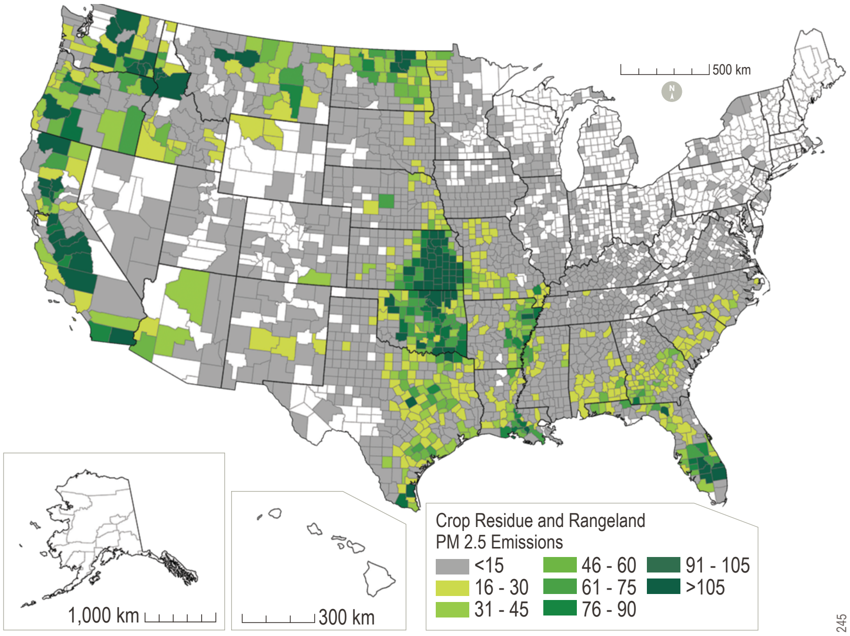


Figure 9-36. *PM2.5 air pollution derived annually from cropland and rangeland burning [144].*

regulations, each method has well-documented environmental implications. Amongst burning, composting, mulching, and landfilling, *the most environmentally harmful disposal methods for woody biomass are burning and landfilling, due to polluting air emissions* (PM2.5, hydrogen sulfide (H_2S), ammonia (NH_3), methane (CH_4)). Burning is cheap, efficient, and a preferred method for remote areas. However, the burning of agricultural wastes (for example), especially corn, cotton, rice, soybean, and sugarcane wastes, on croplands and rangelands in the United States accounts for ~30,000 tonnes of PM2.5 pollution per year and disproportionately impacts the nation's most socially vulnerable western and southeastern counties (**Figure 9-36** [144]). Furthermore, wildfires absolutely cause far greater air pollution concerns than prescribed burning, which is tightly regulated, and the fact remains that forest thinning needs to be scaled up at a rapid pace to avoid catastrophic forest losses due to wildfires in the western United States and Alaska (Figure 9-13; [60]; **Chapter 2 – Forests**). Without valuing the carbon in this woody biomass to compensate for the costs involved with transporting it, burning these wastes will be the practical alternative, inherently decreasing air quality in the western and southwest United States, as well as central Alaska—all especially vulnerable communities, according to the SVI (Figure 9-3; [69]). By diverting woody biomass to

BiCRS instead of burning it, we can avoid smoke pollution that disproportionately impacts the United States' most vulnerable counties, thereby avoiding the inequitable public-health burdens that these smoke sources represent. Similar to burning, landfilling woody wastes also results in air pollution, predominantly from odorific vapors (e.g., H_2S and NH_3) and GHGs (e.g., CO_2 and CH_4). By diverting these woody wastes to BiCRS, including woody construction materials, it is possible to reduce these emissions across the nation's landfills (**Chapter 6 – BiCRS**).

As discussed previously, while classified as wastes (in bulk), these woody wastes have some environmentally beneficial uses, with which BiCRS could compete. These uses include composting/mulching for increased water conservation in arid environments and local decarbonized energy production (e.g., wood pellets for individual and micro-grid use) [37]. By diverting 100% of woody wastes to BiCRS, these environmental co-benefits of alternative waste-utilization methods would be lost, potentially causing environmental harm. Therefore, before sourcing woody wastes for BiCRS projects, it is advisable to evaluate whether the potential sourcing location has place-based challenges (e.g., limited grid connectivity or intermittent sunlight/wind resources) that make energy decarbonization especially difficult without local bioenergy. If so, then calculating the percentage of woody wastes to set aside annually for decarbonized energy must be a priority, since carbon-intense energy sources carry disproportionately large environmental burdens on communities, especially those with large populations of people of color and higher poverty rates [8].

Wet Wastes

Socioeconomic Impacts

By valuing the carbon content of wet wastes (e.g., manure) diverted to BiCRS, waste-removal costs to farmers may decrease ([140]; **Chapter 6 – BiCRS**). The baseline end-uses for these wet wastes, currently, are collection followed by reapplication as fertilizer over fields (predominantly for silage) or landfilling. Some farms—predominantly large ones—across the United States have transitioned from storing manure on-site in manure lagoons to anaerobic digestion (AD), used to produce biogas for electricity, heating, or injection into a compressed-natural-gas pipeline [145]. However, the AD process still results in waste product. By giving practitioners the option to sell their wastes to BiCRS facilities, their revenue streams may diversify, making their businesses more resilient to climatic, economic, and/or other challenges.

The key economic drawback that could give animal-production operators pause, however, is the loss of cheap fertilizer for their silage fields. Two potential solutions could overcome this challenge, one geared toward small farms and another geared toward large operations (i.e., confined animal feeding operations or CAFOs). If manure is free of PFAS and it is in a county that does not have critical eutrophication issues (Figure 9-11) [146], then affordable, on-site options, like AD with biogas capture, are an effective way for a small farm to maintain their access to free fertilizer while also reducing carbon intensity. Large farms, in contrast, could instead opt for win-win purchase agreements with BiCRS facilities that would use their manure but return an ecologically responsible amount of fertilizer back to the farm to produce silage.

Environmental Impacts

Due to economies of scale, the most economically lucrative locations for manure sourcing will likely be CAFOs. These operations have a long-documented history of pollution issues; specifically, noxious-odor emissions (e.g., H_2S and NH_3), other GHGs (N_2O and CH_4), and eutrophication issues related to nutrient runoff and leaching [147-149]. CAFO locations are also correlated inequitably with minority and low-income communities, which bear the brunt of environmental injustices associated with their operations and have a greater risk of cardiovascular mortality [128, 150]. In this report, we show geospatial similarities between eutrophication risk (Figure 9-11) and CAFO density (**Figure 9-37**) [146, 151]. Hotspots for CAFO density and eutrophication risk appear to be the California

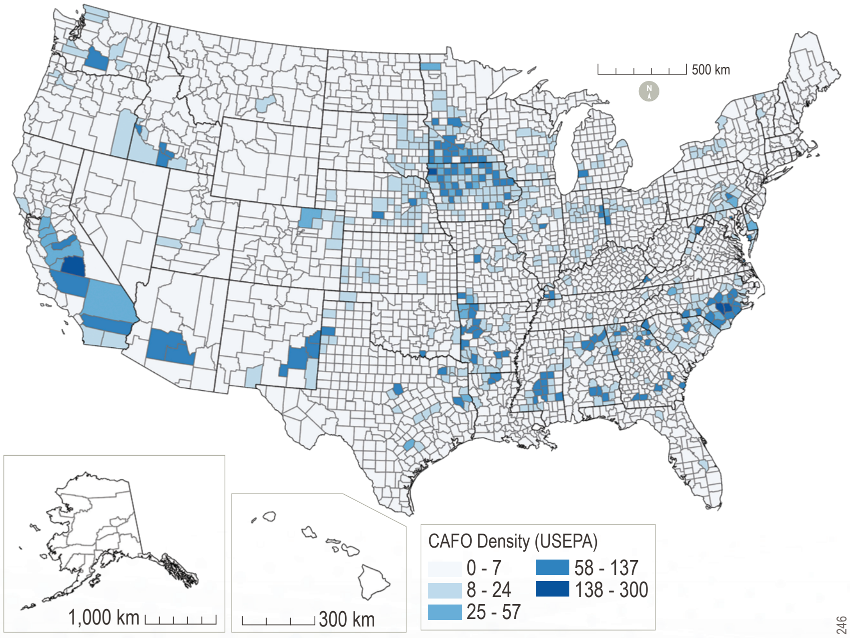


Figure 9-37. *CAFO density data by county, from the EPA (2007) [151].*

Central Valley, Upper Midwest, South-Central regions and eastern North Carolina. With environmentally optimized operations, however, BiCRS methods can be used as a pollution-mitigation tool. An excellent example of manure-based BiCRS being developed in an economically viable, but environmentally optimized, method is the Qualco Energy biodigester in Washington state—a non-profit, public-private partnership between the Tulalip Tribes, Northwest Chinook Recovery, and the Wekhoven Dairy [131]. In 2008, Qualco Energy began diverting dairy manure from field applications that risked local stream and fish-population health to an anaerobic digester to produce biogas for the public utility district [131]. Now that value has been put on low-carbon fuels, however, the operation is taking the conversion process a step farther and is preparing to produce hydrogen from the biogas [152]. While this is only one example of BiCRS being used as a restorative environmental justice tool, it is one that exemplifies key potential co-benefits associated with BiCRS methods, when scaled responsibly (**Chapter 6 – BiCRS**).

Municipal Solid Wastes (MSW)

Socioeconomic Impacts

At the point of feedstock collection from landfill-destined MSW-collection centers, the socioeconomic impacts of diverting MSW to BiCRS is clear: *the cost that counties pay for MSW disposal could decrease and there would be additional revenue streams for waste-collection and/or landfill companies, who would financially benefit from the value of MSW's carbon content, which is often greater than its bioenergy value alone* ([140]; **Chapter 6 – BiCRS**). The baseline end-use for MSW is landfilling or, in rare instances, combustion. Its disposal is costly and presents contentious siting challenges, often resulting in inequitable siting of landfills, even nonhazardous ones, in more vulnerable communities, such as those with higher percentages of people of color, populations living below the poverty line, and single female-headed households [129, 153]. Without policy changes that directly address inequitable landfill siting, the most likely outcome is that new proposed landfills will follow this historical trend. Therefore, to slow the expansion of landfilling, which will help retain property values in disenfranchised communities, diverting as much MSW as possible from landfilling may be beneficial for reducing further disenfranchisement. BiCRS technologies targeted for heterogenous MSW, such as gasification, pyrolysis, or combustion, could be sited with equitable placement principles in mind—making a conscious effort to develop in less socially vulnerable locations that have the bandwidth to advocate for strict emissions controls, monitoring, and risk-management plans.

Environmental Impacts

The top concern for MSW-based BiCRS facilities, using waste-to-energy as our technical analog, is air emissions ([154]and references therein). Mass-burn incineration, the baseline method currently used in waste-to-energy-plant operations, can take unprocessed or unsorted MSW, recover energy from burning the waste, and reduce the volume to be landfilled by ~90% [154]. Reducing the volume of waste sent to landfill by ~90% would greatly reduce the number of communities exposed to new landfill siting, an important co-benefit for MSW-based BiCRS. However, these mass-burn incineration facilities have perception issues regarding air emissions, which has led to growing commercial interest in gasification and pyrolysis methods, which have fewer emissions (**Chapter 6 – BiCRS**) [154]. In a comprehensive life-cycle assessment (LCA) of climate- and health-relevant emissions from gasification and landfilling of MSW, *landfilling—in all cases—was worse for the environment and human health than gasification of MSW* [155]. When landfilling is the baseline, all BiCRS technologies evaluated in this chapter are likely to incur environmental co-benefits that outweigh negative impacts. However, a key catalyzing factor that could encourage responsible deployment of gasification- and/or pyrolysis-based MSW conversion is that its price restricts early adopters to more affluent coastal and/or urban communities, which have land limitations that prohibit the construction of new landfills [154]. Once these less vulnerable coastal and urban communities adopt first-of-their-kind gasification/pyrolysis of MSW in the United States (they are already ubiquitous in Europe), a broader swath of communities nationwide may be able to point to well-managed projects as examples of the acceptable baseline for operational standards when projects are proposed locally.

BiCRS Conversion Methods

Fermentation, Anaerobic Digestion (AD), and Combustion

Socioeconomic Impacts

Several BiCRS facilities already exist and are operational across the United States, such as industrial ethanol fermentation, farm-scale anaerobic digesters, and MSW combustion facilities. The key challenge of these conversion processes as BiCRS methods, however, is integrating carbon capture in their operations. The socioeconomic benefits of these methods are that they are cheaper and are thus adoptable by smaller operations (e.g., family-owned farms or remote villages) and can be scaled immediately for maximal climate impact.

Environmental Impacts

As discussed previously, a key environmental drawback of these more approachable BiCRS conversion methods is that they do not have the co-benefit of being able to destroy PFAS [136, 138, 139]. Ideally, these methods would not be used for PFAS-bearing feedstocks or, if they are, they would be used only sparingly when landfilling is the ultimate end-point for the solid byproducts. If re-application of byproducts onto fields is a desired end-result, then PFAS testing prior to using these conversion methods may help safeguard agricultural communities (Figure 9-34). Beyond this issue, AD can reduce some of the nutrient-pollution issues associated with manure through collection and managed deposition, but this may only benefit small dairies and not CAFOs, whose nutrient loads are notoriously greater than their land area can ecologically accommodate. If AD is still chosen, then community benefit agreements may want to include transportation mandates for excess manure beyond what the land can reasonably maintain. Furthermore, CAFOs can also employ a suite of operational changes to reduce their emissions (**Chapter 6**), which can be negotiated in community benefit plans for maximal public-health and climate benefits.

Hydrothermal Liquefaction (HTL), Gasification, and Pyrolysis

Socioeconomic Impacts

Larger, more technologically advanced BiCRS methods have greater upfront and operating costs associated with them, so it is unlikely that an individual farm or facility would build and operate one of these methods. However, at the county level, especially in places that have wide-ranging waste types with uncertain chemical composition, these high-temperature (>300 °C) BiCRS methods are generally considered cleaner and more robust and produce solid byproducts that are easier to transport (e.g., biochar instead of sludge). An important operating cost for these facilities will be energy sourcing and price, which could be written into power-purchase agreements or community benefit plans as enforceable commitments not to divert decarbonized energy or increase energy costs for local residents. Another operating cost that will be important to constrain as this industry develops is workforce needs and how they can be designed with energy-community workforces in mind, maintaining job quantity and quality in counties that depend on the energy sector. Furthermore, explicit considerations regarding how small, local, and minority-owned businesses can be equitably uplifted through BiCRS infrastructure could be discussed in future project plans.

Environmental Impacts

A key environmental impact of larger industrial BiCRS conversion methods is their ability to destroy PFAS chemicals ([136, 138, 139]. Beyond this co-benefit, air emissions with climate and human-health impacts from these thermochemical reactions are expected to be less difficult to abate than their feedstock's alternative end-use (e.g., landfilling and combustion) [154, 155]. The key environmental challenges that these conversion technologies are likely to face are those inherent in the construction of any large industrial facility—traffic, noise pollution, and diesel-derived PM2.5 emissions from on- and off-road vehicles. As discussed previously, however, with decarbonized energy and transportation, these environmental impacts can be decreased with the co-benefit of increasing worker safety and job quality. Beyond this decarbonization, the key to mitigating any negative environmental impacts from these facilities will be frequent and enforced monitoring of emissions, byproducts, and the impacts these byproducts have if applied to working lands.

BiCRS Summary

We have created a first-of-its-kind EEEJ optimization index that merges geospatial data on variables relevant to each BiCRS feedstock and conversion method to individual indices to identify counties that could maximally benefit from feedstock sourcing and BiCRS facilities (**Figures 9-38–9-41**). In this report, we regard BiCRS as a collaborative CO_2 removal method; it is not commonly known of in the public realm and its co-benefits are a mixture of environmental and socio-economic in nature, depending on size, scope, and feedstock; thus, projects may benefit from early, collaborative planning that ensures these co-benefits are distributed fairly for local residents. To leverage BiCRS as a tool for restorative justice, as the country aims to decarbonize deeply while still reconning with historically inequitable pollution burdens from waste streams, prioritizing its early adoption in counties that are most likely to benefit but are also less vulnerable may be advisable to ensure that there is adequate social infrastructure and bandwidth to engage in project development. To facilitate the identification of potential early adopters, we constructed a 3-dimensional map that compares our EEEJ index values for BiCRS facilities to SVI [69], as well as the capacity : cost ratio for all BiCRS feedstocks/methods in the 'No cropland change, 90% of carbon removal' scenario data from this report (**Chapter 6 – BiCRS**) (**Figure 9-42**).

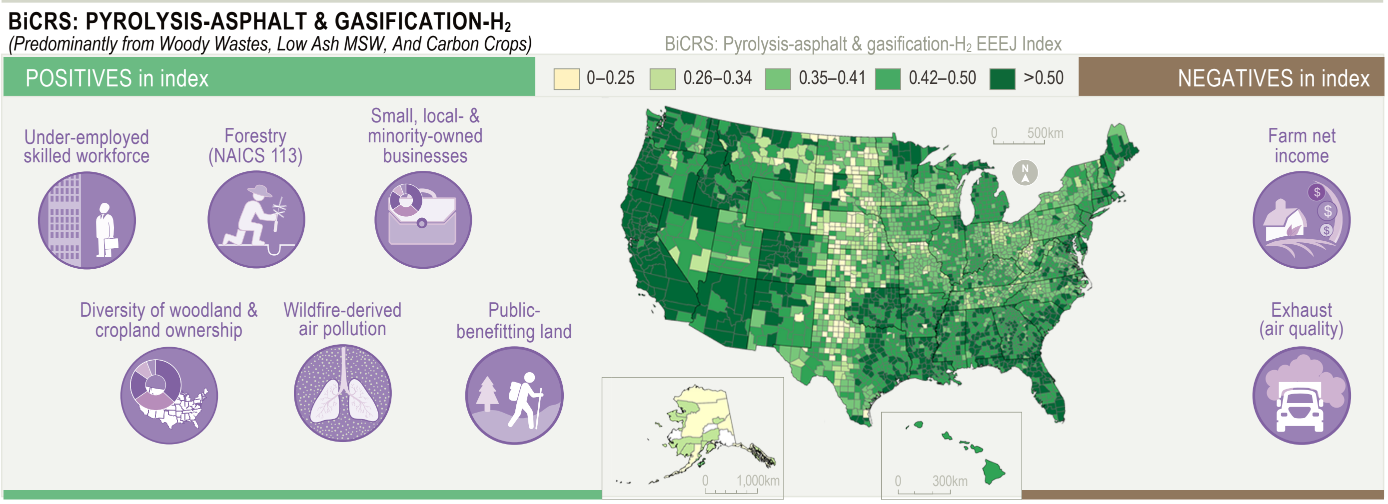


Figure 9-38. *Geographic representation of EEEJ Index values for pyrolysis to asphalt and gasification to H_2, with illustrative positives and negatives in the Index. Darker green represents counties with minimal risks and the highest opportunity for co-benefits, such as supporting forest management efforts in counties with air pollution risks from wildfire smoke. Refer to Table 276 (Chapter 6 – BiCRS) for greater detail and references.*

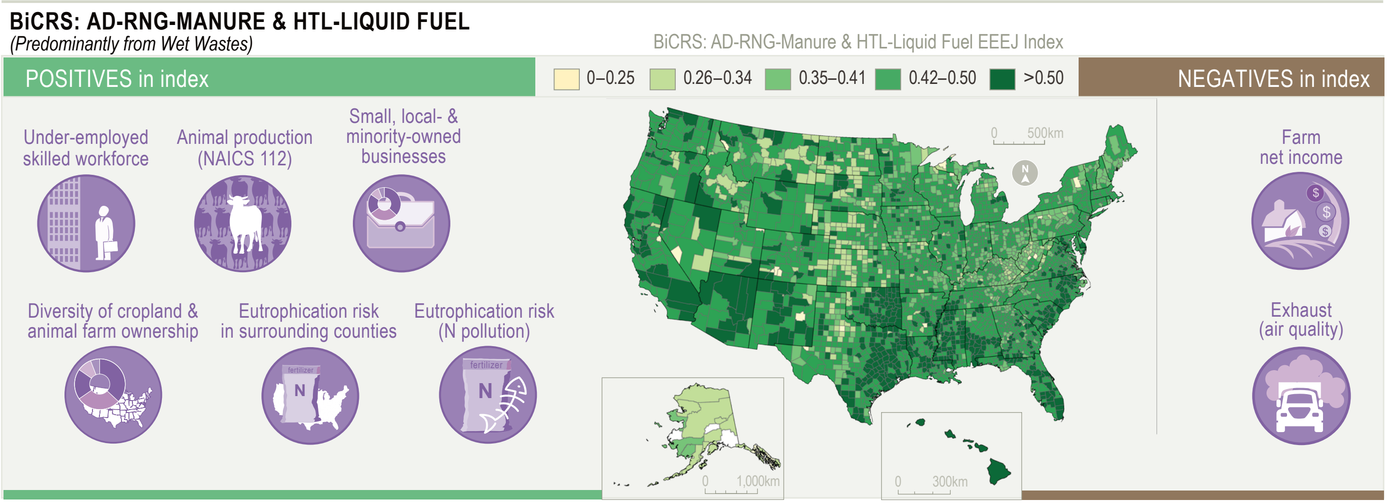


Figure 9-39. *Geographic representation of EEEJ Index values for anaerobic digestion (AD) of manure using renewable natural gas (RNG) and hydrothermal liquefaction (HTL) to liquid fuel, with illustrative positives and negatives in the index. Darker green represents counties with minimal risks and the highest opportunity for co-benefits, such as reducing water pollution in counties that host a diversity of small, local- and minority-owned businesses and farms. Refer to Table 276 (Chapter 6 – BiCRS) for greater detail and references.*

In conclusion, the diversity of BiCRS feedstocks and conversion methods yields opportunity for real-time workforce transitions across America, as well as the remediation of past environmental injustices, if deployed and scaled-up responsibly through EEEJ-optimized considerations. By co-evolving the BiCRS industry alongside widespread and comprehensive contaminant testing, as well as responsible regulation of waste-management practices, it is possible to envision BiCRS technologies as a tool for restorative justice in overburdened communities. Specifically, overabundant wastes could be transported from their county of production to another county with the BiCRS facility. At the facility, the bulk of the waste composition would be converted into valuable products (e.g., CO_2 and H_2) and solid phase fertilizer product, likely easier to transport than the original material for application over fields in an ecologically responsible fashion. Equity-enhanced outreach to small farms, especially those with minoritized ownership/operatorship, has the potential to improve the resiliency of US agriculture and avoid air and water pollution in some of the nation's most

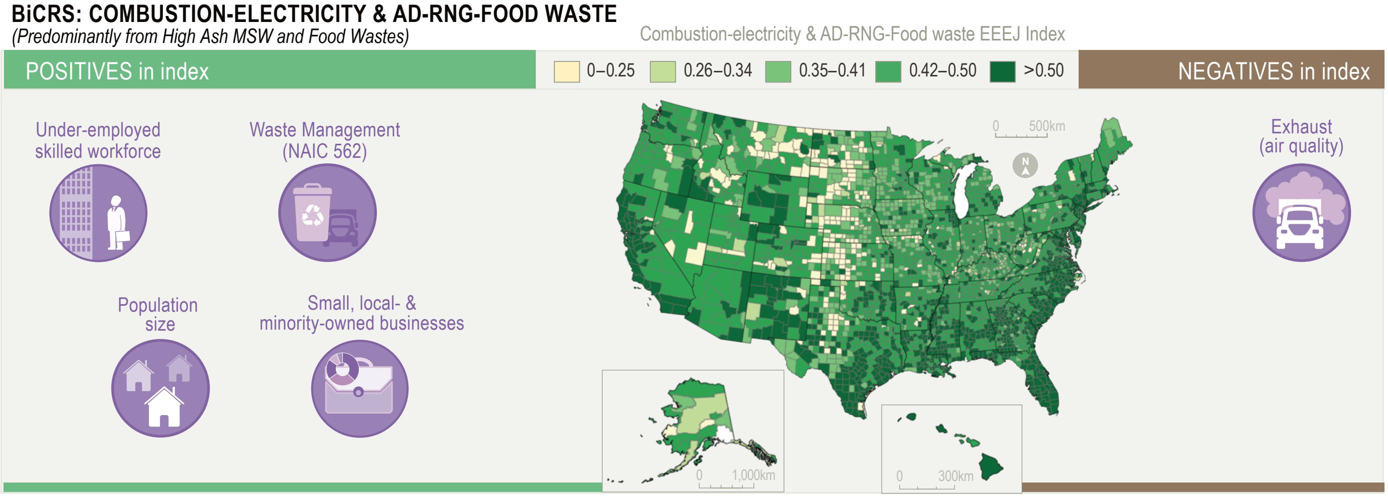


Figure 9-40. *Geographic representation of EEEJ Index values for combustion to electricity and anaerobic digestion (AD) of food waste using renewable natural gas (RNG), with illustrative positives and negatives in the index. Darker green represents counties with minimal risks and the highest opportunity for co-benefits, such as reemploying skilled workforces from the waste management industry, in counties with healthy ecosystems of small, local- and minority-owned businesses. Refer to Table 276 (Chapter 6 – BiCRS) for greater detail and references.*

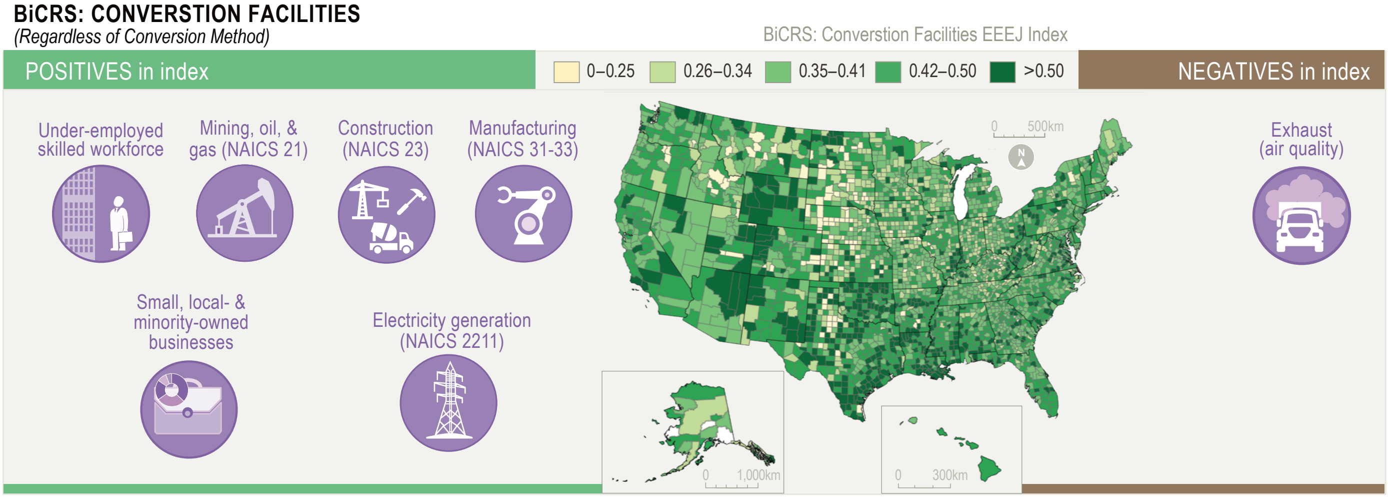


Figure 9-41. *Geographic representation of EEEJ Index values for all BiCRS conversion methods combined, with illustrative positives and negatives in the index. Darker green represents counties with minimal risks and the highest opportunity for co-benefits, such as reemploying skilled workforces that have been recently (in the past six years) laid off in counties with a healthy ecosystem of small, local- and minority-owned businesses that could support the growing industry. Refer to Table 276 (Chapter 6 – BiCRS) for greater detail and references.*

socially vulnerable counties. However, we must proceed with caution when it comes to diverting any feedstock that are otherwise necessary for other energetic or environmental services, such as decarbonizing a remote village's electric grid or conserving water in arid agricultural lands. *By optimizing for maximal socioeconomic and environmental benefits, we can foster sustainable and equitable BiCRS-feedstock sources with conversion locations that safeguard people, promote environmental justice, and respect the diverse needs and rights of our nation's communities.*

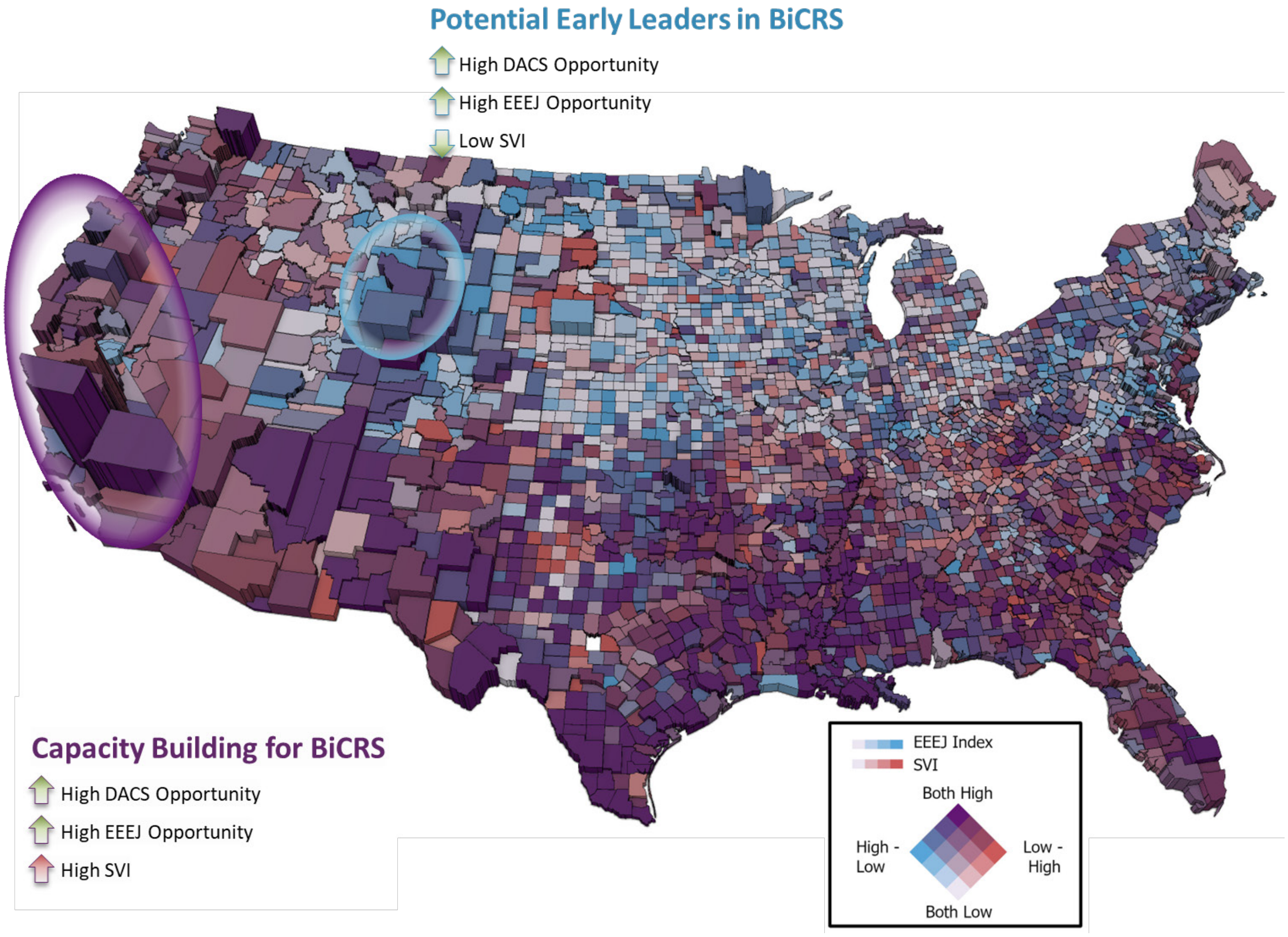


Figure 9-42. *Map of the CDC's Social Vulnerability Index (SVI) on the red axis and the EEEJ Index, calculated in this report, on the blue axis for BiCRS facilities. The height of the counties represents the capacity (tonne of* CO_2 *that can be removed) : cost ($) ratio for the summation of all feedstocks, amortized from the regional values presented in Chapter 6 (BiCRS) to county-scale evenly via land area data for counties. Taller counties, therefore, represent the greatest amount of* CO_2 *removal potential via BiCRS, with the lowest cost, cumulatively. This may bias the data somewhat toward an overrepresentation of larger counties within regions, but the comparison between regions should be minimally impacted. This map is annotated to reflect our premise that BiCRS is a collaborative* CO_2 *removal method. Therefore, we highlight some less vulnerable counties that may be equipped to collaborate on projects as early adopters, as well as some counties with high* CO_2 *removal opportunities, but high SVI, which suggests that they may benefit from some targeted capacity building around the topic and its trade-offs.*

Direct Air Capture with Storage (DACS)

As the most expensive but most straightforward option to directly remove CO_2 from our well-mixed atmosphere, DACS deployment is only constrained by the availability of both local geologic storage and renewable energy to power the facilities without competing with decarbonization of the US economy. As we consider DACS deployment and technologies from an EEEJ perspective, it becomes evident that its co-benefits are predominantly socioeconomic in nature, with specific opportunity to provide job-transition opportunities in traditional energy communities (**Chapter 7 – DACS**). This economic opportunity will be especially beneficial in counties where BiCRS-feedstock availability is inadequate to sufficiently transition local workforces, especially those that are already underemployed with the skills and expertise to scale projects swiftly (Figure 9-28).

Socioeconomic Impacts

Due to the limited deployed capacity of DACS and the research-oriented nature of existing facilities, there are no precise estimates for job-creation potential with scale-up. Given the data currently available (**Figure 9-43** [156, 157]), we assume ~270 long-term maintenance and operation jobs created per 1-million-tonne-CO_2-per-year facility, in line with estimates by the Rhodium Group [158]. These long-term employment estimates, when combined with indirect-job-creation estimates, yield an estimated ~3400 total jobs per 1-million-tonne-CO_2-removal DACS facility [158]. These jobs

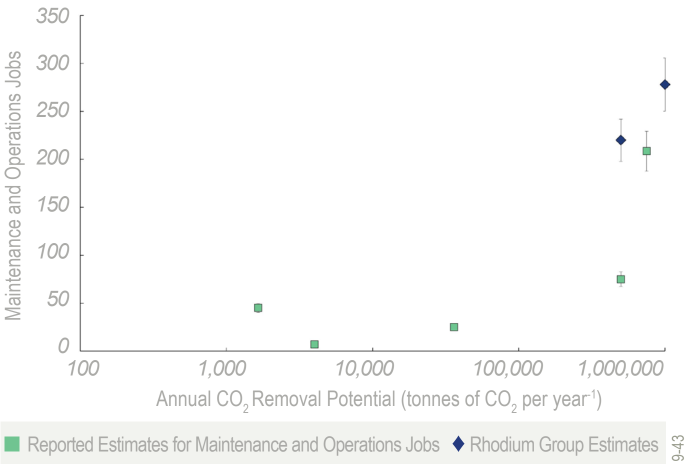


Figure 9-43. *Estimates of long-term maintenance-and-operations job creation for DAC facilities, including pilot plants that are currently operational and planned facilities, alongside the Rhodium Group estimates from 2020 and 2023 [156, 157]. Employment estimates were derived from publicly available news articles and corroborated by representatives at their respective companies.*

are expected to be skilled, high-wage jobs that align with current federal policy goals [36]. Of critical importance is where these jobs would likely be created and how they can play a role in an equitable transition. A study by Vanatta et al. (2018) [142] found that renewable energies, which are also expected to play a large role in job transitions, will not sufficiently cover coal-related job losses in UT, MT, NM, AZ, WY, or CO if optimized for costs. Coincidentally, however, these are the same regions where DACS is especially well suited (**Chapter 7 – DACS**). As outreach proceeds regarding job prospects in these regions, however, it is prudent to keep in mind that there is public distrust around job quantity and quality prospects associated with DACS; focus-group participants in counties primed for DACS-facility proposals voiced skepticism around DACS companies' willingness to support unionizing and follow through on local-hire commitments [159]. Making good on promises through enforceable community benefit agreements and transparent hiring reports at early DACS facilities may address these concerns and increase public trust as the industry matures.

Similar to geologic carbon storage, DACS projects also have opportunity, beyond jobs, to bring infrastructure improvements and new sources of revenue for landowners and public entities (e.g., federal, state, and local governments). Care must be taken, however, to ensure that these benefits are realized and distributed equitably, since land purchase/leasing agreements from private parties will disproportionately benefit landowners, who are rarely non-white due to discriminatory histories and practices (discussed at length in forestry and soils sections of this chapter). However, if optimizing for maximal equity in economic benefits flowing from DACS projects, then assessing what percentage of land in each county is publicly (versus privately) owned could help guide democratized opportunities, spearheaded by local governments, where revenues would be shared through lease agreements that benefit a tax base (e.g., federal, state, county, or tribal nation) (Figure 9-29) Box 9-6. DACS facilities are likely to be sited in rural, vacant tracts of land, so projects may develop new infrastructure that can mutually benefit the community, such as new roads, broadband internet access, water, or electricity infrastructure, which are not homogenously distributed in the United States currently (Figure 9-30). Communities can negotiate with project developers regarding infrastructure build-out to identify points for improvement that have the greatest shared benefit, including an initial regional assessment of infrastructure deficiencies [101-104].

To ensure that all members of the community receive benefits, not just those who are directly involved with a project, communities may also negotiate with project developers for a broad community benefit fund, with a designated portion of project revenue going to support projects or causes important to the community [105]. Another example of this is equity-enhanced subcontracting, such as giving small, local, and minority-owned businesses bidding priority to support the project, rather than bringing in external companies to support the build-out. Counties across the United States have varying abundances of minority-owned business that could be uplifted through partnerships with DACS; New Mexico and West Texas are examples of locations that have overlapping capacity for DACS at affordable prices (**Chapter 7 – DACS**), high minority-owned business abundance [48], and poor broadband availability (~30% is several counties; Figure 9-30). To be clear, however, these counties are under-resourced, highly vulnerable (Figure 9-3) [1], and overlap with several sovereign tribal nations. To avoid perpetuating industrial siting injustices, especially in the communities least responsible for climate change (a

key component of climate justice), projects would ideally be developed and designed internally, which will likely require capacity building that grows local carbon-management talent.

Environmental Impacts

Similar to many other large-scale industrial facilities, DACS will incur some temporary environmental and human-health impacts associated with constructing, operating and maintaining, and eventually decommissioning facilities. Impacts may include, but are not limited to, noise and light pollution, increased vehicle traffic and associated air pollution and safety risks, dust or other air pollution associated with site clearing and construction, water use, and visual impacts. These activities are limited in both duration and frequency but their negative impacts would be reduced by conversion to EVs and electrified equipment (e.g., trucks, drill rigs, other heavy machinery), which decrease airborne contaminants (i.e., diesel fumes) and noise pollution for employees, as well as any nearby communities [28, 124, 125]. Due to the specialized nature of some machinery, it is possible that a fully decarbonized fleet of construction vehicles/machinery will not be feasible. However, project developers and community members can negotiate mitigation and avoidance measures in advance of the project's permitting, which can be integrated into a community benefits plan [105]. Beyond emissions, other mitigation measures to reduce construction impacts are common for projects, such as the use of light/sound barriers, water-recycling practices or using non-potable water where possible, practices to reduce dust emissions associated with land clearing/road construction, and others. As demonstrated in the introduction to this chapter (Figure 9-2), the amount of suitable land available for DACS in the United States is vast. Most of that land is in remote areas where few or no people live and overlies geologic storage sites, which minimizes CO_2 transportation needs; remote locations like this could be prioritized for DACS to eliminate potential human impacts and avoid sensitive ecosystems. Beyond the construction phase, communities are often concerned by persistent impacts. Without commercial-scale DACS facilities and long-term operational records, there is minimal monitoring data on environmental impacts from DACS to report here, so we conducted a literature review to separate environmental impacts into two categories: those hypothesized from a technical lens and those resultant from studies of public perception.

Technology-Specific Environmental Impacts of DAC

Prior technical reports focused on water and energy usage, as well as air emissions. Water usage varies significantly between DAC processes and depends on the local climate, but solvent-based DAC processes require 1–7 tonnes of water per tonne of captured CO_2, with water usage stemming from evaporation in the air contactor [160]. Solid-adsorbent DAC can require less water per tonne of CO_2 captured, with some estimates suggesting approximately 1.6 tonnes of water per tonne of captured CO_2, where water usage stems from evaporation of a fraction of the steam used for regeneration [161]. For a 1-million-tonne-per-year facility, this could result in upward of 19,000 tonnes of water per day for a solvent-based process, equivalent to almost 17,000 average United States households [162]. In some DAC processes, particularly those that employ moisture-sensitive adsorbents, water harvesting from ambient air can be employed as a method of treating the air before it is sent to the DAC system, producing liquid water as a byproduct alongside CO_2. Considering the local water supply and current use, alongside the water consumption requirements of the DAC facility, and clearly communicating potential impacts early may assist with gaining the social license to operate in a county, especially if processes and materials with low water usage (or net water positivity) are chosen in water-scare counties.

As discussed previously, DAC technologies are energy intensive, requiring approximately 8 GJ of energy per tonne of CO_2 removed. Similar to water usage, this varies by location and climate. Regardless of these variables, however, DAC facilities require significant energy resources wherever they are located and will likely require additional energy-generation buildout. The additionality of the renewable energy build-out, including suitable land area for renewable energies that do not compete with community needs, is discussed in **Chapters 7 – DACS** and **8 – Cross-Cutting**. However, careful consideration of local communities' current and future land usage is required when expanding energy generation.

There are also concerns around the emissions released during DAC operation. Keith et al.'s study on solvent DAC (2018) [160] reported the model plant discharging approximately 1% of circulating calcium carbonate, acting as a purge stream for non-process elements, such as particles and dust accumulating during air intake. In addition, aerosolized potassium hydroxide solution is a likely emission due to its crossflow configuration with incoming air. Keith et al. reported that inspections carried out by Carbon Engineering measured a hydroxide concentration below 0.6 mg/m^3, but additional studies on the impact of plant scale and ambient environment, as well as potential buildup of these hydroxide and carbonates over time, are needed. Emissions from amine-based adsorbent DAC are almost entirely due to volatile species, primarily ammonia, released during the gradual degradation of the solid adsorbents during operation. Based on estimations of volatile-release rates [163], material-replacement intervals, and the quantity of air processed during operation [164], a 1-million-tonne-per-year facility would result in an average ammonia-concentration increase of only a few dozen parts per billion, well below US Occupational Safety and Health Administration (OSHA) exposure limits—50,000 parts per billion—and US Environmental Protection Agency (EPA) (2002) [165] air limits—2000–10,000 parts per billion [166]. However, accumulation is likely to be a concern over long periods of time, and additional studies on long-term emission profiles and new materials and processes that avoid these emissions are needed.

Public Perception of DACS' Environmental Impacts

These technical considerations of DACS' environmental impact overlap, in part, with community concerns around DACS facilities, excluding the geologic storage component, which was always was the largest source of environmental concern for study participants [159, 167, 168]. DACS-

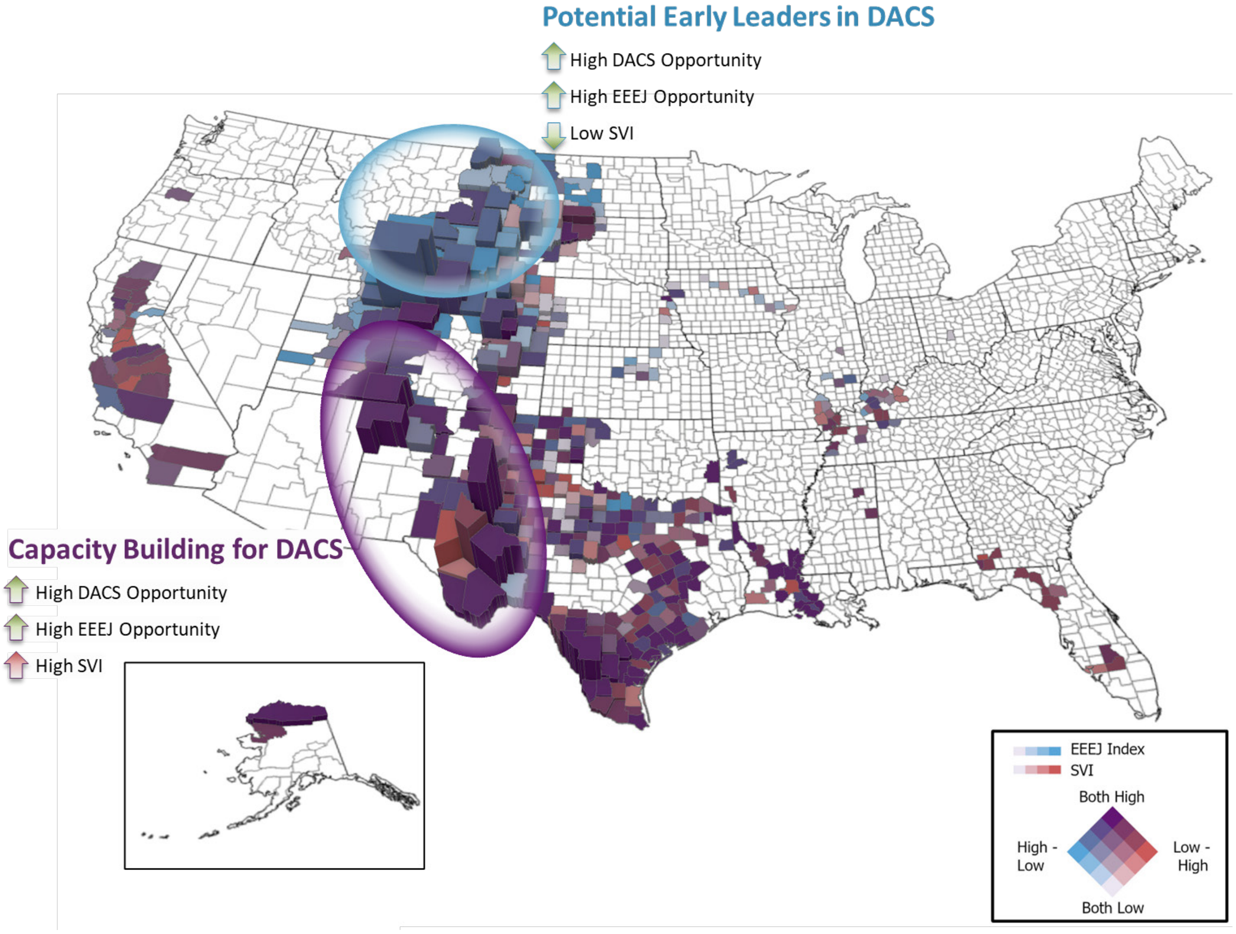


Figure 9-44. *Map of the CDC's Social Vulnerability Index (SVI) on the red axis and the EEEJ Index, calculated in this report, on the blue axis for DACS. The height of the counties represents the* CO_2 *removal and storage capacity of renewable energy-powered adsorbent DACS, relative to cost. This map is annotated to reflect our premise that DACS is a collaborative* CO_2 *removal method. Therefore, we highlight some less vulnerable counties that may be equipped to collaborate on projects as early adopters, as well as some counties with high* CO_2 *removal opportunities, but high SVI, which suggests that they may benefit from capacity building around the topic and its trade-offs.*

specific concerns that overlap include the uncertainty in air emissions, which many compared to the unknowns and subsequent pollution issues they faced when power plants were constructed [159], and competition with energy decarbonization [159, 167, 168]. The concerns voiced by study participants that were not reflected in the technical literature to date revolved around the durability of DACS as an industry, with concerns about its economic resiliency to mutable federal funding and the aesthetic and environmental burden it would leave behind if constructed and then shuttered [159]. Furthermore, participants voiced concerns over the impact that DACS facilities could have on local wildlife and hunting. No research exists on these impacts to date, so this represents a knowledge gap in publicly oriented CO_2-removal research.

DACS Summary

We created a first-of-its-kind EEEJ optimization index that merges geospatial data on variables relevant to DACS into a single index value to identify counties that may maximally benefit from DACS projects (**Figure 9-44**; methods detailed in the Appendix). This index is essentially the same as for geologic carbon storage but with the addition of anticipated water scarcity serving as a negative (DACS projects are cautioned to optimize for water conservation methods). In this report, we regard DACS as a collaborative CO_2 storage method; it is not commonly known of in the public realm and its co-benefits are predominantly socio-economic in nature; thus, projects may benefit from early, collaborative planning that ensures these co-benefits are distributed fairly for local residents. To leverage DACS as a tool for distributive justice, as the country aims to decarbonize deeply without inequitably causing economic hardship to energy communitie, prioritizing its early adoption in counties that are most likely to benefit but are also less vulnerable may be advisable to ensure that there is adequate social infrastructure and bandwidth to engage in project development. To facilitate the identification of potential early adopters, we constructed a 3-dimensional map that compares our EEEJ index values to SVI [69], as well as the affordability of CO_2 storage in each county with data from this report (**Chapter 7**) (**Figure 9-45**).

When plotted against SVI [69], we can identify counties with outsized opportunities for co-benefits, minimal social vulnerability, and—with the inclusion of cost data from **Chapter 7 – DACS**—maximal opportunity for DACS-based CO_2 removal (Figures 9-44). These counties may be strong candidates for early projects with accelerated timelines, while counties with higher SVI are prioritized for capacity building to engage on the topic/with DACS projects.

In conclusion, DACS represents a flexibly placed technological solution to climate-change mitigation that can bolster economies of traditional energy communities, which are experiencing the greatest hardships amidst decarbonization trends. This flexible placement offers outsized opportunities for equity-enhanced outreach to a diversity of landowners, who stand to financially benefit from lease/purchase agreements with DACS facilities. However, we must proceed with caution when it comes to siting DACS facilities in vulnerable counties which are likely not equipped to

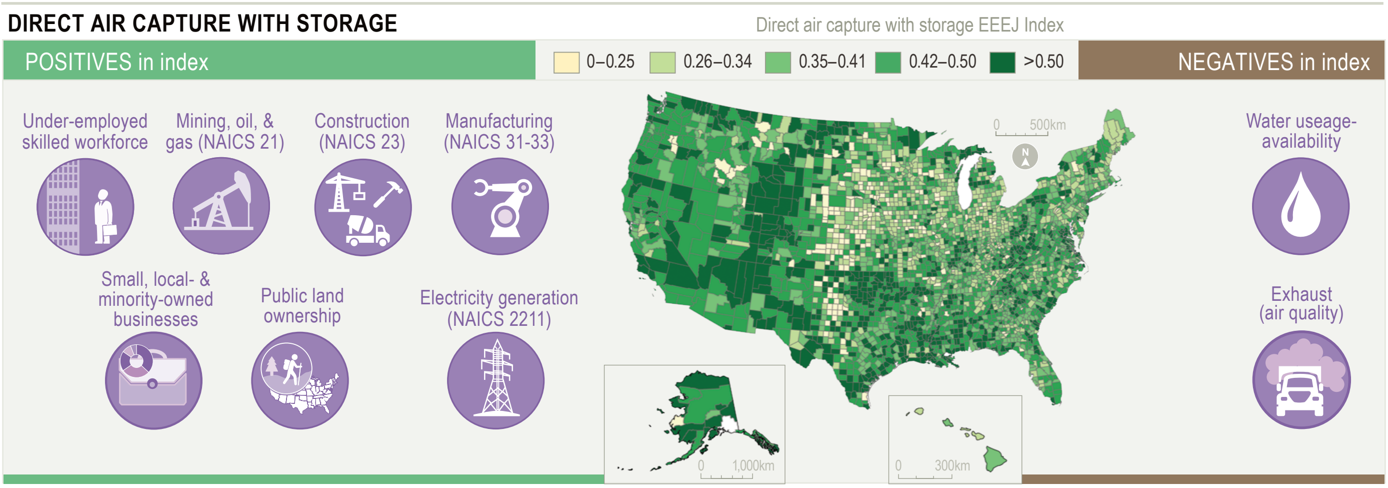


Figure 9-45. *Map of the EEEJ index for direct air capture with storage, alongside each variable that contributed, positively or negatively, to the index. The index is normalized from 0 to 1, where higher values represent a potentially greater opportunity for socio-economic co-benefits, including reemployment of skilled workforces and public pore space that distributes revenues to the tax base. Higher values also represent a smaller potential for negative environmental impacts, such as competition for scarce water resources or air pollution risks from the construction and/or operation phases, indicated by diesel-derived PM2.5.*

BOX 9-7

Community Benefit Fund

A community benefit fund is a financial pool created by businesses or organizations to support local projects and initiatives, contributing to the well-being and development of a specific community. These funds could be established through pre-determined contributions or other financial mechanisms (e.g. $ per tonne of CO_2 removed or stored geologically) to address community needs and enhance residents' quality of life.

engage with DACS project developers from an informed position of power regarding the value of their land and underground pore space. Capacity building that is not associated with or financed by specific projects could help bridge this community-hesitancy gap in regions ideal for DACS deployment. According to our combined EEEJ and SVI analyses (Figure 9-44), alongside the modeling results from **Chapter 7 – DACS**, we find that Wyoming and North Dakota have some of the best examples of counties poised to experience maximal co-benefits, with minimal risks and low social vulnerability, alongside technoeconomic benefits. Some counties in New Mexico, such as Lea, Harding, Lincoln, and Colfax, are also poised to experience outsized co-benefits from DACS deployment. However, their high social vulnerability suggests that supplemental capacity building and investments prior to outreach may benefit the communities and the DACS industry as a whole. The commercial-scale DACS industry is in its infancy, providing ample opportunity to design best engagement and operating practices for deploying DACS around EEEJ principles, such as prioritizing workforce transitions, investing in community infrastructure, implementing equity-enhanced outreach to landowners, and going above and beyond regulatory emissions-monitoring requirements. By doing so, we can hopefully foster a DACS industry that mitigates both climate change and the socioeconomic challenges associated with it.

Regional Highlights and Opportunities

In this section, we are compiling highlights from every region, as well as the aspect of environmental justice with which it most closely aligns.

- **Alaska (recognition justice):** The North Slope of Alaska clearly has some of the greatest workforce-transition needs in the nation, with approximately half of its total county jobs stemming from the mining, oil, and gas sector (NAICS 21). Its limited biomass, forestry, and renewable-energy availability, as well as economically stranded natural-gas reserves and abundant geologic carbon-storage-suitable pore space make DACS the CO_2-removal method best-suited to its workforce-transition. Recent (2017–2022) job-loss trends in the NAICS 21 sector in the North Slope are ~480 jobs per year. Re-employment of these individuals at a DACS facility, if employment trends persisted, would be enough to scale up DACS in the North Slope at a rate of ~1.7 million tonnes of CO_2 per year. There is also ample room for infrastructure improvements and publicly owned land, which opens the opportunity for democratized benefits. Furthermore, Alaska has an infrastructural resource that no other state has—the Permanent Dividend Fund—a statewide revenue-sharing program for all the state's residents, which is currently funded through oil and gas but could be funded based on carbon sequestration as well. This program sets Alaska apart as one with exceptional opportunity for statewide democratization of the financial benefits of carbon management. Finally, Alaska's other unique revenue-sharing methods—the Permanent Dividend Fund and ANCSA, Section 7(i)—provides a unique opportunity, found nowhere else in the United States, for revenue sharing to directly, financially benefit all residents across the state, with additional benefits for Native Alaskans.

- **Appalachia (recognition justice):** The Appalachia region has been hit famously hard by coal-job losses. We found consistent job-loss trends in Appalachian states, such as Kentucky and West Virginia, that had a large impact on each county's job inventory. The county in Kentucky that stood out as having exceptional opportunity for affordable geologic carbon storage was Muhlenberg County, with an estimated cost of only \$6.50/tonne CO_2. In West Virginia, however, the storage costs were much more expensive—the cheapest was Grant County at \$14.32/tonne CO_2. This geospatial heterogeneity in CO_2-storage costs indicate that the Appalachian region may benefit from collaborating to create a holistic plan for the region that prioritizes re-employing those affected by coal-job losses and reimagining what their future could look like. Beyond geologic carbon sequestration, however, there were also opportunities for soil-carbon storage, specifically from cover cropping and especially in KY (e.g., Logan and Christian counties).

- **California Central Valley (restorative justice):** The California Central Valley has some of the worst air quality in the nation; its residents are inequitably burdened with PM2.5 emissions from the energy and agricultural industries, automotive/freight travel, wildfire smoke, and cropland/rangeland burning. These air-quality issues compound water-quality issues, predominantly due to fertilizer- and manure-derived nitrogen. According to the CDC, the California Central Valley is one of the most socially vulnerable regions of the United States, and thus it is questionable how residents can be engaged in geologic-storage-based CO_2-removal projects from a place of power. This may necessitate locally grown capacity building and, in the near-term, a focus on its outsized co-benefit potential from implementing soil-management practices for carbon storage, which could be a suitable avenue for impactful engagement that rectifies some of the current pollution issues currently. Further, swift decarbonization may greatly reduce air pollution as well. As a highly vulnerable region, adoption of well-established soil-carbon management methods may be positively received in this region; Merced and Colusa Counties had some of the highest opportunities for soil-based CO_2 removal (with high EEEJ co-benefits) from perennial field borders and cover cropping, respectively. These practices could immediately reduce nitrate pollution, herbicide runoff, and soil erosion for nearby residents.

- **Desert Southwest and Lower Rocky Mountains (procedural justice):** New Mexico has some of the best opportunities for DACS in the United States, but it is also one of the most socially vulnerable regions, with high density of different sovereign tribal nations. Given the social vulnerability of the region, it is unlikely to have capacity to engage from a place of power on carbon management, so instigating distrust around the CO_2-removal industry by engaging prematurely may be ill advised. That said, affordable DACS capacity is present in the region, and the tribes own their land and pore space. If they chose to develop a project for their community that maximizes their economic benefits and minimizes risks, then there is the potential that their energy communities, who were hit hard by coal closures (e.g., Navajo Generating Station), could rebound as DACS leaders.

- **East Cascades (restorative justice):** In part due to climate change, Idaho's Clearwater region has high burn probabilities and has also experienced a recent decline in its forestry and logging sector workforce, upon which some of its counties heavily rely. Furthermore, it experiences high PM2.5 pollution from all the western forest fires due to its position in the "smoke wave." Policies or programs that support re-employment of the broader western US forestry workforce to mitigate burn probability and divert the forest residues to BiCRS, would likely help avoid further PM2.5 pollution and improve much of the region's inequitable wildfire-induced air-quality burden.

- **Great Basin (distributive justice):** The Great Basin region has uniquely limited opportunities for any of the CO_2-removal methods discussed in this report. However, while the northern part of Nevada has limited forestry and soil-carbon opportunities, southern Nevada does have a White-House-designated energy community. This minimal opportunity to engage in CO_2 removal has the potential to economically benefit a region forecasted to experience greater burn probability of its limited forests due to drought. These limited CO_2 removal opportunities around concerns around the role of distributive justice in engaging the Great Basin region in a way that benefits them since they are slated to experience some challenging effects of climate change.

- **Hawai`i (procedural justice):** Currently, the permitting structure for Class VI wells is not set up for mafic storage, but research is gaining momentum in this space. If Hawai`i were ever to be considered for CO_2 mineralization in its basaltic pore space, it would be advisable to build locally grown capacity to engage on the topic as soon as possible, well before it may be proposed. Furthermore, the island chain's unique land limitations and abundant biomass and renewable-energy resources represent an outsized opportunity for BiCRS implementation as a method of reducing landfill pressures.

- **Lower Midwest (restorative justice):** The lower Midwest has high soil-based CO_2-removal potential, with high opportunities for environmental mitigation of several pollution issues relevant to human health—high nitrate concentrations in local waters, herbicide application rates, and soil erosion rates. There are also several tribal nations along the Kansas-Oklahoma border, where equity enhanced outreach could take place if financial assistance were available for soil-based CO_2-removal methods to assist the diversity of crop producers that live in the Lower Midwest region.

- **South Central (restorative justice):** The South-Central region has an abundance of diverse farm operators, likely derived from its abundance of tribal nations, but an average county farm net income that is often negative. Thus, this region has opportunity to experience both economic and environmental co-benefits from policies/programs that incentivize soil-carbon storage and the diversion of biomass from croplands/rangelands, which cause inequitably large impacts on the region's air quality, with >100 short tons per year of PM2.5 pollution in many counties from agricultural waste burning.

- **Southeast (procedural and restorative justice):** PFAS contamination is common, so the long-term safety and sustainability of BiCRS operations in the region may opt to focus on one of the three PFAS-destroying methods. This region has many opportunities for BiCRS, which can reemploy skilled, underemployed workforces. However, the region also has a large tribal-nation presence with many struggling farms and high agriculture-related pollution issues, minimal broadband access (indicative of subpar infrastructure, in general), and high crop-residue burning-derived PM2.5 air pollution. Thus, this entire region is really a challenge when it comes to capacity building in such a vulnerable and highly disinvested/marginalized region. Focusing on immediate restorative justice opportunities through well-understood and accepted CO_2-removal methods (e.g., soil management and forestry) may help reduce some of the immediate pollution concerns. Further, simultaneously investing in capacity building around less ubiquitous CO_2-removal methods (e.g., DACS) might benefit this region.

- **Upper Midwest (distributive justice):** Ecological CO_2-removal methods (e.g., forestry and soils) are likely to work well in northern counties of the Upper Midwest, and geologic solutions would help with energy-community workforce transitions in the southern counties. We also observed some potential early adopter opportunities in northern Minnesota, if there were interest in BiCRS projects.

- **Upper Rocky Mountains (recognition justice):** Wyoming clearly has some of the greatest workforce-transition needs in the nation, the highest DACS and geologic carbon storage potential (by geophysical and EEEJ potential), and ample publicly owned land, which opens the opportunity for democratized benefits. Furthermore, the region is relatively low on the social vulnerability scale, which suggests it may have the social bandwidth and infrastructure to productively engage in early-adoption carbon-management projects.

- **West Coast (recognition and restorative justice):** Southeastern Oregon counties have experienced exceptional job losses relative to their county job-inventory size. Furthermore, with climate change, this region is expected to experience a relatively high burn probability, further contributing to smoke that negatively impacts the health of many Americans in the west.

- **Western Cities and Florida Peninsula (distributive justice):** Relative to the rest of the United States, some of the coastal counties in these two regions have low social vulnerability with high EEEJ index values for BiCRS methods—specifically, pyrolysis-asphalt and gasification-H2 in both regions and wet-waste-based BiCRS (AD and HTL) in the Florida Peninsula. This suggests that, perhaps, these two regions may be ideal for early adoption of BiCRS-conversion projects.

Conclusions

Every CO_2-removal method has potential co-benefits and risks; however, there is even greater risk, especially to highly vulnerable counties, from climate change and failure to act against it. Through the context of the four facets of environmental justice (procedural, distributive, recognition, and restorative), we conclude with key findings from the nexus of EEEJ, SVI, and CO_2-removal from this chapter. First, less vulnerable counties may be better poised to engage in collaborative CO_2 removal project developments,, which sets them up for a more procedurally just negotiation around a community benefit agreement. For this reason, we recommend that *project developers for CO_2-removal methods that are perceived as first-of-their-kind prioritize collaboration with less vulnerable counties for projects requiring accelerated deployment*. More vulnerable counties may be better suited for collaboration with projects that have a less compressed timeline, allowing time to establish trust, build engagement capacity, and clarify co-benefits between developers and the community. Second, public lands are inherently well-distributed resources, given the shared responsibility across pertinent taxpayers. For this reason, we recommend *considering CO_2-removal projects on public lands when possible*, which have the potential to flow financial benefits directly back to taxpayers (e.g., state, federal, or tribal residents), rather than inequitably benefiting corporations or individuals. Third, we must recognize that not all counties are/will be impacted by climate change or decarbonization in the same way or with the same magnitude. Where negative impacts are expected to have outsized consequences (e.g., worsening wildfires), especially on counties that likely played a minimal role instigating climate change overall (e.g., remote tribal nations in forested regions), we recommend *considering the restorative-justice opportunities that increase county-level resilience and pollution/hazard-mitigation opportunities.*

We recommend that the results in this chapter, as well as the EEEJ sections of other chapters in this report, be used in the following ways:

1. By *community members* to understand the plethora of trade-offs associated with each CO_2-removal method analyzed here to negotiate or participate in project development from a position of informed power.
2. By *project developers* of different CO_2-removal methods to understand that perceptions regarding common practice versus first-of-its-kind matter when assessing sites to propose; considering counties that are poised to support the project is critical to a project's overall potential to come to fruition.
3. By *policymakers* to contextualize the opportunities and potential challenges that they may want to balance when considering CO_2-removal scale-up.

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