Equitable Housing Decarbonization: Implementation Approaches

Final Report

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Disclaimer

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Executive Summary

Housing decarbonization is essential to meeting California's climate and equity goals. Beyond reducing greenhouse gas (GHG) emissions, retrofitting homes to be cleaner and more efficient delivers profound social and health benefits. It improves indoor and outdoor air quality and reduces respiratory illnesses such as asthma in communities most burdened by pollution. It strengthens resilience to extreme heat and other climate hazards, and it improves housing quality by remediating hazards such as mold, lead, and asbestos. When paired with energy efficiency and solar, decarbonization can also lower energy burdens, advancing long-term economic and energy security for vulnerable and disadvantaged populations.

Yet the households that stand to benefit most have largely been left out. Low- and moderate-income (LMI) households, renters, and residents of disadvantaged communities have historically participated in decarbonization programs at far lower rates than wealthier homeowners. To build a stronger knowledge base of how to undertake equitable decarbonization programs, the California Air Resources Board (CARB) partnered with researchers at the University of California, Berkeley and a coalition of community and environmental justice organizations. Using a Participatory Action Research approach that engaged community partners throughout, the study combined a statewide analysis of programs and policies, an in-depth case study of households navigating retrofit programs, and an analysis of how cost-effectiveness frameworks can better account for equity. This executive summary presents the study's main findings and recommendations.

Key Findings

The participation gap is not a matter of insufficient interest. It is the product of barriers that accumulate across every stage of a household's journey. We organize these barriers into five dimensions: Learning (awareness and motivation), Capacity, Affordability, Buildings and Neighborhoods, and Governance. LMI households face disproportionate barriers at each dimension, and those barriers compound—only households able to clear all five reach project completion. The central takeaway of this report is therefore that equitable decarbonization requires coordinated action across all five dimensions simultaneously. Programs that address one barrier in isolation—a rebate without navigation support, or an incentive without funding for the health-and-safety repairs that must precede electrification—will continue to leave priority communities behind.

Several interlocking factors explain why current programs fail to reach priority communities:

- **Disparities in the built environment.** Priority communities are more likely to live in older homes—56 percent of California's housing stock predates 1980—that require health-and-safety remediation (mold, lead, asbestos) before electrification can begin, and in neighborhoods with inadequate electrical infrastructure (electric panel, circuit, and transformer capacity). These upgrades are costly and typically not covered by residential energy programs, making participation prohibitive for the households that need it most.

- **A mismatch between incentives and financial reality.** High upfront capital requirements put tax credits and rebates out of reach for LMI households; poorly coordinated eligibility criteria make it difficult to stack incentives across programs; and California's high electricity rates relative to natural gas threaten to raise energy bills after electrification, undermining its financial viability.
- **Workforce shortages and limited navigation support**. Contractors are the primary guides through program complexity, yet a shortage of skilled, decarbonization-trained labor—most acute in rural parts of the state—leaves households to manage the technical, administrative, and financial steps largely on their own.
- **Uneven local government capacity and coordination.** A household's ability to electrify their home depends heavily on the capacity of its local government to coordinate the process. Higher-resource jurisdictions may have staff resource centers that connect residents to programs and contractors, coordinate across building, planning, and utility functions, and offer streamlined, same-day permitting—lowering administrative burden, shortening timelines, and reducing implementation cost. The lack of these services in low-resource communities makes it more difficult to navigate and complete programs.
- **Unaddressed challenges in multifamily and manufactured housing, and weak renter protections.** Multifamily buildings and mobile and manufactured home parks face distinct regulatory and energy-infrastructure hurdles. Forty-five percent of California households are renters, who confront split incentives—landlords lack motivation to upgrade energy systems, while tenants risk rent increases or displacement when retrofits occur without enforceable protections.

Drawing on 126 in-depth interviews with policy designers, energy providers, implementers, community-based organizations, and households, the study also found that program fragmentation and lack of coordination across agencies exacerbated these barriers. State and local agencies and utilities operate more than 300 distinct housing decarbonization programs, and while this has produced experience and innovation, it has also created an uneven landscape of service provision in which priority communities remain underserved. Because programs are spread across federal, state, and local initiatives with divergent goals, eligibility criteria, and reporting requirements, households struggle to stack the incentives needed to fund retrofits, and implementers shoulder an administrative burden so heavy that, as one local government respondent put it, applicants sometimes "forego the money" rather than navigate it.

The in-depth pre- and post-retrofit case study made these barriers concrete. Of 18 Bay Area homeowners who had actively sought to electrify their homes—working in a region rich with incentives and "one-stop-shop" implementers—only 11 completed their projects. The reasons for drop-off divided sharply along income lines: higher-income households that withdrew did so as a discretionary calculation about return on investment, whereas the LMI households that withdrew did so because of structural, technical, and financial barriers. Notably, even high-income, well-supported participants struggled to navigate the process.

The study also addresses a gap in the evidence, assessing the outcomes of electricity retrofits among low-income households. Using a multidimensional Energy Security Score developed for this project, the team surveyed households before and after their retrofits. Improvements in energy security depended on usability—whether residents could both operate their new equipment and were satisfied with the quality of the installation. Only 43 percent of participants met both conditions. Among these high-usability households, energy security scores rose by a statistically significant 26.9 points; among low-usability households, scores rose just 8.1 points, a change indistinguishable from zero. Installing heat pumps and electric appliances is therefore necessary but not sufficient: without resident education, in-language guidance, and quality assurance on installation, retrofits may not produce the intended benefits of electrification.

Recommendations

To scale residential decarbonization equitably, California must shift from an individualized model—in which each household assembles its own retrofit—to a coordinated, structural approach. Our recommendations are organized by program stage.

System Level

- **Coordinate across agencies.** Form an inter-agency working group to align program design, implementation, and evaluation across state agencies and local representatives, and to report on progress toward climate, energy, and equity goals.
- **Build cross-sector partnerships.** Align funding across energy, housing, and healthcare partners so the combined health, safety, and electrification work needed in the worst housing conditions can be financed together.
- **Fund CBOs as strategic partners**. Engage community-based organizations as fully compensated partners across program design, implementation, and evaluation.

Program Design

- **Fund retrofit needs in priority communities.** Allocate flexible funding for health, safety, and electrical upgrades as a fundamental prerequisite to electrification.
- **Enable incentive stacking.** Coordinate measures and eligibility criteria across energy, health, and housing programs so households can layer support efficiently.
- **Match incentives to need.** Rely on no-cost direct-install programs for low-income households and expand inclusive utility investment or green financing for moderate-income households.
- **Protect energy affordability.** Scope programs to reach bill neutrality or savings and help participants enroll in bill-assistance programs and rate plans suited to their needs.
- **Invest in participant support and renter protections.** Provide support across learning, capacity, and post-installation education—scaling proven California models such as the energy navigator and local resource centers—and adopt enforceable tenant protections in all programs affecting renters.

- **Tailor to ownership structure.** Design targeted programs for HOAs, affordable housing, multifamily buildings, and manufactured home parks, addressing split incentives and ensuring solar and storage benefits are distributed equitably across all units rather than a single meter or owner.

Program Implementation

- **Align energy infrastructure with retrofits.** Coordinate electrical panel and grid-capacity upgrades with decarbonization projects so homes have the technical capacity to electrify.
- **Invest in workforce development.** Standardize decarbonization certifications, fund high-road training partnerships, and support small contractors with capital access and simplified reporting to help them enter the market.
- **Equip local governments.** Provide building departments with training and standardized guidelines for new technologies to expedite and standardize permitting.
- **Use place-based approaches.** Apply geographic clustering or zonal decarbonization to coordinate building retrofits, grid upgrades, and gas decommissioning at the neighborhood scale.

Program Evaluation

- **Refine benefit-cost analysis.** Incorporate health, comfort, and safety non-energy benefits into the Societal Cost Test (SCT) and Total Resource Cost (TRC) Test to reflect the full value of programs serving priority populations.
- **Embed distributional equity analysis**. Require programs to report participation, drop-off rates, and funds distributed by income, race, tenure, housing type, and geography.
- **Standardize equity metrics.** Collect granular, participant-level data on race, income, tenure, and housing type across all programs rather than relying on neighborhood proxies.
- **Measure energy insecurity.** Use standardized pre- and post-retrofit surveys built on the project's Energy Security Score to verify that programs improve the physical, economic, and coping dimensions of household energy security.

Conclusion

Equitable housing decarbonization is not solely a technical challenge; it is an institutional and social one. California has already built an extensive set of programs, but fragmentation across agencies and funding streams has produced barriers that fall hardest on the households the state most needs to reach. Meeting California's climate and equity goals will require moving beyond isolated programs toward an integrated framework that coordinates across energy, housing, health, and workforce development—one that aligns incentives, simplifies participation, and ensures the benefits of cleaner, healthier homes are shared broadly. By centering the needs of priority communities and strengthening collaboration across agencies and stakeholders, California can accelerate building decarbonization while advancing housing stability, public health, and economic opportunity for residents across the state.

1. Equitable Housing Decarbonization: Implementation Approaches: Project Overview

Introduction

In June 2023, the California Air Resources Board (CARB) partnered with researchers from the University of California, Berkeley, to conduct a study on equitable implementation pathways for housing decarbonization. This project was conducted in collaboration with community-based and environmental justice organizations via a participatory action research (PAR) model. This report summarizes key findings and policy recommendations organized by research tasks:

- **Chapter 1: Participatory Action Research (PAR)** is the project's framework for co-creating research alongside community and environmental justice partners. We describe the project and formation of an advisory committee and the workshop process used to guide data collection, analysis, and the development of policy recommendations.
- **Chapter 2: Literature Review** synthesizes existing research on the equity implications of residential decarbonization program design, implementation, and outcomes.
- **Chapter 3: Statewide Analysis.** Drawing on 126 interviews with key actors, this chapter evaluates the enabling and inhibiting factors that affect the adoption of housing decarbonization programs, with a focus on priority communities. [1]
- **Chapter 4: Household Survey.** This chapter focuses on the engagement experience of homeowners and renters and its impact. We present two key findings: (1) a framework to understand the cumulative factors impacting household ability to complete installation, and how they differ by income; and (2) we introduce a standardized diagnostic survey tool to measure the impact of energy retrofits on a household's energy insecurity.
- **Chapter 5: Policy Cost Analysis.** This section explores new approaches to embed equity into policy evaluation, ensuring that the health, safety, and comfort benefits experienced by priority populations are accurately valued. This section also presents recommendations for collecting and reporting on equity metrics, and for incorporating a distributional equity analysis framework into program evaluation.
- **Chapter 6: Policy Recommendations.** Grounded in the study’s mixed-methods research design and findings, this concluding chapter presents actionable strategies for the State to scale equitable housing decarbonization. It organizes structural recommendations across program design, implementation, and evaluation to shift the administrative burden away from individual households and onto coordinated institutional systems.

[1] Priority communities include low- and moderate-income (LMI) households, renters, disadvantaged communities as defined by California SB 535 (https://oehha.ca.gov/calenviroscreen/sb535), and tribes.

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Participatory Action Research (PAR)

This project utilizes a Participatory Action Research (PAR) framework to co-create research activities alongside community partners. The PAR framework is particularly well suited for this project because it (1) centers the perspectives, needs, and priorities of underrepresented communities in the production of knowledge; (2) ensures findings and recommendations for action are grounded in the experiences of the population the intervention seeks to serve; (3) is an effective methodology to bolster local leadership and capacity for action; and (4) is action-oriented. In the context of making recommendations for equitable housing decarbonization in California, PAR both centers equity in the production of knowledge and responds to the demand of environmental justice communities to participate in housing decarbonization research and decision-making.

The UC Berkeley team implemented the PAR model in several steps:

1. **Formed a project Advisory Committee** which includes non-academic organizations that bring essential field-based expertise to the project. These partners, with specialized knowledge in implementing housing decarbonization programs for priority populations, contribute critical perspectives and practical insights that academic institutions alone cannot provide. Together with UC Berkeley's academic team, they ensure that the research is grounded in community needs and poised to inform equitable policy outcomes.

    a. **The Building, Energy, Equity, and Power (BEEP)** coalition members are representatives of community-based organizations across California who together work to advance equitable housing decarbonization. BEEP coalition members have insider knowledge and expertise regarding the multiple conditions that affect participation in housing decarbonization programs among low-income households and communities of color. They have previously published reports highlighting their concerns and recommendations for equitable decarbonization (Solis, 2022; Solis et al., 2022; Chelsea Kirk, 2021). Further, as community leaders, they have established relationships with priority communities and are best positioned to advise on outreach, socialization of knowledge, and strategies for building local capacity for implementation.

    b. **The Green and Healthy Homes Initiative (GHHI)** is dedicated to addressing the social determinants of health, opportunity and equity through the creation of healthy, safe and energy-efficient homes. By delivering a standard of excellence in its work, GHHI aims to eradicate the negative health impacts of unhealthy housing and unjust policies for children, seniors and families to ensure better health, economic and social outcomes in historically disinvested communities – with an emphasis on communities of color. GHHI is engaged in program design, implementation, and evaluation of housing decarbonization programs for priority communities across the U.S. and has published studies to advance knowledge on these topics (Norton and Brown, 2014; Green & Healthy Homes Initiative, 2023).

c. **The Association for Energy Affordability (AEA)** has been contributing insights on this project as a steering committee member and through interviews. AEA is a 501(c)(3) not-for-profit technical services and training organization at the forefront of increasing energy efficiency and green building practices in multifamily buildings. Since 1992, AEA has carried out a broad range of activities and programs benefiting low-income multi-unit residences, including: providing energy audits for thousands of buildings representing hundreds of thousands of dwelling units; conducting extensive energy usage analysis; research, development and demonstration of advanced residential building load control technologies; commissioning and retro-commissioning; delivering energy-efficient building operations training to several hundred property management and maintenance personnel; and designing and implementing high-impact programs that serve the needs of the communities.

d. **The Greenlining Institute** participated in the first year of the project. Greenlining is an Oakland-based nonprofit organization advancing racial equity in California via research and policy advocacy efforts. The Greenlining Institute advances energy equity by supporting the development of policies, programs, and initiatives toward equitable building decarbonization and ensuring that communities of color have access to clean energy technologies. The Greenlining Institute previously engaged in a coalition on issues surrounding clean energy and housing, developed a framework for equitable building electrification (Miller et al., 2019), and advanced regulatory reforms for equity in California state agencies.

2. **Co-designed the collaboration process** with members of the Advisory Committee. The academic team facilitated two workshops to design the participatory action research process with Advisory Committee members. The outcome is a Memorandum of Understanding (Appendix A).

3. **Facilitated workshops for collaborative research design and analysis.** For each of the research tasks, the Advisory Committee convened once before commencement of the task to provide guidance on the proposed research design and data collection, and once during the data analysis phase to provide guidance on analytical approaches and results interpretation. The Advisory Committee also convened to provide guidance on policy recommendations and dissemination strategies to effectively reach decision-makers, communities, and other audiences.

Schedule of Advisory Committee Meetings

We conducted the following workshops to develop the research process and research design, and to analyze preliminary findings.

TABLE 1: ADVISORY COMMITTEE WORKSHOP TOPICS

Meeting Date	Workshop Topics
May 2023	• Develop research design for the household survey
July 2023	• Develop the Participatory Action Research (PAR) approach • Develop research design for the statewide analysis • Receive guidance on the literature review
March 2024	• Develop research instruments for the statewide analysis (interview guides for program designers, community organizers, and implementers)
May 2024	• Develop a strategy for knowledge sharing as part of our PAR process
July 2024	• Data analysis of preliminary findings from the household survey
October 2024	• Data analysis of preliminary findings from the statewide analysis
February 2025	• Data interpretation of the pre-retrofit household survey
March 2025	• Data interpretation of findings from the statewide analysis
April 2025	• Data interpretation of findings from the statewide analysis
June 2025	• Development of policy recommendations
November 2025	• Development of policy recommendations
January 2026	• Approaches to embed equity in benefit-cost analysis
February 2026	• Development of policy recommendations
April 2026	• Data analysis of post-retrofit surveys • Finalize policy recommendations

2. Literature Review – Executive Summary

Energy retrofits of residential buildings support the achievement of California's climate and environmental justice goals.[2] In support of these state goals, the California Air Resources Board (CARB) partnered with researchers from the University of California, Berkeley, as well as community and environmental justice organizations, to conduct a study on equitable implementation pathways for housing decarbonization. Part of this study included a literature review designed to provide state and federal agencies with an overview of research findings related to the equitable implementation of housing decarbonization programs.

This executive summary presents the key findings of the literature review. The full literature review can be accessed on the California Air Resources Board website: https://ww2.arb.ca.gov/equitable-housing-decarbonization-implementation-approaches. It is also included as Appendix G of this report.

The literature review is structured as follows: the introduction describes the project and team, California state goals and policy alignment, housing decarbonization measures, and their impact on public health. The section on equity in program design discusses existing conditions in the home and opportunities to meet retrofit needs; electricity rates and infrastructure readiness; landlord/tenant split incentives; access to technology, capital, and financing; perceptions, knowledge, and concerns about decarbonization; workforce issues; and social factors. The section on equity in program implementation discusses welfare approaches, market-based incentive and regulatory approaches, and community-based approaches. The final section on equity in program outcomes, including greenhouse gas (GHG) emission reductions, climate resilience, housing security, energy security, population health, and health equity. Below, we summarize the key findings from each section of the literature review.

Equity Implications for Program Design

Housing decarbonization program designers, often staff in state or local governments and energy utilities, need to address a complex set of conditions that affect the ability of households to participate in decarbonization programs. Evidence shows that priority communities (e.g., low- to moderate-income (LMI) households, renters, and disadvantaged communities, as defined by California Senate Bill 535 and the U.S. Department of Energy through the Justice40 Initiative) are disproportionately affected by conditions that limit their ability to participate in housing

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[2] Relevant legislation includes AB 32: https://ww2.arb.ca.gov/resources/fact-sheets/ab-32-global-warming-solutions-act-2006; SB32: https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160SB32; AB1279: https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=202120220AB1279; SB 350: https://www.energy.ca.gov/rules-and-regulations/energy-suppliers-reporting/clean-energy-and-pollution-reduction-act-sb-350; SB535: https://legiscan.com/CA/text/SB535/id/179871; AB1550 https://digitaldemocracy.calmatters.org/bills/ca_201520160ab1550; AB197: https://digitaldemocracy.calmatters.org/bills/ca_201520160ab197.

decarbonization programs. Often, households face several barriers simultaneously, demonstrating the need for comprehensive program designs that take the following barriers into consideration:

- **Existing Conditions in the Home (Retrofit Needs):** Fifty-six percent of housing units in California were built before 1980.[3] Older homes are more likely to have irregular construction, structural issues related to the roof, a roof orientation unsuitable for solar panel installation, hazardous materials (e.g., asbestos siding or insulation, vermiculite insulation, and lead paint), unsuitable electrical systems, mold, pests, or other issues often related to deferred maintenance. Even though remediation of these conditions is often a prerequisite for implementing decarbonization measures, funding for retrofit needs is often not included in existing programs.
- **Electricity Infrastructure and Rates:** Seventy percent of California households use combustible fuels (e.g., natural gas, propane, wood) for heating and cooking.[4] Transitioning to electric appliances will increase demand on the electric grid, and in some cases, will require upgrades to the distribution infrastructure. Ratepayers can face long waiting times to get a cost estimate for the required upgrades and must pay out of pocket for the upgrades between the transformer and the home. Acknowledging these challenges, the California Public Utilities Commission (CPUC) is piloting a new program to relieve low-income ratepayers of these costs. At the same time, it is still unclear how many people will have access to this pilot. There remain unanswered questions about who should be paying for grid upgrades as well as what the impacts will be for ratepayers, LMI households. Furthermore, the higher the electricity rates compared to natural gas rates, the less likely electrification will be financially feasible. Disadvantaged communities disproportionately live in areas with low circuit capacity (Brockway et al., 2021), which limits solar adoption, and pay higher energy bills per square foot of living space (EIA, 2023), thus hindering their ability to adopt decarbonization measures. Therefore, there is a need to consider the impact of electricity price and infrastructure on the feasibility and affordability of housing decarbonization projects.
- **Access to Capital and Financing:** Most market-based incentive programs rely on the premise that investment in home energy efficiency pays for itself over time. However, LMI households may not have the financial ability to finance the upfront costs of decarbonization projects and upgrades. Electrification retrofits may not be cost-effective without further investment in energy efficiency, solar panels, or both. While low-income households should be targeted for no-cost direct install programs, among moderate-income households, there is a need to address the green financing gap.
- **Landlord/Tenant Split Incentives:** Forty-five percent of households in California are renters who have lower incomes than homeowners.[5] Renters face barriers due to split

[3] 2022 American Community Survey, Table B25034.
[4] 2022 American Community Survey, Table A10034.
[5] 2022 American Community Survey, Table B25003.

incentives with landlords, where neither party has sufficient motivation to invest in energy efficiency upgrades. This can lead to two different negative outcomes for renters: (1) if their home is excluded from retrofitting, they could incur higher energy bills as a result of energy inefficiency in their units and increasing utility prices, or (2) if their home is retrofitted by the landlord, the landlord might try to recover the cost of the investment via higher rents, which could displace low-income residents. Policy designers must include strategies to both financially incentivize landlords to undertake retrofits and protect renters from rising costs and displacement pressures.

- **Capacity to Engage:** The capacity of households to engage with a decarbonization project depends on a variety of factors, including the ability to make changes to the housing unit, language and cultural access, knowledge about the program, ability to find and connect with opportunities, ability to navigate bureaucracies, an understanding of the benefits and risks of program participation, time and capacity for project management, the ability to conduct a cost-benefit analysis and access financing, and the ability to manage a construction project. Limited capacity in one or more of these areas can undermine the ability of households or property owners to participate in complex decarbonization programs. Integrating technical assistance and project management support into program design, and throughout the process, can address these barriers.
- **Perceptions and Concerns:** Concerns about utility bills, electricity reliability, and lack of knowledge about new technologies influence household decisions regarding decarbonization. Adapting programs to the specific needs of target communities can help overcome this barrier.
- **Social Factors:** Structural racism, age-related limitations, immigration status, and language barriers contribute to disparities in housing quality and participation in decarbonization programs. Adapting programs to the specific needs of target communities can help overcome this barrier.

Equity Implications for Program Implementation

In the literature review, we identify three distinct implementation approaches and discuss their equity implications.

Welfare approaches involve government initiatives that directly install no-cost energy retrofits for LMI households to reduce energy demand and costs. One of the challenges for these programs is identifying who is eligible for assistance. There has been a shift away from using income as the sole criterion and toward using multiple indicators to determine a household's eligibility for assistance. Lessons from programs in the United Kingdom (UK) and the U.S., including the Weatherization Assistance Program (WAP) and utility-operated programs, highlight other common challenges:

- Income-based targeting is ineffective at reaching energy-burdened, priority households.
- The metrics chosen for program evaluation often exclude non-energy benefits such as improvements in human health, leading to an incomplete assessment of societal benefits.

- Lack of funding for retrofit needs precludes participation for those living in the worst housing conditions.
- Complex engagement processes raise administrative costs and burdens.
- In some cases, low-income households might consume more energy post implementation due to latent demand.
- Racially and ethnically marginalized groups have disproportionately lower participation rates in welfare-based decarbonization programs.

Despite these challenges, the literature shows that for households that do participate, most welfare programs contribute to reduced energy demand, improved housing quality, and better health, demonstrating the potential for approaches that target LMI households that experience the worst housing and energy conditions.

Market-based incentive and regulatory approaches refer to government interventions that incentivize the transition to low-carbon homes through regulation (e.g., appliance standards, building codes, benchmarking, utility regulation) and financial incentives (e.g., rebates, tax credits). These predominant interventions are designed to address market failures (e.g., unpriced externalities, imperfect information, principal-agent problems, credit constraints) and consumer decision-making barriers that hinder energy efficiency and decarbonization efforts.

These strategies have significant equity implications. While building standards have improved the overall quality of new buildings, in some cases, they have also increased the costs of development and raised the price premium for homes with energy-efficient features. Appliance standards and eco-labels have improved the energy efficiency of appliances. However, research has found lower adoption among renters and LMI households due to lack of information about benefits, cost and credit barriers, and split incentives between landlords and renters.

Benchmarking and energy audits can encourage energy savings if they are accompanied by technical assistance and financial incentives, but so far small property owners are not mandated to share energy usage information and have had less access to energy audits. Rebate programs encourage the purchase of energy-efficient appliances mostly among higher-income households who, in some instances, may purchase them absent the rebate. Access to effective subsidies, credit, or both remains a persistent barrier among lower-income households. Therefore, despite the desire to create incentives that serve all households, limited attention to the needs of lower-income households has led to ineffective targeting and less adoption than is needed to expand decarbonization to the levels required to meet climate and other sustainability goals.

Community-based approaches are place-based initiatives that address the specific needs of households living in a particular geography and that share commonalities in climate exposure, energy prices, building types, or income. By engaging communities actively in the decarbonization process, state and regional governments seek to tailor strategies to the unique characteristics of places. Motivations for community-based approaches include supporting grassroots innovation, adapting policies to local needs, building local capacity, achieving multiple sustainability goals, and addressing social and economic inequalities.

Diverse implementation strategies include innovation grants to build local capacity, pilot projects targeting priority communities, and initiatives integrating health promotion with decarbonization. Examples from the UK and U.S. demonstrate the success of community-led initiatives in increasing participation and achieving sustainability goals. Approaches that specifically target priority communities and partner with local leadership and community-based organizations for program design, delivery, and evaluation can increase participation and contribute to social benefits such as improved housing quality and household health.

Deeper engagement with community leadership in priority communities can help overcome the compounding challenges of historical disinvestment, distrust in government and other institutions, worse housing and energy infrastructure conditions, limited resources and knowledge of decarbonization, and higher sensitivity to increases in energy bills. To address these intersectional challenges, research has highlighted the need for sustainable community-level institutions that can act as intermediaries between the state, energy utilities, implementers, and households.

Equity Implications for Program Outcomes

This section of the literature review provides evidence of equity outcomes across decarbonization programs, including greenhouse gas (GHG) emission reductions, climate resilience, housing security, energy security, population health, and health equity.

Greenhouse Gas Emissions and Sustainability: Housing decarbonization efforts can significantly reduce greenhouse gas emissions and indoor and outdoor air pollution, leading to improved population health outcomes. Strategies such as electrification, energy efficiency, and renewable energy integration are essential for achieving these reductions. Disadvantaged communities that are disproportionately exposed to air pollution will disproportionately benefit from clean air, contributing to reductions in health disparities. Furthermore, neighborhood-scale electrification can support decommissioning parts of the natural gas system, further contributing to lower GHG emissions and reducing the burden on individual households to maintain the natural gas system.

Climate Resilience: Housing plays a crucial role in protecting communities from climate hazards such as extreme heat, wildfire smoke, and flooding. Decarbonization measures that improve the thermal comfort and air quality of the home can enhance the resilience of residential buildings to extreme weather and mitigate health risks. Disadvantaged communities that face disproportionately higher exposure to climate risks will reap outsized benefits from protective retrofits.

Housing Security: Decarbonization programs have the potential to improve housing quality and stability, thus contributing to housing security. By addressing issues such as hazard remediation (e.g., mold, lead, asbestos), inadequate heating and cooling, and other health and safety hazards, these programs can reduce health risks and promote overall well-being among residents. To achieve contributions to housing security and avoid displacement, program designers must address the split incentives between landlords and tenants and enact enforceable renter protections.

Energy Security: Housing decarbonization can help alleviate energy insecurity by reducing energy costs, improving thermal comfort and safety, and enhancing energy efficiency, all with economic benefits to utilities and consumers. These efforts can benefit low-income households disproportionately affected by high energy bills and inadequate housing conditions. To reduce energy bills, there is a need to reduce consumption or to combine electrification with energy efficiency, solar photovoltaics (PV), and bill assistance programs.

Health Equity: Housing decarbonization strategies advance population health with outsized benefits to vulnerable populations. These initiatives have the potential to advance health equity by addressing structural determinants of health and prioritizing households facing social inequities. By targeting priority communities, these programs can mitigate health disparities among population groups.

3. Statewide Analysis

Introduction

California is the most energy-efficient state in the United States (Kresowik et al., 2025), ranking among the top five for over a decade. This achievement is the product of legislative, regulatory, and programmatic efforts. Most notably, California has set ambitious climate goals to achieve at least an 85 percent reduction in greenhouse gas emissions below 1990 state levels by 2045. Specific aims for the residential sector include the installation of 6 million heat pumps by 2030 and making 7 million homes climate-friendly by 2035. Equity goals include “ensuring that incentive programs prioritize energy affordability and tenant protections, promote affordable and low-income household retrofits that improve habitability and reduce expenses, protect and empower non-professional landlords and homeowners, address overlooked consumer groups, and pair decarbonization with other critically needed renovation efforts to ensure that buildings support human health and are climate and weather-resistant” (CARB, 2022b).

To support housing decarbonization goals, state and local governments and energy utilities operate over 300 different programs for housing decarbonization (CPUC, 2023; Dolfie et al., 2026), leading to significant experience and innovation in implementation. At the same time, the fragmentation of household decarbonization programs across California has resulted in an uneven landscape of service provision and uptake. Evidence shows that housing decarbonization is moving at a slower pace than needed to meet state goals, and priority communities (including low-and moderate-income households, renters, disadvantaged communities, and tribes) are underserved by decarbonization programs (Guo and Kontou, 2021; Ju et al., 2020; Pigman et al., 2021; Sunter et al., 2019; Walker et al., 2023). Furthermore, housing advocates warn that without robust renter protection measures, decarbonization efforts may inadvertently trigger rent increases, evictions, and displacement (Kirk et al., 2025). In this context, the implementation of climate mandates without sufficient tenant protections risks accelerating the displacement of the very populations these programs are intended to serve, potentially turning home retrofits into a catalyst for housing instability.

Maintaining the current approach to housing decarbonization can further entrench inequitable access to the financial, health, and energy security benefits of low-carbon homes and hinder the state’s ability to meet its decarbonization targets. If priority communities, which already face the compounding effects of historical disinvestment in housing and energy infrastructure, continue to be underserved by decarbonization programs, they are likely to remain in energy-inefficient and unhealthy homes. These residents will not only continue to face higher energy demand and poor indoor air quality, but they may also bear a disproportionate share of the costs to maintain aging natural gas infrastructure and, potentially, the electricity grid for those without access to solar panels (Borenstein et al., 2023; E3, 2020, 2022).

Transformative action to advance equitable housing decarbonization is essential to fulfilling California’s climate goals and overarching equity goals. Expanding the scale and diversity of participating households is a prerequisite for achieving the wide-scale adoption needed to reduce GHG emissions, enhance public health, and bolster grid stability through deep energy efficiency improvements. Moreover, reaching priority low- and moderate-income (LMI) communities, who are often residing in housing that requires significant health and safety upgrades, presents a vital opportunity to improve statewide habitability and health equity by addressing unhealthy living conditions.

Research presented in this section is designed to uncover the barriers and opportunities for scaling up housing decarbonization equitably. Based on 126 in-depth interviews with policy designers, energy providers, implementers, community-based organizations, homeowners, and renters, we identify key factors that impact the ability of property owners to participate in housing decarbonization programs, with a focus on priority communities. We organize interventions into three key areas:

- **System-level** intervention areas include the need for **deep engagement** with community organizations to ensure fit between program design and the needs of priority communities, and **program coordination** among state and local agencies to ensure efficient use of public funds.
- **Program design** intervention areas include integrating **support services** to ensure participants can successfully navigate complex programs from start to finish, addressing the fragmented **ownership structure** in the residential sector, and ensuring sufficient funding by coordinating **eligibility criteria** and **incentive structures**. In priority communities, program designers must dedicate funding to address health and safety hazards (e.g., lead, asbestos, mold, and old electrical systems) that are a prerequisite to electrification.
- **Program implementation** intervention areas include the coordination of technical aspects essential for program success, but that often fall outside of the direct responsibility areas of program designers. This includes addressing concerns that high **electricity rates** make electrification unattractive, ensuring that the **electrical infrastructure** can support additional electric loads, growing a knowledgeable **workforce,** inclusive of training and provision of technical and administrative support to small-scale business, ensuring streamlined **permitting**, and choosing **efficient delivery** models. Implementers suggested that focusing on one geographic area at a time can increase program efficiency by reducing outreach costs and travel time for contractors. If coordinated with clean energy infrastructure planning, this neighborhood scale approach (a.k.a. zonal decarbonization[6]) can support the decommissioning of natural gas service lines.

[6] Neighborhood-scale building decarbonization ("neighborhood decarbonization") is an emerging strategy that focuses on transitioning street segments, developments, or even entire neighborhoods to decarbonized energy sources and electric appliances with the end goal of managing the transition off of the gas system (George Bagdanov et al., 2023). In 2024, the California legislature passed SB 1221 (Min), requiring the California Public Utilities Commission (CPUC) to establish a voluntary zonal decarbonization program and designate priority neighborhood decarbonization zones.

Within each intervention area, we describe the challenges and recommend strategies to address them, based on lessons learned from the research. Our analysis suggests that achieving equitable decarbonization requires actions across intervention areas to remove participation barriers in priority communities.

Methodology

This Participatory Action Research (PAR) project was conducted in partnership with community-based organizations, non-government organizations, program implementers, academics, and state government staff who all serve on an advisory committee. Together, our advisory committee members bring expertise in embedding equity in policy and program design, implementation, and evaluation. As part of the PAR process, we held multiple workshops with the advisory committee to shape the research design, analysis, and interpretation of results (See Chapter 1).

The academic team conducted 57 interviews with actors involved in different aspects of housing decarbonization program design, implementation, and evaluation between July 2024 and February 2025 (Table 2). We also conducted 69 interviews with households, including both renters and homeowners, between August 2023–December 2025. Interviews lasted approximately 60 minutes and were conducted via Zoom, phone, or in-person.

TABLE 2: NUMBER OF INTERVIEWS BY SECTOR AND GEOGRAPHY

	Community Organizers	Energy Providers	Implementers	Policy Designers	Households
San Francisco Bay Area	2	6	3	6	45
Los Angeles Area	2	2	2	2	24
Central Valley	3	3	1	2	0
State level	3	3	6	11	0
Total	**10**	**14**	**12**	**21**	**69**

Our analytic strategy included two steps: First, we analyzed interviews with implementers and homeowners to understand the stages of engagement with decarbonization programs and to identify enabling and inhibiting factors. Second, we analyzed interviews with policy designers, energy providers, implementers, and community organizers to understand how housing decarbonization programs respond to participant barriers and facilitate successful implementation, especially in priority communities.

Overview of Equitable Implementation Findings

The research identified key interventions needed to overcome the participant burden in housing decarbonization programs. We categorize these interventions across five key dimensions: (1) Learning (Awareness and Motivation), (2) Capacity, (3) Affordability, (4) Buildings and Neighborhoods, and (5) Governance.

Each dimension, described below, is impacted by a combination of participant-level and community-level factors (Table 3), highlighting the important interplay of barriers and interventions at multiple levels. Participants' journeys often begin with learning about decarbonization programs. Motivated participants then need the capacity to navigate the challenges related to the affordability of the retrofit and resulting energy costs, the conditions in their home and neighborhood, and the multitude of government programs and regulatory requirements. While the journey is not linear, these dimensions affect participants' ability to adopt residential energy retrofits.

TABLE 3: INDIVIDUAL AND COMMUNITY-LEVEL FACTORS IMPACTING PARTICIPATION IN RESIDENTIAL ENERGY PROGRAMS IN CALIFORNIA

Dimension	Description	Participant-level factors	Community-level factors
Learning	Access to trusted sources of information, understanding of program benefits, and motivation to act	Knowledgeable networks (e.g., friends, family, colleagues)	Community-based organizations and/or online communities with expertise in residential energy programs; knowledgeable workforce; enabling public policy (e.g., energy assessment at point of sale, reach codes); and marketing that resonates with local priorities
Capacity	Time and ability to navigate and manage complex, multi-step programs	Organizational, technical, and administrative capacity	Access to participant support services (e.g., energy navigator model); access to programs that address the specific needs of renters, multi-family homes, mobile home parks, and tribes; and a local workforce with decarbonization knowledge and skills

Dimension	Description	Participant-level factors	Community-level factors
Buildings and Neighborhoods	Level of physical readiness of housing and energy infrastructure for electrification	Home compliance with health and safety codes (e.g., are there health and safety prerequisites such as fixing gas leaks, remediating lead/asbestos, or upgrading panel capacity?), and in an area ready to receive additional electric loads	Readiness of energy infrastructure, including transformer and circuit capacity
Affordability	Ability to cover costs	Access to capital	Availability of financial incentives that meet participants' needs, efficient delivery, and rate schedules that enable bill neutrality or savings post-implementation
Governance	Level of coordination among government agencies to streamline services to participants; partnerships with community organizations to adapt programs to local needs	Impacts of individual decision-making and capacity within all other program dimensions	Coordination among government programs; inclusion of community partners in the design, implementation, and evaluation of programs; tenant protections; technical assistance to local governments to streamline and speed up permitting; and local resource centers and/or technical assistance for participants, HOAs, and contractors

We find that LMI households face disproportionate barriers at each dimension compared to higher-income households. For example, LMI households are less likely to have access to people within their social networks who have experience with these programs, have fewer resources to undertake retrofits, and may be less likely to have sufficient time or capacity to engage with decarbonization programs. They may also be more motivated by health and cost concerns than the longer-term benefits of climate mitigation.

Addressing the participant burden requires coordinated action across government agencies. In Figure 1, we categorize key intervention areas by the participant burden dimension.

FIGURE 1: KEY INTERVENTIONS BY THE PARTICIPANT BURDEN DIMENSION

The diagram emphasizes the importance of a comprehensive strategy that addresses barriers to engagement in each stage. Below, we discuss each of the dimensions and interventions in more detail.

Governance Dimension

- **Deep engagement** is necessary to raise awareness and to ensure the alignment between program design and implementation and participant needs. Meaningful engagement with community-based organizations (CBOs) strengthens implementation across all other areas. Critically, programs should fund CBOs as partners in program design, implementation, and evaluation, rather than limiting their support to outreach activities.
- **Program coordination among government agencies**, such as through structured monthly meetings between key state energy entities, is essential to reduce administrative complexity, lower burdens for both staff and participants, and ensure the efficient use of public funding. This coordination must extend across sectors, specifically bridging the gap between energy, public health, and healthcare entities to ensure that housing decarbonization programs both improve public health outcomes and utilize healthcare sector funding to support vulnerable populations. By focusing on high-risk groups, including the elderly, children, and individuals with chronic conditions or electricity-dependent medical equipment, health-conscious housing programs can implement evidence-based interventions to mitigate hazards such as asthma triggers, lead poisoning, and unintentional home injuries. These cross-sector partnerships not only improve program efficiency and equitable targeting within low-income and disadvantaged communities, but also offer participants holistic support through case management and direct referrals to healthcare network resources.

- **Local government support** includes training and technical assistance to local governments on new electrification technologies to streamline permitting and provide information and coordination support to residents. Providing municipal staff with clear guidelines on new technologies can help reduce inconsistent approval processes that disproportionately burden small contractors.

Learning and Capacity Dimensions

- **Participant support** refers to a range of services that support participants (e.g., homeowners, non-professional landlords) from initial contact to project implementation. Participant support impacts awareness and motivation by tailoring outreach strategies to the target community, enhances the capacity to implement by providing technical, administrative, and organizational assistance, and improves outcomes by providing post-installation support. This strategy directly addresses non-financial barriers such as energy literacy, access to information, language accessibility, as well as the limited time, resources, and skills needed to manage a complex multi-step process. Examples include programs that offer an energy navigator to guide participants and contractors from start to finish, as well as state and local government information hubs that help households fill out forms, understand incentives, and connect with contractors.
- **Ownership structure and building type** significantly dictate the capacity for decarbonization, necessitating tailored support to achieve meaningful scale. Ownership structure refers to who owns the property (e.g., renter v. homeowner, non-professional v. corporate landlords, subsidized housing v. lower-cost, non-subsidized properties) and building type refers to construction type and number of units per building (e.g., multi-family vs. single family, mobile and manufactured homes). Multifamily apartment buildings or those belonging to a Homeowner’s Association (HOA) require additional approval processes. Rental properties face multiple barriers to decarbonization, including split incentives between landlords and tenants. Mobile and manufactured homes—housing over one million Californians—represent a particularly underserved market segment due to complex legal frameworks where building and landowners are often separate entities. Residents in these homes frequently experience heightened disparities regarding extreme heat and poor air quality, yet they remain excluded from many traditional decarbonization programs. Scaling housing decarbonization also requires specific protections for LMI renters to mitigate displacement risks and cost-pass-throughs.
- **Workforce** development is essential for scaling decarbonization implementation and requires training contractors in new technologies, streamlining fragmented certifications, and supporting small businesses through capital access and technical guidance. These efforts should be anchored in High-Road Training Partnerships that invest in apprenticeship programs and that engage local unions. By prioritizing the recruitment, training, and placement of low-income residents from disadvantaged communities, programs can

ensure that the economic benefits of building decarbonization accrue to local economies and create long-term career pathways.

Buildings and Neighborhoods Dimension

- **Existing home retrofit needs impact the feasibility and costs of residential energy retrofits.** Because priority communities disproportionately occupy older housing stock (Fournier et al., 2024), they frequently face challenges accessing decarbonization programs due to pre-existing health and safety hazards in the home. Lead, asbestos, mold, or outdated electrical systems act as barriers to equipment installation (Dan Farrell et al., 2025). To close this participation gap, equity-focused programs must provide flexible funding that treats health and safety remediation as a fundamental prerequisite to decarbonization rather than a secondary concern.
- **Energy infrastructure interventions** are needed to address the long waiting times and high cost of upgrades to the local distribution grid to meet higher electricity demand.

Affordability Dimension

- **Eligibility criteria** impact the ability of participants to access financial incentives. Households and landlords often need to layer funding across programs to afford retrofits, but inconsistent eligibility criteria make that challenging to achieve. Different strategies, discussed in this review, can reduce the administrative burden of verification as well as harmonize and streamline eligibility across programs.
- **Incentive structures**, encompassing both the specific technologies (e.g., heat pumps, electric panel upgrades) and the delivery mechanisms (e.g., rebates, no-cost direct installation), must be redesigned to address the unique realities of priority communities. Programs must fund retrofit needs in priority communities. Furthermore, the delivery of these incentives is critical; while no-cost direct installation programs are the most effective model for low-income residents, rebate-based structures that target moderate-income households must be bolstered by upfront subsidized "green financing" to support households that cannot afford the upfront costs and don’t qualify for traditional loans.
- **Efficient delivery** refers to the opportunity to reduce costs through efficient implementation strategies such as geographic targeting (e.g., neighborhood decarbonization/zonal decarbonization) and right-sizing equipment and electrical panels.
- **Progressive energy rate setting** is needed to remove cost and feasibility barriers by addressing the high price of electricity relative to natural gas. These intervention areas are inter-connected. Addressing challenges in one area requires coordination with others. For example, simplified eligibility criteria are meaningless without adequate support to help participants navigate applications, and retrofit funding is ineffective without trained workforce capacity.

Equitable decarbonization requires policymakers and implementers to take coordinated action across all five dimensions simultaneously, rather than treating them as separate areas to be addressed independently.

Research Findings: A Closer Look at the Five Dimensions

The sections that follow examine each of these dimensions in greater depth. For every dimension, we identify the specific challenges that contribute to the participant burden and the interventions that can address them, drawing on the interview data and analysis. Each discussion is organized around the key areas within that dimension, presenting an overview of the challenge followed by concrete recommendations for policymakers and implementers. We begin with governance, which shapes how all other interventions are coordinated, funded, and delivered.

Governance

Program Coordination

California's housing decarbonization programs, while numerous, suffer from fragmentation and misalignment that undermine their effectiveness in reaching LMI households. Streamlining these programs is critical to enabling incentive stacking, a process necessary for funding the retrofits required in priority communities. Additionally, enhanced coordination between funding entities and regulatory agencies is vital to ensure financial support scales with mandatory building standards, protecting vulnerable populations from the financial strain of compliance.

Overview of Challenge

Structural misalignment across programs prevents coordinated delivery and increases administrative burden. Program designers report significant challenges in coordinating among federal, state, and local initiatives due to divergence in program goals, eligibility criteria, and reporting requirements. As one local government respondent shared, *“Different funding streams have different requirements. So just the administrative burden of trying to take [program name] funds, as well as any federal incentives as well as any local incentives, and just figuring out what the requirements are, reporting all of it, it's so much…it becomes so administratively burdensome that sometimes people just will forego the money in the project because they just can't do it right. It's just too much.”* Uncertainty about program availability over time further complicates planning for both implementers and participants. This fragmentation results in inconsistent measure coverage and incentive levels across service areas, leaving many eligible households unable to navigate or access available support.

Recommendations

Establish a dedicated interagency working group to convene state agencies that directly design policies and programs for housing decarbonization or that have responsibility over key issues impacting housing decarbonization, such as workforce development, financing programs, or the identification of priority communities to be included in these programs. This interagency working group can have distinct task forces dedicated to core areas such as program design and evaluation (including health and safety considerations), building and appliance standards, energy rates and infrastructure, workforce, licenses and certifications. Our analysis identified multiple state agencies that have responsibilities related to housing decarbonization, often across overlapping domains (see Appendix E: State Agencies).

In addition to state agency representatives, the interagency working group should include representatives from priority communities across the state. These roles should be compensated. Our advisory committee recommends including members of the Building, Energy, Equity, and Power (BEEP) coalition, which represents priority communities across California, as well as members of the Healthy Homes Working Group. The interagency working group should also be required to develop clear public processes to solicit input from constituents across sectors and geographies across the state.

We propose hiring a third-party contractor to facilitate the interagency group's work and to be responsible for reporting. A third-party facilitator can help build trust among the different actors and support coordination and alignment across agencies that have distinct missions. The interagency working group should meet at a regular cadence and publicly report every two years on progress.

The interagency working group would have oversight responsibility for the following areas:

<u>Program Design, Evaluation, and Habitability</u>

- Ensure sufficient funding and attention to integrating participant support in priority communities.
- Ensure that decarbonization programs meet the needs of different property owners and building types, with a special focus on multifamily housing and mobile and manufactured home parks.
- Track progress towards creating tenant protection guidelines and enforcement mechanisms.
- Coordinate eligibility criteria across energy, housing, and health programs to ensure incentives can be stacked.
- Coordinate reporting requirements and evaluation to ensure equity metrics are tracked and to reduce administrative burden.

<u>Energy Rates and Infrastructure</u>

- Evaluate the impact of high electricity rates on the financial feasibility of electrification.
- Evaluate progress towards public-facing reports on the local capacity of the distribution grid in priority communities across the state.
- Track how the CEC and CPUC coordinate electrical infrastructure upgrades with electrification projects in priority communities.

<u>Workforce, Licenses and Certifications</u>

- Evaluate progress towards developing the decarbonization workforce and supporting small-scale businesses.
- Evaluate progress towards streamlining certifications.

<u>Building and Appliance Standards</u>

- Evaluate progress towards streamlining permitting at the local level.

SB X1-2 provides an example of this type of interagency collaboration, directing the California Air Resources Board (CARB) and the California Energy Commission (CEC) to jointly develop the Transportation Fuel Transition Plan. A third-party contractor facilitates the process by convening state agencies and important constituencies—including community organizations and businesses—to deliberate on key issues. Each agency retains distinct responsibilities but coordinates closely with the other agencies and the advisory group.

Improve coordination across housing and health sectors. Dedicate funds to cross-sector partnerships to ensure contracts between energy service providers, housing agencies, and healthcare partners. Pilot programs that create a seamless pipeline from home repair to decarbonization have proven especially effective. For example, several low-income weatherization programs pair basic health-and-safety repairs (like electrical upgrades or roof stabilization) with heat-pump installation, allowing the housing program to address habitability issues while the energy program covers the energy retrofit. Health-focused initiatives also offer promising models: some counties partner closely with local health departments to identify households with asthma or Chronic Obstructive Pulmonary Disease (COPD), referring them to healthy-homes interventions that integrate mold remediation, ventilation improvements, and electrification measures. Additional opportunities include aligning lead remediation programs with decarbonization efforts and exploring how California Advancing and Innovating Medi-Cal (CalAIM) Community Supports (e.g., asthma remediation) could be braided with energy funds to finance health and safety upgrades that are necessary prerequisites for electrification.

Standardize reporting requirements. Collecting and analyzing the data required by program funders is a significant administrative burden, especially when the same implementer is coordinating across different programs that have different program requirements. One implementer noted that they have a whole IT department dedicated to data collection and reporting. Another noted that it is the most time-consuming aspect of their job in managing projects: *"[The benefit of] standardizing reporting across programs is hard to overstate because of how much administrative time gets spent trying to quantify or report on the work in a way that the funder needs it, that's different from another funder… less time spent on admin could go toward actual measure incentives."* Overall, many noted that standardizing reporting requirements and format across programs can increase efficiency and reduce costs. Another benefit of standardizing reporting requirements will be the inclusion of equity metrics (see Chapter 5 on Policy Cost Analysis) and the ability to track those across programs.

Deep Engagement with Community-Based Organizations

Engaging priority communities in housing decarbonization programs is critical to ensure fit between program design and participant needs. Despite evidence showing greater completion rates when CBOs are involved, most programs do not have adequate engagement models and funding structures to ensure CBO compensation scales with the level of support they provide. This section describes strategies engaging CBOs in housing decarbonization programs.

Overview of Challenge

This research finds that CBOs play a crucial role in implementing decarbonization programs in priority communities, primarily through established trusted relationships with target communities and an understanding of community needs in program engagement. Policy designers, energy providers, and implementers reported better outcomes for enrollment and project completion when CBOs were involved.

At the same time, interviewees reported that the following challenges hinder the ability of governments and other organizations to engage with CBOs:

- Limited access to adequate CBO-engagement models. We note that since conducting the interviews for this report, CARB has published a detailed CBO-engagement model that could potentially address this gap.
- Lack of sufficient compensation for CBOs, which are often funded at hourly rates and only for outreach. This limits their ability to contribute to program development, evaluation, and improvement.
- Not all CBOs have energy-related expertise. Many CBOs have other missions (e.g., housing affordability, health, education, or faith-based work) and may not be set up for assisting with the technical demands of decarbonization.
- Not all CBOs have administrative capacity to apply for grants or co-design processes. Some CBOs can move fast to apply for funding while others cannot.

Recommendations

The recommendations below provide guidance to staff in state and local governments and energy utilities that are responsible for the design, implementation, and evaluation of housing decarbonization programs.

Form a community advisory board to guide program design, implementation, and evaluation. This advisory board can include members from several CBOs that are active in the target communities, and can provide valuable insights into community needs, effective implementation strategies, and which metrics to track to ensure effective implementation in the target communities.

Engage with CBOs that are trusted in the target community. It is critical to identify those CBOs and other non-governmental organizations (NGOs) that work in the target community to ensure that they have the necessary network and trusted relationships to be effective messengers.

Interviewees noted that expanding decarbonization programs in priority communities relies on these networks: *“Community networks are probably the most effective for reaching the lowest income residents. [Our success was due to] a lot of nonprofit partners that were already established in the community and had broad networks.”*

In a specific geographic area, there could be several CBOs serving different segments of the population (e.g., Latinx community, Chinese community, faith-based communities, etc.), and hence there may be a need to contract with several CBOs. The ideal partners are CBOs that have long-standing relationships and networks in priority communities, with the capacity to identify how to meet households where they are. One respondent shared, *“[The CBO staff] know practically everybody… They'll go out to, maybe there's a Latino community center. It could even be a faith-based organization, like a church or something of that nature. And kind of direct people or let them know what the services are like, what the qualifications are, and what our website is for signing up and that kind of thing. So, yeah, really helps us to get at the folks most in need.”* CBOs also ensure that decarbonization events are well attended, with one interviewee noting *“We sponsor community dinners, radio ads, or tabling at local fairs, but it’s the CBO relationships that bring in participants.”* It is also critical for CBOs to provide information in appropriate languages and frame it in a way that resonates with the community's cultural context.

Provide capacity-building funds and training to CBOs on decarbonization programs in geographies where there are active CBOs, but which may not have energy expertise. CBOs can utilize funding to hire and train a staff person to work on decarbonization. Some implementers already provide training, support, and materials (e.g., leaflets with program information in relevant languages) to build decarbonization knowledge and capacity for local CBOs.

Fund CBOs as consultants/vendors to support all stages of the program. Interviews highlighted that CBOs are not just about outreach—they should be partners from the beginning, including program design, implementation, and evaluation. During the program design phase, CBOs can help adapt the program to local needs by providing guidance on community energy needs and community outreach needs, including building awareness and tailoring messaging to local priorities.

Interviewees who engaged in a longer program design process with CBOs and other actors highlighted the importance of engagement in improving program design and getting buy-in from priority communities. For example, through the participatory design process of the Equitable Building Decarbonization (EBD) Program led by the CEC, program designers decided that the geographic inclusion criteria will encompass areas where there are already active CBOs that focus on decarbonization. The underlying idea was to focus on specific communities with existing interest, higher awareness, and local partners, and then extend to other geographies. Further, the engagement process itself served as a catalyst for implementation collaborations.

Interviewees also highlighted the importance of creating feedback loops with CBOs. This includes creating a clear process for constant evaluation (including building the infrastructure to collect and analyze indicators for success) that can provide ongoing and timely insights for program development, implementation, and evaluation. Programs should also create a process by which CBOs can participate in ongoing communication of insights to program implementers, state and federal agencies to improve program design and effectiveness over time. Finally, it is important to include CBOs in program evaluation to ensure that the metrics used appropriately capture relevant outcomes in the target communities.

Provide CBOs adequate compensation for ongoing consultation instead of compensation for a specific task such as outreach. Several interviewees noted that funding for CBOs rarely aligns with project needs and that they have seen better results when CBOs were hired as vendors or grantees to support all project aspects, rather than just outreach. For example, one interviewee who works for a local government described the challenges of partnering with CBOs on a project-specific basis due to limited grant funding. The interviewee highlighted that small stipends ($50/hour) don't adequately compensate CBO staff for their time, let alone enable CBOs to build capacity for sustained engagement (for example, through staff expansion or training). To address this challenge, the city created a request for qualifications (RFQ) to build a pre-approved list of CBOs and consulting firms for community engagement work, establishing larger, more sustainable contracts to fairly compensate CBOs for their time and expertise as well as to build capacity to meet the city's needs.

In the absence of CBOs, identify community leaders who can provide services that CBOs typically provide, including information about community needs and priorities, networking, and outreach. Community leaders may be municipal staff, long-term residents trusted by the community, or other prominent figures recognized and valued by community members.

Permitting

This section provides recommendations to streamline permitting of decarbonization technologies (e.g., heat pumps, induction stoves) across jurisdictions to reduce administrative costs and delays.

Overview of Challenge

Interviews revealed that jurisdictional fragmentation in permitting processes creates its own barriers to scaling decarbonization programs. Each jurisdiction operates independently with unique permitting requirements, timelines, and processes. This creates an unpredictable landscape for contractors and energy providers. In addition, city or county building and safety department personnel may lack familiarity with decarbonization technologies like heat pumps and EV charging systems, leading to inappropriate flagging of non-issues, inconsistent inspector guidance, and unnecessarily complex approval processes. This unfamiliarity translates directly into project delays and increased costs. The gap is especially acute for rural and unincorporated areas, as these jurisdictions often have the least capacity to adapt to new technologies while serving communities that could benefit significantly from clean energy programs.

Recommendations

Provide standard, statewide guidelines for local building departments on new electrification technologies to provide clarity on health and safety requirements, reduce confusion, and streamline permitting. This can involve written guidelines, training for inspectors, and models for simplified online forms for same-day approvals. One interviewee mentioned that it would be helpful to have a state mandate to require streamlined permitting, following the example of AB2188 which required local governments to adopt a streamlined process for solar panel permitting.[7] Developing model permitting processes and requirements for common clean energy technologies would reduce complexity and training needs while enabling contractors to work efficiently across multiple areas.

Offer training programs for building department staff. Regular education initiatives should focus on the unique characteristics and safety considerations of heat pumps, induction stoves, electric vehicle charging systems, and other emerging technologies to ensure appropriate and consistent review processes.

Learning and Capacity

Participant Support

This section discusses strategies to build local capacity for implementation through shifting the heavy lifting of program management from individual participants to a professional organization. These recommendations are based on evidence from interviews with implementers and local government staff who described how they instituted support services for their programs across California. Across different support models, key services include matching participants with an energy navigator that can guide them from initial enrollment, through all program stages, including post-installation education.

Overview of Challenge

The ability of property owners, including homeowners and non-professional landlords, to engage with housing decarbonization programs depends on several non-financial factors, not only program costs. Especially in priority communities, households may not be aware of decarbonization programs, understand their benefits and impacts, or have the necessary capabilities to participate in a complex and multi-step process, including having organizational capacity (managing multi-step processes and engaging with contractors), technical understanding (evaluating technologies, incentives, and bids), and administrative capacity (completing complex paperwork). They may also not know how to use and maintain new appliances. Interviewees acknowledged that while these challenges affect participants across income levels, they disproportionately affect LMI households that lack access to information, personal networks with relevant expertise, or the resources to hire consultants.

In response to non-financial barriers, implementers, community organizers, and local governments have developed new initiatives to support the engagement of priority communities with decarbonization programs. These emerging strategies have the potential to expand equitable implementation and provide a strong framework for policy recommendations. However,

[7] Cal. Assembly Bill 2188 (Muratsuchi), 2013–2014 Reg. Sess. (Cal. 2014).

policymakers will need to include funding for these services in equity program budgets and build the capacity of local governments and CBOs in priority communities.

Recommendations

Program designers should dedicate funds for participant support in priority communities across four key areas:

- **Awareness:** Deep engagement via trusted messengers, including multilingual staff and professional translations of program engagement materials.
- **Motivation:** Adapting messaging to local needs (e.g. focus on health, safety, and comfort), and using trusted messengers such as CBOs, community leaders, and community members who are past program participants. We note that motivation is also tied to removing structural and financial barriers discussed in other sections of this report.
- **Capacity:** Fund an energy navigator, who can provide guidance through all stages of program engagement to ensure participants can complete the process. Navigators are the key point of contact to explain the program, technologies, and financial implications. They help with filling in the necessary forms, provide guidance throughout the process, and are available to answer questions as they arise.
- **Education:** Provide post-implementation guidance on how to use and maintain the new appliances and equipment, which requires post-installation follow-up.

Our interviews revealed that although these services are critical for priority communities, moderate and higher-income participants could also benefit from support services.

We note that while CBOs can effectively address awareness, motivation, and post-implementation education, addressing capacity constraints requires technical expertise that not all CBOs possess. Staff must be knowledgeable of residential energy technologies, panel capacity, government incentives, and financial planning. Therefore, in considering how to integrate participant support in housing decarbonization programs, it is important to clearly state who can provide which types of services and ensure coordination among organizations providing support to participants.

Create support models within local governments and implementers. Interviewees in the private and public sectors described innovative strategies to provide this support. Two recommendations emerged:

- Local governments should provide support services via a decarbonization hub.
- Implementers can expand support by providing an in-house energy consultant or navigator.

Common among these emerging strategies is the provision of technical, administrative, and organizational assistance to both participants and contractors.

Local government model:

Local governments, at the municipal level for densely populated areas and at the county or multi-county level for rural areas, should be encouraged to establish local resource centers for the coordination and implementation of decarbonization programs. San Francisco, for example, co-developed a hub with community partners to provide a one-stop shop for decarbonization actions for both participants and contractors. A local stakeholder explained: *“the idea for the [decarbonization hub] is to be the public facing one stop shop for building decarbonization, particularly for low rise residential… we really want to be the place where things funnel into and out of so that, for residents, there's no new branding and every time new programs they have to interact with, [they can still just come here].”*

The local government model has the potential to support participants across diverse programs and income levels. A local resource center, such as a resilience hub, that can help households identify incentive programs, understand program costs and benefits, as well as find qualified contractors in their area can increase adoption at a larger scale and support workforce development. In rural areas or areas with many smaller local governments, a resource hub can be established at the regional level.

<u>Implementer model:</u>

Among implementers operating programs in priority communities, interviewees said the most successful strategy was to build in personal guidance through all stages of the process, from start to finish. In these models, participants are matched with a personal guide, often called an energy navigator, who explains the program, technologies, and financial implications, scopes the project, helps households fill the necessary forms, guides them throughout the process, and is available for questions as they come up. Interviewees shared that these roles are a huge improvement over previous approaches, which relied largely on contractors to provide support, but which sometimes led to “*the workforce, oftentimes they'll say, how do we just maximize the rebate value so that we can capture as much scope as possible?*” One implementer shared: *“…I think it's really important to have an advocate for folks, especially in disadvantaged communities… We send someone who is an energy expert…trained and qualified to speak to the measures and the home as a system… It's kind of like a coach for the homeowner that can answer questions intelligently, and most importantly, not trying to sell anything…”* Energy navigators can also provide support after installation. The implementer continued, *“if they have a problem with a unit three months after the installation, they have somebody they can call and say, hey, this thing's happening. What do I do?…you need to have somebody that can answer those questions. And it's nice that they have the same person all the way through. It's not like a 1-800 number where you could get one of 250 different representatives and they don't know what you're talking about.”*

Create messaging that directly addresses concerns in priority communities relating to thermal comfort, health, safety, and energy bills. Interviewees who work with priority communities reported that health, safety, and comfort were the key motivating factors for participating in decarbonization programs. For example, when asked about the motivation of LMI clients to engage with decarbonization, an implementer said: *“Comfort, comfort. I'm not comfortable in my home…my children are not comfortable… my wife - there's this area that she's* *always saying is cold in the home."* To further illustrate the significance of health and safety in decarbonization, a staff member in the local government explained: *"Community members, they don't care about whether their hot water is coming from electricity or gas. They care that there's mold in their building, and they care that they have a leaky roof. ...we can't just force a heat pump on someone, they're not going to want it, and they don't care, especially if you're not fixing the things that they care about."*

Education on program benefits can also increase motivation to participate. As one community organizer explained: *"A lot of people are not aware of indoor pollution, poor ventilation that can cause mold... people with asthma did not know that home energy issues are contributing factors. With education they can learn about stuff that anyone can do to reduce bills and improve indoor air quality."*

Deliver ongoing education to maximize program benefits. All interviewees with experience in program implementation reported that post-implementation education was needed for participants across income levels so that they understood how to use the new technology and how to maintain it over time. A community organizer explained the importance of post-installation education: *"People need to understand how to use these appliances. A lot of cooking is done traditionally on gas. People bring in pans and pots that don't work with induction. We met a person that didn't understand how to turn on the stove and had not been able to cook at home for three months because there was no one on site to explain."* Interviewees shared that households often need support using heat pumps, cleaning solar panels and filters. Providing these services can help to avoid complaints about equipment malfunctioning, which was often the result of participants not understanding how to use the new technology, as well as to improve program outcomes.

Ownership Structure

This section focuses on strategies to address the unique challenges of complex ownership structures and building types, such as multi-family buildings, mobile and manufactured home parks, and affordable housing developments. We also highlight the vulnerability of renters living in unsubsidized affordable housing and the need to develop enforceable tenant protections.

Overview of Challenge

Ownership structure refers to who owns the property that would benefit from decarbonization investments. Interviewees highlighted that low-income homeowners and non-professional landlords may not have the capacity to engage in decarbonization programs. The previous section on participant support explains their challenges and strategies to overcome them. In more complex ownership and housing type contexts, there are additional challenges to address. Landlords may be hesitant to decarbonize due to split incentive problems, as well as deferred maintenance and code compliance challenges. Affordable housing operators often face distinct challenges in advancing decarbonization efforts, stemming from limited organizational capacity as well as complex financing and regulatory constraints. Condominiums and/or properties governed by homeowner associations (HOAs) can pose barriers to replacing HVAC systems or installing solar panels. Manufactured homes and parks face unique challenges due to irregular construction, mixed ownership, and outdated energy infrastructure. This diversity of property ownership and building types also makes it difficult to target and scale decarbonization interventions effectively.

Interviewees emphasized the importance of focusing on renters to advance equitable decarbonization implementation. Renters, especially LMI households, may benefit the most from decarbonization efforts through improved health and energy security, but they also face the highest risks. If retrofitting costs are passed on through higher rents, this could lead to increased housing cost burdens, housing insecurity, and possibly eviction. Current tenant protections are insufficient, can be difficult to pass at the local level, and even when in place, are often poorly enforced. Even among decarbonization programs that include tenant protections, interviewees highlighted the lack of clarity about who is responsible for enforcing them.

In light of California's housing decarbonization goals, advocacy organizations raised significant concerns about the potential negative implications of these policies for tenants. Strategic Actions for a Just Economy (SAJE), a Los Angeles housing rights nonprofit, has been developing recommendations for tenant protections in the context of decarbonization programs. Key recommendations include pairing tenant protections with strong enforcement mechanisms, including well-resourced government enforcement and, for subsidy programs, protections that tenants can assert in court (Kirk, 2021; Kirk, 2023; Kirk et al., 2025).

Addressing the needs of different property owners is challenging, especially when policies may pose trade-offs (e.g., balancing tenant protections with landlord motivation to undertake retrofits). Some strategies are common to broader efforts to overcome participation barriers, such as addressing capacity gaps across ownership and building types. But to support equitable decarbonization, interviewees highlighted the need for policymakers to remove barriers to implementation in multifamily housing (e.g., utility allowances, distribution of solar benefits to all units), protect renters, and develop programs for manufactured homes and parks.

Recommendations

Plan utility allowances in subsidized housing to support decarbonization. In subsidized affordable housing, gross rent (the total of rent plus utilities) is capped to ensure affordability for low-income residents. To calculate the maximum rent a landlord can charge, they must subtract a Utility Allowance, an estimate of the tenant's monthly energy and water costs, from that total cap (York et al., 2022). Most affordable housing in California uses standard allowances set by local Public Housing Authorities (PHA). These do not always reflect the actual energy performance of a building. Consequently, if an owner invests in high-efficiency heat pumps or solar panels that lower a tenant's actual bills, it may not change the allowance amount. This means that the owner cannot capture any of the energy savings as rent to help pay for the upgrades, effectively penalizing them for decarbonizing.

To address this gap, the California Energy Commission (CEC) developed the California Utility Allowance Calculator (CUAC). The CUAC provides a data-driven, consumption-based estimate, allowing owners of efficient buildings to use a lower, more accurate allowance and, in turn, collect more rent to offset the cost of green technology. However, use of the CUAC is largely restricted to new developments or projects undergoing substantial renovation. According to the California Tax Credit Allocation Committee (CTCAC) which administers the federal and state Low-Income Housing Tax Credit (LIHTC) programs, only 15 to 25 percent of their developments have used the CUAC each year since 2011 (Armstrong et al., 2022). This means the vast majority of California's existing affordable housing stock remains tied to antiquated HUD allowances. Without a pathway for existing buildings to adopt consumption-based allowances, owners lack the financial incentive to transition away from fossil-fuel-based systems.

To bridge this gap which impacts the existing affordable housing stock, the legislature should require the use of the CEC Utility Allowance Calculator in decarbonization retrofits across agencies (PHAs oversee Section 8 housing, CTCAC oversees LIHTC properties, and USDA oversees some rural housing). CTCAC should allow existing properties to switch to the CUAC whenever a verified decarbonization retrofit occurs, regardless of whether the project is undergoing a major renovation. Further, the legislature should require that local PHAs update their standard schedules to include specific tiers for High-Efficiency or All-Electric buildings, ensuring that owners who cannot afford a full CUAC analysis still see some rent relief. Some PHAs in California have already begun this. For instance, the Housing Authority of the City of Los Angeles (HACLA) and Santa Rosa have offered energy-efficient schedules. In these jurisdictions, an owner of an energy-efficient building can opt for a lower allowance, effectively increasing their revenue to pay for the retrofit without increasing the tenant's total "out-of-pocket" costs.

Lastly, there is a need to clarify state regulations to ensure that when owners install onsite solar that reduces tenant bills, the resulting reduction in the Utility Allowance can be directly applied to debt service for solar installation. While the CUAC mathematically enables an owner to capture energy savings as higher net rent, this revenue is often excluded from permanent financing calculations. Lenders and tax credit investors frequently view CUAC-based rent increases as volatile income because utility rates and allowance schedules can fluctuate annually. Furthermore, a split-incentive conflict exists within green subsidy programs, such as the Solar on Multifamily Affordable Housing (SOMAH) program, which often mandate that solar benefits flow directly to tenants as bill credits. Without explicit guidance from the CTCAC and HCD stating that captured Utility Allowance savings are a stable, protected revenue stream intended for debt repayment, owners cannot leverage that increased income to secure the private capital needed for the initial solar investment.

Adopt tenant protections in all housing decarbonization programs impacting renters and clarify their enforcement. While some existing programs include tenant protection provisions (such as CSD's Weatherization Assistance Program (WAP), CEC's Equitable Building Decarbonization (EBD) program, and local programs such as the LADWP Comprehensive Affordable Multifamily Retrofits (CAMR) program, interviewees consistently noted that enforcement is limited or unclear.

In their 2025 report, SAJE made the following recommendations for tenant protections in housing decarbonization: First, landlords receiving public subsidies should enter into a contract with their tenants, which would stipulate the terms and conditions of participation in the subsidy program and establish enforcement authority, clear penalties for violations, and remedies (e.g., a civil action). The state government can ensure local governments have sufficient staff and resources to enforce these contracts. Second, SAJE recommends several actions to ensure affordability and avoid evictions: rent stabilization, the banning of pass-through costs for decarbonization-related work and establishing just-cause evictions to prevent evictions related to decarbonization work. Finally, they suggest several recommendations to minimize disruption to tenants during retrofits such as ensuring living conditions are habitable during construction or renovation, or provision of temporary relocation, allowing tenants to petition for rent decreases if construction activities result in a decline in services, deferred maintenance, or health and safety hazards, and requiring that property owners who violate laws regulating construction work in occupied units pay stiff penalties (Kirk et al., 2025).

Considering the complexity and sensitivity of this topic, we recommend that the proposed interagency working group, in consultation with the California Department of Justice's Housing Justice Team and tenant advocacy groups, develop standard tenant protection agreements and identify enforcement mechanisms. The interagency working group should determine which programs should require landlords to sign a standardized Tenant Protection Agreement (TPA) as a condition of funding and provide a standard contract to be used by all eligible decarbonization programs. This contract should address the issues raised by SAJE and the regulatory framework in California to protect tenants. Key issues to be addressed in this contract include defining which rent increases are allowed and preventing evictions due to substantial remodels, as defined by SB 567.[8]

The interagency working group should also determine a transparent process for monitoring compliance, reporting violations, and clear enforcement mechanisms. For example, in some cases, it may be appropriate to require certified rent rolls before and after retrofits as a condition of final rebate disbursement; such a mechanism helps program administrators identify and mitigate predatory rent hikes without relying solely on tenant-initiated complaints. In other cases, the interagency working group should consider the strengths of different legal authorities in protecting tenants. The first "line of defense" is the tenant protection agreement, which provides program administrators with contractual power. Second, the interagency working group should encourage local housing departments and rent boards to use Tenant Habitability Plans (THPs) and local Rent Ordinances to enforce protections during the construction phase (e.g., ensuring temporary relocation is paid for) all the way through permitting. AB 628 could provide further protections: it adds a working stove and refrigerator to the legal habitability standard for rental units,[9] suggesting that local enforcement could work to ensure that all-electric transitions (like induction stove installs) are completed in a way that tenants are never left without working essential appliances. Lastly, the Office of the Attorney General (OAG), through its Housing Justice Team, has statutory authority to enforce the Tenant Protection Act (AB 1482, Cal. 2019, as amended by SB 567, Cal.

[8] Cal. Senate Bill 567 (Durazo), Ch. 290, Stat. 2023 (approved Sept. 30, 2023).
[9] Cal. Assembly Bill 628, Stat. 2025 (approved Oct. 2025), amending Cal. Civ. Code § 1941.1.

2023), including its rent cap and just cause eviction provisions. The Attorney General (AG) has sued large-scale corporate landlords who use decarbonization as a pretext for mass displacement.

In summary, legislators and regulators should assign oversight responsibilities, establish transparent enforcement mechanisms, and ensure landlords are held accountable. While it is important to provide financial incentives to landlords to retrofit rental properties, it is equally important to ensure renters have effective enforcement to prevent decarbonization from inadvertently deepening housing inequities.

The CPUC should ensure residents of multifamily buildings can enjoy solar benefits equally. The primary challenge is the behind-the-meter physical constraint, where standard Net Energy Metering (NEM) requires a solar array to be hard-wired to a single electrical meter. In a typical apartment building, each household has its own independent meter; wiring a single rooftop system to dozens of individual units is often physically impossible or prohibitively expensive. Consequently, solar benefits frequently remain trapped in one meter, often the meter for the common areas, leaving tenant utility bills untouched.

To address this barrier, Virtual Net Metering (VNEM) serves as an administrative framework that allows a utility to credit energy generation across multiple tenant accounts without separate physical wiring. However, the efficacy of this strategy has been significantly challenged by the CPUC's recent transition to the Net Billing Tariff, or NEM 3.0. Under this new framework, the value of exported solar energy is determined by a much lower avoided-cost rate rather than by the previous retail-rate credits. Crucially, the CPUC's decision on NEM 3.0 often prohibits multi-family residents from self-consuming their own solar power behind the meter across different accounts. This effectively forces residents to sell their clean energy to the grid at low wholesale prices and buy it back at full retail prices, even when generation and consumption occur simultaneously within the same building. This regulatory shift erodes the financial savings for tenants and undermines the business case for multi-family decarbonization, reinforcing the need for policy safeguards that preserve the economic value of solar for disadvantaged communities.

The CPUC should ensure community solar is viable in priority communities. The CPUC, in coordination with the CEC and CARB as required under the Clean Energy and Pollution Reduction Act (SB 350, Cal. 2015), should implement reforms to it community solar policy in low-income and disadvantaged communities. Specifically, the Community Solar policy, to expand access to lower-income renters, should adopt a solar and storage valuation closer to Net-Energy Metering (NEM) 2.0 values, allow more streamlined virtual NEM enrollment, and align decarbonization incentive programs to provide financial support for community solar and storage projects.

The CPUC should expand dedicated decarbonization programs for mobile and manufactured homes (MMH) to address the systemic split incentives and infrastructure deficits that leave these residents behind in the clean energy transition. Unlike site-built homes, over 50 percent % of California's MMH communities utilize aging master-metered systems where park owners control the electrical infrastructure, but residents pay the bills, a split incentive structure that discourages individual energy upgrades. Furthermore, these units frequently operate on limited 30A to 100A electrical panels and pre-1976 HUD-code construction, making standard electrification impractical without significant electric upgrades.

While the CPUC currently manages a Utility Conversion Program to modernize aging distribution systems, this initiative is primarily a safety and reliability measure focused on grid-side infrastructure rather than building-side decarbonization. Expanding these programs to include direct subsidies for behind-the-meter electrification retrofits and weatherization is essential to ensure that grid modernization directly translates into lower energy burdens for residents. Given the unique energy infrastructure and housing conditions in this sector, there is a need for dedicated programs tailored to the needs of residents of manufactured homes, which account for approximately 4 percent of California's housing units and are a critical component of California's unsubsidized affordable housing options.

Local governments should provide information and technical assistance to HOAs to encourage electrification. HOAs have an untapped potential to encourage electrification through their policies (Carr and Boyd Kramer, 2022), yet many pose barriers to decarbonization such as "no energy production" clauses or other constraints to shared heating and cooling equipment. Engaging HOAs directly can help both in removing administrative barriers to decarbonization, and in potentially increasing awareness and motivation among HOA residents.

Workforce

This section describes the mechanisms behind the shortage in labor skilled in decarbonization technologies, and highlights strategies to build an equitable decarbonization workforce. Key strategies include improving opportunities to get education, streamlining certification, supporting small businesses, and evaluating which wage strategy is the best fit for this sector.

Overview of Challenge

Program administrators and implementers reported significant workforce shortages for residential decarbonization. The shortage is especially acute in rural areas like the Central Valley and Eastern Sierra region, where few local contractors have the necessary certifications for electrification and remediation of hazardous materials (lead, asbestos). Interviewees also noted differences in skills between large-scale implementation companies, those that typically manage large decarbonization contracts, and small-scale contractors, those who typically work on home retrofit projects. While large-scale companies typically have in-house energy consultants and administrative teams, small-scale contractors are unfamiliar with decarbonization technologies and often require training in both technical aspects (e.g., how to install heat pumps, upgrade electrical panels) and administrative aspects (e.g., reporting, permitting, and prevailing wage compliance).

Interviewees attributed the decarbonization skills gap to the following factors:

- **Trade schools** typically don't teach the specialized skills required for weatherization and electrification work.

- **Fragmentation of certification programs.** Most construction licenses are certified by the Contractors State License Board. Most hazardous materials certifications are under the Department of Industrial Relations. Training and certifications for lead abatement are overseen by the Department of Public Health. The fragmentation of certification programs contributes to the difficulty in acquiring skills for decarbonization projects, which often include remediation of lead or asbestos in older homes.

Interviewees attributed the labor shortage to these factors:

- **Low wages and intermittent contracts**. Interviewees who recruit local contractors for decarbonization projects said that decarbonization project funding often only allows for low wages and benefits ("low road" jobs) and the inability to promise a steady stream of projects hinders recruitment. Local contractors may not be incentivized to learn new decarbonization skills because there is no guarantee that decarbonization jobs will remain a stable source of income.
- **Market access and entry barriers.** New contractors shared that it can be challenging to secure bids. Most large-scale decarbonization programs sign contracts for the program's duration (typically several years) with large firms, making it difficult for new businesses to be considered. Furthermore, new businesses and small-scale contractors faced cash flow challenges, as most programs operate on a reimbursement basis, requiring contractors to purchase equipment upfront without guaranteed payment timelines.
- **Administrative burden and retention.** Both program administrators and implementers reported a significant administrative burden associated with program reporting requirements. While interviewees working for large-scale businesses reported having staff dedicated to administrative tasks, interviewees engaging with small-scale contractors or owning a small business reported challenges in complying with the complex administrative requirements of decarbonization programs, including extensive paperwork, permitting processes, prevailing wage requirements, and specialized reporting standards. Program administrators reported that these factors also hindered contractor retention. While some of these challenges are not unique to decarbonization programs, they did emerge as significant barriers in interviews.
- **Diversity and inclusion challenges.** Several implementers reported observing little racial and ethnic diversity in the workforce, particularly among unionized trades. Minority business owners shared that they faced limited access to traditional capital and equipment, as well as difficulties establishing credit lines with suppliers. As one interviewee shared, *"A lot of the programs that we're talking about are rebate-based programs. You actually have to do the work first and then you get the rebate, right? But you're working with minority firms who have not had access to traditional forms of capital."*

Recommendations

The interagency working group should coordinate strategies to make it easier to acquire decarbonization skills by investing in workforce development. There is a need to create public training programs for decarbonization, so that these programs are available to more workers than those working for large-scale contractors who train their own employees in-house. Interviewees highlighted several strategies for workforce development:

- Creating decarbonization courses in trade schools and colleges. The State should take the responsibility for standardizing the curriculum, certification, and provide administrative support.
- Collaborate with community partners to create workforce development programs in priority communities. These programs could help to ensure sufficient labor to expand policies that encourage hiring of Disadvantaged Workers (DAW).
- Make programs available in languages other than English.
- Create financial incentives for experienced contractors to learn new decarbonization skills, such as paid training and childcare support. Interviewees noted that to get contractor buy-in to invest time and effort in training, there's usually a need to either compensate contractors for their time or promise a certain amount of work to offset the costs of learning new skills.
- Collaborate with large-scale program implementers for apprenticeship, fellowship, and placement, so that those acquiring new skills will have a streamlined path to getting a job.

Coordination across state agencies is needed to advance workforce development. The California Workforce Development Board and the Department of Industrial Relations should take the lead on standardizing curricula and creating high-road training partnerships that prioritize disadvantaged workers. Simultaneously, the California Community Colleges Chancellor's Office is best positioned to scale technical courses and offer them in multiple languages to increase accessibility. To ensure contractor buy-in, the CEC and the CPUC could provide financial incentives, such as paid training and childcare support, to offset the costs of learning new skills. By collaborating with community-based organizations and large-scale program implementers, these agencies can create streamlined apprenticeship and placement paths that turn training into stable employment within priority communities.

The interagency working group should coordinate the streamlining of certifications for housing decarbonization. This group should consider offering one standard housing decarbonization certificate. At a minimum, consolidate housing decarbonization certification into one space by integrating lead and asbestos remediation training and certification into the same place that certifies other construction programs. Standardizing certification requirements across California jurisdictions to reduce complexity would also make it easier to develop a trained workforce and would benefit small contractors.

As an example of a streamlined process, the Electric Vehicle Infrastructure Training Program (EVITP)[10] is the industry-recognized gold standard for training and certifying licensed electricians to install, maintain, and commission electric vehicle supply equipment (EVSE). The curriculum focuses on technical standards, load calculations, and national electrical codes specific to vehicle power systems. This certification is a common requirement for publicly funded infrastructure projects to guarantee a high-quality workforce and long-term network performance (McKinny et al., 2024).

Program designers should establish multi-year program commitments (3-5 years) to provide contractors with reliable business prospects that justify investments in specialized training and equipment. One respondent said that the long-term security of a contract can overcome hesitation to take on decarbonization work: *"if we go to the workforce and we say, we need you guys to do this really uncomfortable work, like remove asbestos or remove an oven, but we've got a three year or a five-year program. We have guaranteed business over a long period of time, and there's going to be a lot of jobs. Then the workforce says, okay, you know what? I will go do the hard work, because I know that I can hire up. I can staff up if the business is reliable. It's worth the investment to go after this."*

Address financial barriers for small businesses. Creating a bridging capital program can help small contractors access capital to implement projects before receiving reimbursements. Programs that provide or lend specialized equipment (like insulation blowers) to new contractors who lack the capital or credit relationships to purchase equipment independently can also overcome workforce barriers.

Prioritize small scale contractors in program implementation. In programs that are first-come first-served, large-scale contractors that can more easily move fast can claim all available rebate money before small-scale contractors are able to place their applications. Reserving a portion of incentives for small-scale contractors will enable them to participate and potentially expand the reach of programs to areas underserved by large contractors.

Address capacity barriers: business operations, administrative burden, and technical knowledge. Growing small business capacity to engage with decarbonization programs requires support beyond technical training, to include business operations and administrative knowledge. An implementer who works with small-scale contractors explained the necessity of business support: *"we have workforce development programming, but we're also increasing focus on contractor services, really just the mechanics of running and growing a small business, because those are the firms that serve single family residential homes."* Implementers also emphasized the importance of addressing administrative burden. Decarbonization programs should include additional pay and technical assistance for small businesses on administrative tasks (data collection, reporting, permitting) related to these programs. For example, some programs already pay contractors separately for permitting and include technical training: *"We have compensation*

[10] See https://www.energy.ca.gov/programs-and-topics/programs/clean-transportation-program/clean-transportation-funding-areas-2-0 for more information.

for pulling a permit. We recognize that it's labor, and labor is never free, so we have a line item for that…you don't call it out, it gets smeared in the measure price."

Create a contractor network to ease market access. One promising way to streamline market entry is to develop a contractor network. In Sacramento, for example, a contractor network connects contractors with residents, provides technical and administrative support, and implements quality checks to ensure quality jobs. To become eligible to be included in the network, contractors must have the appropriate certifications and positive customer reviews. Each contractor accepted into the network receives training to familiarize them with the program offering, incentives, and reporting requirements. Further, there is an energy advisor on staff available to answer contractor questions about system size or installation adjustments, which contributes to improved quality of installations. Each quarter, providers receive a score based on customer surveys and random field quality checks. Customers don't have access to this score, but they are more likely to be recommended contractors with high scores through the contractor network system, which is a way to reward high service quality with more leads.

Convene a task force of CBOs and small contractors to study wages in the decarbonization sector. While all interviewees agreed that jobs need to pay a living wage,[11] views on prevailing wages[12] were mixed. While they ensure higher wages and benefits, they can also introduce higher costs and administrative reporting burden, especially for small contractors. In some cases, the higher costs of prevailing wage and administrative burden of complying made projects infeasible, especially given limited subsidies. The state should conduct a study, in consultation with organizations that have direct experience with workforce development in priority communities (such as Emerald Cities), to explore wage guidance strategies.

Buildings and Neighborhoods

Retrofit Needs

This section describes the challenges of retrofitting older buildings, which are more common in priority communities, and strategies to address them.

Overview of Challenge

Retrofit needs in priority communities are systematically under-addressed. Older buildings and mobile homes require foundational remediation before electrification can proceed. Current data gaps on building conditions and retrofit needs mean program designers often lack the information needed to appropriately structure financial incentives. As a result, decarbonization programs frequently exclude health and safety upgrades (e.g. lead/asbestos/mold remediation, electrical panel upgrades, roof replacement, or wiring fixes) that are prerequisites for electrification. For example, interviewees consistently shared that older homes often need

[11] Living wage refers to the minimum income a worker needs to meet basic life necessities (like housing, food, and healthcare) in their specific location.
[12] Prevailing wage is a mandatory hourly rate set by law for workers on government-funded public works projects. For more information, see: https://www.dir.ca.gov/public-works/prevailing-wage.html.

additional investments: *"The electrical panel is a cross-cutting issue across a variety of decarbonization programs... Many homes are older and have a lot of deferred maintenance or were not necessarily designed with this future of electrified everything in mind...There hasn't been dedicated funding for that."* Further, in case of health and safety issues, there is often a need for tenant relocation costs, but those are rarely covered. Consequently, the homes most in need of energy assistance are effectively excluded from programs.

Energy providers further described how the lack of sufficient funding leads to the exclusion of priority communities from decarbonization programs. Even when funding exists, it is spread across multiple programs. One respondent described how this creates additional complexity: *"We have an aging population, and a lot of the people we're taking care of are disabled. I have no money to put in grab bars or a ramp. So the person who lives there, instead of having one group of people come into their home to help them, we go... you're going to have to call somebody else to do that, because I don't have the funding for it."*

Recommendations

Program designers should integrate retrofit needs into decarbonization programs in priority communities through either coordination with health/housing programs or direct provision of these services. Retrofit needs include home health and safety upgrades and code compliance issues such as lead/asbestos/mold abatement, electrical system and wiring upgrades, and roof replacement. As one interviewee shared, *"Every program that provides money for electrification caps the repairs too low."* In retrofits of subsidized affordable housing, program designers need to include funding for tenant relocation costs in case there is a need to address significant health/safety/code compliance issues. Since addressing retrofit needs requires substantial funding, there is a need to improve program efficiency and coordinate funding across sectors. If funding for retrofit needs can be built into one decarbonization program (e.g., the CEC EBD program), this would improve program efficiency by reducing administrative burden on program administrators, implementers, and participants. Alternatively, funding could be provided through formal coordination (including eligibility criteria and reporting requirements) with housing, health, and transportation programs. If additional funding cannot be secured, there is a need to reduce scope, and focus on serving households most in need—in other words, reach fewer households with higher-per-household investments to ensure those living in the worst energy and housing conditions are prioritized.

Program designers should adopt place-based strategies that combine program outreach, workforce training, infrastructure improvements, and community development within a specific geographic area, creating a virtuous cycle of investment and growth that can become self-sustaining. Geographic clustering at the neighborhood or urban scale reduces travel time for contractors, capitalizes on word-of-mouth outreach, and enables coordination of upgrades to electricity infrastructure and where appropriate discontinued service to natural gas infrastructure. Several providers noted that it is easier to implement projects in one geographic area at a time. This method reduces investment in outreach, cuts contractor travel time, helps neighbors learn from each other, and can be more cost effective than responding to calls within the entire service area.

As one implementer explained: *"we have a couple of programs that cover two different counties ...When we're doing that kind of boots on the groundwork, we will cluster cities such that are our energy advisors are spending their entire day in [one city] versus running back and forth all over the place."*

The CPUC and CEC should coordinate panel capacity and circuit capacity programs with local electrification programs to ensure electrification projects are coordinated with the capacity of the energy infrastructure. Where possible, programs should encourage low-capacity planning to avoid costly panel upgrades and support grid stability. This requires workforce education on low-capacity planning, including an understanding of how to maximize the use of existing panels and how to adequately size equipment to the household's needs. Where panel upgrades are necessary, the programs should cover the cost.

Energy Infrastructure

This section addresses the need to upgrade electricity infrastructure to meet higher loads. We provide strategies to ensure transparency about grid upgrades and prioritization of priority communities.

Overview of Challenge

Housing decarbonization requires both adequate electric panel capacity at the household level and adequate grid capacity at the circuit and transformer levels. Interviewees raised several challenges relating to energy infrastructure:

- The long waiting times (6-18 months) for panel capacity upgrades, transformer upgrades, and connection of solar to the grid are a significant problem for electrification projects, causing both delays in installations and cash flow challenges for contractors and property owners alike.
- In some multi-family buildings, energy providers only assign solar benefits to one unit.
- Charging individual customers for transformer upgrades is a challenging model for cost recovery and electrification affordability, since it is often the last customer to electrify who has to pay the bill. Several interviewees mentioned that to electrify their homes, they needed to upgrade the local transformer to handle the additional load from their home, as well as service to other buildings on the same street. Since transformers can handle a set amount of electric demand, the first few houses may electrify without triggering a need to update the transformer, and it is only when the last few buildings on the same line electrify that capacity is maxed. It is inequitable for only a few (often last) households to bear the full cost of an upgrade that enabled everyone before them to electrify. .
- There is a tension between the 'obligation to serve' and the desire to decommission gas lines. Discontinuing natural gas service will require all residents in that area to electrify, which could disproportionately impact low-income households.

- For utilities that provide both natural gas and electricity, there's limited incentive to decommission natural gas lines in territories where publicly owned utilities (POUs) or Community Choice Aggregators (CCAs) provide electricity services.
- There is anecdotal evidence about geographic variation in grid adequacy, but there is need for research to provide a more complete assessment of the state of energy infrastructure across communities.
- Communities that suffer from energy-related pollution, such as those hosting power plants, should be prioritized for decommissioning polluting facilities and home electrification.

Interviewees also discussed zonal decarbonization as a financial opportunity. If there is no need to maintain natural gas pipelines, funding can be redirected from natural gas line maintenance to the electrification of buildings.

Recommendations

The CEC and CPUC should establish transparency about grid capacity through mandatory, public-facing reporting on granular electric grid capacity to identify infrastructure gaps in priority communities. In partnership with community-based organizations, design a community education campaign to support understanding of the state of electric infrastructure in priority communities and the infrastructure upgrades needed to achieve electrification goals. As one interviewee who works in a state agency shared, "*I would love to see research on loading capacity [in different neighborhoods]. I think generally wealthier areas are the ones who are upgrading their infrastructure …and my understanding is, how utilities upgrade their infrastructure is really on a need basis. They're not proactively updating these transformers or the distribution infrastructure."* While the CPUC and the energy utilities study electrification loads across service areas, there is a need for publicly available, granular information on infrastructure readiness in disadvantaged and priority communities, including both circuit capacity and loads.[13]

The CPUC should mandate that utilities proactively invest in energy infrastructure in priority communities, including faster panel capacity, transformer upgrades, and solar connections to the grid, ahead of anticipated demand. By leveraging the granular analysis proposed above, the CPUC should require utilities to align capital improvement plans with local decarbonization projects, ensuring that grid constraints do not stall community-level energy transitions.

In support of the CPUC, the interagency working group, including representatives from the CPUC, CEC, and CARB, could consider several metrics for evaluating progress towards upgrading the electricity grid in priority communities:

- Waiting time: Tracking the time between project application and grid readiness, specifically within disadvantaged communities census tracts.

[13] A ruling in January 2021 directs IOUs to refine their Integration Capacity Analysis online maps: see https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/infrastructure/distribution-planning/data-portals-and-integration-capacity-analysis.

- General Rate Case (GRC)Alignment: Evaluating the percentage of a utility's GRC capital requests that are directly tied to decarbonization projects in priority communities.
- Project alignment: Investment in grid infrastructure should be coordinated with large-scale decarbonization projects, such as the neighborhood-scale (zonal decarbonization) pilots led by the CPUC.

By considering these metrics, the interagency working group can evaluate if utility capital improvement plans are technically robust and directly responsive to California's broader climate equity goals.

The CPUC should optimize regulatory oversight on energy infrastructure upgrades to provide faster panel capacity, transformer upgrades, and solar connections to the grid. While AB 2861 (2016) and AB 643 (2023) established the Expedited Interconnection Dispute Resolution (EDR) process and significant fines for negligence, waiting times remain a barrier to decarbonization. We recommend that the proposed interagency coordination team synchronize retrofit projects in priority communities with grid upgrades and provide clear timelines for infrastructure upgrade projects and decarbonization projects.

Affordability

Eligibility Criteria

This section suggests how to streamline eligibility criteria across energy, health, and housing programs to reduce administrative burden and enable incentive stacking – a process necessary to offset the costs of retrofitting older homes.

Overview of Challenge

In addition to program complexity, housing decarbonization programs are characterized by fragmented and inconsistent eligibility criteria across federal, state, and local levels. Interviews with program designers revealed that this variation reflects efforts to tailor programs to the demographic and geographic profile of their jurisdictions. Yet, this patchwork approach has created widespread confusion among recipients and administrators alike, increased administrative burdens, and complicated the ability to "stack" funding from complementary programs.

Income-based criteria are commonly used to identify eligible households, yet across California's energy and housing programs, income thresholds vary widely. Some define low-income households as those earning below 200 or 250 percent of the federal poverty level (FPL), while others define low-income as households earning below 60 or 80 percent of area median income (AMI). Moderate-income thresholds are also inconsistent, as some programs use the 250–400 percent of FPL threshold while others use the 80–150 percent of AMI, with some further subdividing the range (e.g. 80–100 percent, 100–120 percent, 120–150 percent of AMI) to prioritize those on the lower end.

While these distinctions aim to target resources equitably, they also generate a high eligibility verification burden. As one interviewee put it: *"it's like one program serving "left-handed" applicants and another "right-handed" applicants."* Applicants must provide extensive income documentation (e.g., tax returns, pay stubs, or benefit statements) that many low-income or immigrant households cannot easily produce. These requirements pose barriers for residents with limited English proficiency or mistrust of data-sharing processes. One interviewee noted that this can be a particularly large problem in priority communities: *"for a lot of folks, they can be very hesitant to provide a lot of personal information [e.g., tax returns] to a program that is perceived as a government program."* Complicated eligibility rules also create additional administrative costs and data security challenges for program implementers.

Geographic criteria are another approach to identifying priority communities, using designations such as CalEnviroScreen's "Disadvantaged Community" (DAC) index. However, local programs often modify or replace these criteria with their own geographic definitions. This allows programs to respond to local conditions but may create challenges if geographic designations are inconsistent with other programs at the state level. Further, geographic criteria can leave households just outside boundary lines, often facing similar economic and environmental challenges, without access to assistance.

Recommendations

Inclusion criteria

The interagency working group should provide guidance on inclusion criteria and track alignment/coordination among programs. Our interviews showed that individual program designers struggle to coordinate among programs at the regional level due to misalignment of priorities and timelines. The interagency working group needs to fill the coordination gap by acting as a consistent reference for all decarbonization programs and enabling coordination over time and across measures.

Policymakers and implementers should coordinate the eligibility criteria across programs at the regional level. Decarbonization programs targeting priority communities should be coordinated at the regional level to ensure streamlined eligibility across decarbonization, housing habitability, and healthy homes programs serving the same households. This coordination is necessary to allow for stacking of incentives.

Program administrators should track and report enrollment by eligibility criteria and use those data to refine program design. If outreach goals are not met, it will indicate a need for change in program design or eligibility criteria. Interviewees emphasized the importance of tracking data to understand the distributional impacts of decarbonization programs (see Chapter 5). These data, coupled with feedback loops from CBOs about program implementation, could inform how best to adjust the inclusion criteria to meet outreach goals.

Verification

Program designers should use categorical eligibility for low-income households, automatically qualifying households already enrolled in other means-tested programs (e.g., Supplemental Nutrition Assistance Program (SNAP), California Alternate Rates for Energy (CARE), Family Electric Rate Assistance (FERA), Medi-Cal, or Housing Choice Voucher program). All interviewees supported this recommendation and pointed to success in programs that already implement it. A state-maintained portal for a one-time verification across means-tested programs could support this even further.

Program designers should introduce more flexible income and geographic verification processes to reach underserved populations more effectively. Allowing CBOs to verify eligibility for households located near designated DACs within their service area could address the issue of rigid administrative boundaries that may not accurately reflect the actual economic or environmental conditions on the ground. In addition, programs could allow CBOs to verify household income for residents within their service regions. This shift helps overcome several systemic barriers in priority communities: (1) Documentation Gaps: Assists residents who lack traditional financial records; and (2) Household Composition Bias: Corrects for "false" high-income readings in multi-generational or crowded homes where multiple earners reside together specifically due to financial hardship rather than disposable wealth.

Program designers should consider self-eligibility declarations. Some interviewees reported using a trust-based system for local programs, noting that the administrative burden of collecting verification documents is higher than the cost of providing incentives to the occasionally ineligible participant. Their process included informing participants of the income eligibility criteria for their programs and asking them if they met the criteria without requiring documentation. Self-eligibility is particularly helpful if program designers suspect that their target community consists of individuals who may be hesitant to provide documentation, living in overcrowded homes with the appearance of higher household income despite financial struggle, and who could be earning income that is just over the eligibility threshold, but still too low to enable them to participate without assistance.

The CPUC should coordinate the statewide eligibility verification tool with the interagency working group. A state-maintained portal for a one-time verification across means-tested programs across the state is incredibly helpful in reducing administrative friction for implementers and households. Using this portal, relevant actors (e.g., households, CBOs, program implementers) can upload documentation only once, and the portal will verify eligibility for the appropriate category (e.g. “qualifies for Tier X” tokens to all programs). The CPUC is currently developing such a portal: as part of that process, it should coordinate with members of the interagency working group to ensure alignment with needs in priority communities.

Incentive Structure

This section describes challenges in structuring financial incentives to meet the needs of priority communities and recommends strategies to overcome them. Key recommendations include funding retrofit needs, scoping projects to reach bill neutrality, expanding access to green financing, and scaling incentives to the compounding needs of addressing historical disinvestments in both housing and energy infrastructure.

Overview of Challenge

Challenges remain in scoping projects effectively. For example, electrification needs to be coupled with energy efficiency measures and/or solar panels to lead to bill savings. Yet, it is challenging to stack incentives across programs to create a comprehensive energy upgrade project. Furthermore, there are varying levels of knowledge among implementers about how to match energy equipment to the household's needs and electrical panel capacity, sometimes leading to unnecessarily costly panel upgrades. Lastly, some programs are designed to change appliances "like for like," meaning that people who have natural gas equipment cannot switch to electric equipment.

Incentive structures are poorly matched to household financial capacity. Tax credits and rebate programs require either sufficient tax liability or upfront capital, making them inaccessible to LMI households. While no-cost direct install programs theoretically address this gap, they operate at limited scale with long waiting lists and often cannot serve households with pre-existing home conditions. Financing programs, such as GoGreen financing, can help bridge financing gaps for moderate-income households, yet these programs also need to scale to meet demand.

<u>**Recommendations**</u>

The interagency working group should provide guidance to local program designers on the coordination of measures among programs for home retrofits, including energy, housing, and health programs. Among energy programs, coordination can ensure the ability of households to stack incentives for different equipment across programs (e.g., utilize the incentive from program A for an induction stove and from program B for a heat pump). Across sectors, coordination of energy programs with housing habitability programs (e.g., home repair, lead remediation) can support households by streamlining services in the home and removing barriers to participation.

Program designers should combine measures to reach bill neutrality or bill savings. Program designers are advised to avoid single-measure incentive programs in priority communities and instead consider a combination of measures. Specifically, electrification needs to be combined with efficiency, clean energy measures, or electrification rates to avoid a bill increase. At the same time, some bill increases should be tolerated in the case of providing air conditioning services to homes that lack air conditioning.

The interagency working group should conduct a study on how to expand access to green financing mechanisms such as Go-Green financing and Inclusive Utility Investment (IUI) programs. These financial mechanisms are essential in mitigating credit barriers for moderate-income households, those that earn just over the threshold for income-eligible programs, but that still struggle to afford a costly retrofit.

Preliminary evaluation of the GoGreen financing program demonstrated successful reach in priority communities, especially for micro-loans, that help households finance one appliance at a time (CAEATFA, 2024; Campbell et al., 2023). At the same time, GoGreen Home Financing's ratepayer-funding model raises equity concerns, as utility rates are regressive compared to income taxes. In a recent evaluation of California's consumer energy finance programs, Campbell et al. (2023) argue that a taxpayer or state-funded model could reach more customers across all utility service areas, reduce limits on which customers can receive funds, and make revenue generation more equitable by relying on more progressive tax sources rather than regressive utility charges.

IUI programs, which utilize tariffed on-bill financing, represent a critical evolution in residential decarbonization financing. By decoupling capital recovery from an individual's credit and tying it to the utility meter, IUI effectively bypasses traditional debt-to-income and credit score barriers (LibertyHomes and Energy Efficiency Institute, Inc., 2022). In California, current policies, such as the Clean Energy Jobs and Affordability Act (SB 350) pilot programs and municipal initiatives in Riverside and Silicon Valley that demonstrate the model's potential for scalability (Dunsky Energy + Climate Advisors, 2024).

However, IUI models often encounter financial feasibility limits in high-need homes where extensive health and safety repairs are required before energy measures can be installed (Ferguson et al., 2022). To reach priority communities living in substandard housing, IUI must be braided with non-repayable grants (such as WAP or EBD). Collaboration with grant programs is necessary because these programs are specifically authorized and funded to address readiness needs (such as roof leaks or mold remediation) that often disqualify homes from CPUC-funded energy efficiency programs. By leveraging grant programs to cover these non-energy costs, the remaining energy-specific equipment can be funded via IUI at a level where on-bill charges are offset by savings, ensuring bill neutrality for the resident (US EPA, 2024).

Energy Rates

Overview of Challenge

Interviewees with experience in implementation report that the high price of electricity relative to natural gas still poses barriers to bill savings after electrification. Further, staff at community choice aggregators report that more than half of electricity price increases are attributed to the distribution line costs controlled by the investor-owned utilities. While all interviewees acknowledged that high electricity prices present a challenge to the cost-effectiveness of electrification, there are mixed views on how to address this challenge.

Some interviewees support providing a discounted rate for electrification for income qualifying customers. This practice is already common among some utilities and CCAs and, according to interviewees, contributes to the participant-level cost effectiveness of electrification in some regions, especially in homes that already have air-conditioning. Others argue that subsidizing electricity rate discounts for electrification is not a sustainable pathway, since this approach increases the cost of maintaining the electricity infrastructure for those that have not fully electrified, many of which are priority communities.

One approach to improve rate affordability is through the design of revenue-neutral time-of-use electrification rates. This rate design strategy differentiates between peak and off-peak rates. When people use electricity off-peak, they get a discounted rate. This reduces peak demand, which improves grid stability and the cost of providing electricity. Key challenges of this strategy include non-flexible loads (e.g., using air conditioning during a heat wave) and ensuring the consumer understands the different rates (e.g., clearly communicating that electricity rates change by hour of the day).

The CPUC, charged with regulating utilities to ensure fair, reliable, and affordable energy services, is exploring a new rate design strategy to address high electricity prices in California. The recently adopted and implemented income-graduated fixed charge aims to achieve several goals:

- **Charge all customers for grid maintenance.** Prior to this rate design, those who adopted solar panels on NEM 2.0 rates (the majority of which are high-income households) avoided paying their fair share in the maintenance of energy infrastructure. Fixed charges will ensure each household contributes to the maintenance of the grid regardless of how much energy they consume.
- **Progressive cost recovery.** Varying the fixed charge by income is intended to reduce energy cost burden among those who face the worst affordability challenges.
- **Reduce volumetric rates.** Currently volumetric rates are high because they include all costs associated with energy services (e.g., public purpose programs, wildfire resilience), and do not differentiate between services and maintenance or consumption costs. By recovering some fixed costs through fixed charges, the CPUC can reduce the costs of volumetric charges to more accurately represent the cost of consumption. Lower volumetric rates will especially benefit customers who are low-income and have high energy needs (for example, those who live in hot climates).

One of the challenges facing the CPUC is determining how to assign fixed charges by income. While the Commission recently moved toward this model by authorizing a graduated monthly Base Service Charge for all residential customers, intended to shift certain fixed grid costs away from volumetric rates (D.24-05-028), the implementation remains complex. Two big questions remain: (1) how to structure income tiers; and (2) how to collect information about income. Not all households that are eligible for low-income rates (e.g., CARE, FERA) apply for them, resulting in ongoing energy cost burdens. To address this, SB1208 (2022) requires the CPUC to develop a concurrent application system — an online portal that enables low-income customers to enter their income information and get referrals for energy, water, telecommunications, and other government programs they are eligible for.[14] The second phase of this platform will also include an income verification mechanism.

Community organizers fear that income-based fixed charges will introduce a lot of friction into energy affordability. First, not all those eligible for CARE/FERA programs are enrolled, highlighting the challenge in ensuring eligible households receive benefits, especially in a climate where low-income households fear disclosing income information. Second, community organizers also fear that income tiers will not reflect the needs of moderate-income households, who may earn more than CARE/FERA eligible low-income households, but who may nevertheless experience energy insecurity. Additional dynamics at play include the potential of misaligned incentives for households who receive electric service from a POU and gas service from an IOU. In these cases, some CARE-eligible households receive discounts on gas bills (from IOUs) but do not receive

[14] Cal. Senate Bill 1208 (Hueso), Ch. 840, Stat. 2022 (approved Sept. 29, 2022), adding Cal. Pub. Util. Code § 731.

comparable discounts on electricity (from POUs). This creates a misaligned price signal, where electricity appears relatively more expensive, which can discourage electrification and slow the transition away from gas.

Recommendations

Program implementers should help participants enroll in bill assistance programs as part of program intake. Since many eligible customers are not aware of bill assistance programs or how they can enroll, implementers in priority communities should help eligible participants enroll in bill assistance programs (e.g., CARE/FERA) as part of their services. Further, program implementers need to assist moderate-income households in enrolling in a rate plan that fits their needs and discuss demand/response where available.

The CPUC should conduct a study to explore the energy bill impacts of the new energy rate structure on priority communities before and after electrification. The study should go beyond the binary CARE/FERA categories to provide insights into the experiences of low- to moderate-income households – those who earn a little over the minimum to qualify for CARE/FERA but might still experience energy insecurity.

Conclusion

California has established some of the most ambitious climate goals in the nation, yet meeting these targets will depend on the state's ability to expand housing decarbonization in ways that reach the households most in need. This chapter demonstrates that while California has built an extensive ecosystem of programs and policies, fragmentation across agencies, funding streams, and implementation structures has created barriers that disproportionately affect LMI households, renters, and other priority communities. Through interviews with policymakers, implementers, community organizations, and households, we find that equitable decarbonization requires addressing barriers at every stage of participant engagement—from awareness and motivation to financing, implementation, and long-term outcomes. The recommendations in this report highlight the importance of stronger program coordination, deeper engagement with community-based organizations, integrated participant support, targeted incentive structures, and investments in workforce, infrastructure, and permitting systems that can support decarbonization at scale.

Ultimately, equitable housing decarbonization is not solely a technical challenge; it is an institutional and social one that requires coordination across sectors including energy, housing, health, and workforce development. Achieving California's climate and equity goals will require policymakers to move beyond isolated programs toward a more integrated implementation framework that aligns incentives, simplifies participation, and ensures that the benefits of cleaner, healthier homes are shared broadly. By centering the needs of priority communities and strengthening collaboration across agencies and stakeholders, California can accelerate the pace of building decarbonization while advancing housing stability, public health, and economic opportunity for residents across the state.

4. In-Depth Case Study of Retrofit Programs

Introduction

This chapter focuses on factors affecting households' engagement with decarbonization programs and the impact of these programs on energy insecurity.

This chapter fills two critical knowledge gaps by

- Advancing understanding of the cumulative factors that affect the engagement of households with decarbonization programs, with a particular focus on the unique challenges in priority low and moderate income (LMI) communities.
- Proposing a diagnostic framework to assess program impacts on energy security to inform program design and budget allocation.

This chapter is organized into three sections:

The factors impacting households' engagement with decarbonization programs. The first section discusses the cumulative time, effort, and resources that individuals must invest to decarbonize their homes, which we call "participation burden." Based on in-depth interviews with 18 homeowners, we categorize the factors affecting households' engagement with decarbonization programs into five dimensions and describe the differences between low- and moderate-income (LMI) and higher-income households in each dimension.

Energy security measurement. The second section introduces a methodology to measure energy security using 10-14 survey questions. The methodology relies on a questionnaire that can be easily integrated into the assessment of housing decarbonization programs to reveal their impact on energy security.

Energy security impacts of housing decarbonization programs. The third section evaluates the outcomes of decarbonization projects using the energy security measurement. We report on the results of a pre/post survey of 60 LMI homeowners and renters participating in housing decarbonization programs. The survey reveals households' perceptions of electrification technologies (e.g. heat pumps, induction stoves) and assesses how the energy retrofit impacted their energy security.

Section 1: The Factors Impacting Households' Engagement with Decarbonization Programs

Understanding how households engage with decarbonization programs is critical to improving program design and expanding participation. Drawing on qualitative interviews, this section examines participants' experiences, highlighting how program requirements, financial considerations, and external constraints interact over time. The findings point to multiple points of friction that can limit uptake or completion, even among motivated participants.

Methodology

As with the rest of the report, the household survey component of the Equitable Decarbonization research study employed a Participatory Action Research (PAR) framework to undertake research activities alongside community partners, which works to ensure that consumers of color and low-income shape decarbonization strategies in California and have access to and benefit from such programs (Solis et al., 2022). The PAR model ensures that data collection, analysis, interpretation and dissemination of study findings are grounded in the lived experiences of the target populations, which can strengthen the rigor, relevance, and policy reach of research (Balazs and Morello-Frosch, 2013).

We operationalized the PAR approach by forming a project Advisory Committee comprised of community-based and environmental justice organizations who were compensated for their time and expertise. Community partners provided essential field-based expertise and insider knowledge regarding the conditions affecting low-income households engaged with energy retrofit projects through a series of five iterative workshops. These workshops focused on developing surveys and questionnaires, establishing data collection protocols, and interpreting and contextualizing findings.

To understand implementation barriers to decarbonization, we conducted interviews with households who were engaging with housing electrification programs in the San Francisco Bay Area. One of the unique aspects of the Bay Area is that it is served by multiple housing decarbonization programs as well as organizations that offer 'one-stop-shop' services designed to reduce barriers to navigating funding streams. Housing decarbonization programs in the Bay Area include those that offer financial incentives to participants of all income levels, and equity programs designed to provide a larger subsidy for lower-income households or those who live in defined "disadvantaged community" [15] areas. Potential participants who are designated as very low-income or disadvantaged can receive discounted or no-cost decarbonization measures. Higher-income participants are offered tax incentives or rebates, which typically require participants to pay upfront and provide supporting documentation to claim a partial refund for their investment costs. Despite the large number of decarbonization programs as well as the availability of deep subsidies, community partners reported limited engagement with decarbonization programs, especially among low-income and disadvantaged households.

To understand the reasons for this gap and answer the research questions described above, we designed interview questions for homeowners (Appendix C), which focused on their experience with decarbonization programs. Interview questions asked respondents how they first learned

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[15] Senate Bill (SB) 535 (De León, Chapter 830, Statutes of 2012), directed the California Environmental Protection Agency (CalEPA) to identify "disadvantaged communities" based on "geographic, socioeconomic, public health, and environmental hazard criteria". CalEPA formally designates "disadvantaged communities" census tracts based on these considerations: The 25 percent highest scoring census tracts in CalEnviroScreen 4.0, census tracts previously identified in the top 25 percent in CalEnviroScreen 3.0, census tracts with high amounts of pollution and low populations, and federally recognized tribal areas as identified by the Census in the 2021 American Indian Areas Related National Geodatabase (OEHHA, 2025).

about programs for home energy upgrades, what motivated them to consider engagement, how they engaged with programs, and which aspects contributed to successful implementation or program abandonment. To reach our target population of homeowners, we partnered with two local implementers who referred their clients to the research team. These implementers provide a wide array of decarbonization interventions, including onboarding, energy assessment, cost and incentive eligibility analysis, scoping, installation of electrification equipment (e.g. heat pumps, induction stoves), and permitting.

During 2023-2024 we interviewed 18 participants who had contacted an implementer, expressed explicit interest in electrifying their home, and were in different stages of implementation. Each interview lasted 60 minutes and interviewees received $50 compensation. Interview transcripts were analyzed using deductive coding. First, we identified themes in the interview notes. Second, we identified key dimensions of participant engagement with housing decarbonization programs. Third, we organized themes by the dimension of engagement, allowing us to understand which themes were most important at each dimension. In describing the interactions of homeowners with the workforce, we refer to both program implementers and contractors as 'implementers,' as these entities technically implement the project from the homeowner's perspective.

Table 4 describes the demographic characteristics of our study population. The sample includes both low- and moderate-income (LMI) homeowners (defined as earning between 80 and 120 percent of the Area Median Income) and those with higher incomes (exceeding regional LMI thresholds, which in our sample included one household earning over $150,000 and 8 households earning over $200,000). The sample is largely homogenous in terms of country of birth (U.S.), English language ability, race, and ethnicity. Therefore, due to sample size limitations, we cannot draw definitive conclusions regarding potential divergence in experiences by these factors. Further, we highlight that the barriers for LMI homeowners in this cohort may be understated because they do not face additional challenges such as language barriers or immigration concerns.

TABLE 4: HOMEOWNER SAMPLE CHARACTERISTICS (N=18)

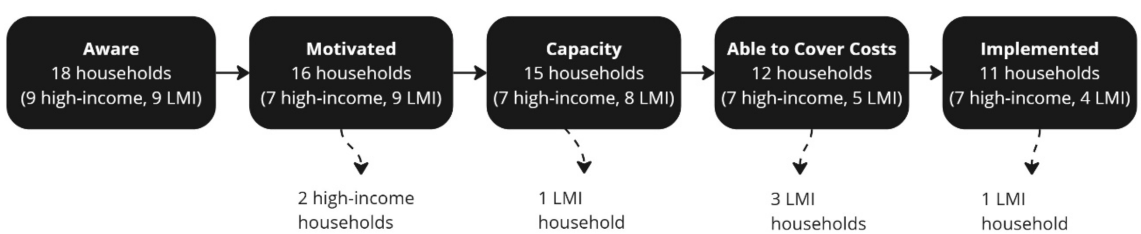
Characteristics	Number of Homeowners (n=18)
Housing Type	
Single-family home	14
Multifamily home	4
US Born	16
Speak English at Home	15
Race and Ethnicity	
White	12
Latinx	0
Asian	1
Black	2
Multiracial	1
Income	
Low- to Moderate-Income	9
High-Income (>$150k)	9

Findings

Interviewees described a multi-layered engagement journey that we categorized into five distinct dimensions: Learning (awareness, motivation), capacity to engage, buildings and neighborhoods, affordability (ability to cover costs), and governance. Each dimension demands a unique configuration of time, skills, and resources. While learning (awareness and motivation) drives the initial decision to seek out an implementer, capacity to engage, defined by the household's ability to navigate program requirements from start to finish, persists throughout the journey. The existing conditions of buildings and neighborhoods impact both the feasibility of energy retrofits and the cost of implementation. Affordability typically becomes a dominant hurdle mid-process following energy audits, though it often influences initial enrollment decisions as well. Finally, while state level governance factors emerged as important in program implementation, for households, it was interactions with local governance structures such as Homeowner Associations (HOAs) and municipalities that impacted the speed of implementation and upstream decisions regarding the costs of expected delays. These dimensions represent the cumulative hurdles that determine participant success or attrition.

Figure 2 illustrates the participant journey for the interview cohort, tracking attrition across the dimensions of engagement (breaking learning into awareness and motivation to highlight that awareness doesn't always lead to motivation). Because the sample consists of homeowners that had already contacted an implementer, the cohort is inherently 'aware' at the outset. The analysis, therefore, focuses on the factors that enabled or inhibited these households from moving from initial contact to project completion. Of the 18 households in the sample, only 11 successfully implemented decarbonization projects.

FIGURE 2: HOUSEHOLDS' ABILITY TO CONTINUE PURSUING ELECTRIFICATION AFTER EACH DIMENSION OF ENGAGEMENT



The reasons for project abandonment reveal a stark socioeconomic divide. Among higher-income households, attrition was primarily a matter of motivation; two participants opted out when they could not justify the investment's capital return. In contrast, five LMI households were forced to abandon their projects due to structural capacity, economic, and technical barriers. While the sample size is small, these results suggest that LMI households face greater challenges in navigating programs, affording retrofits, and meeting the technical needs of implementation.

Table 5 categorizes the primary concerns raised by respondents throughout the engagement process, isolating the specific friction points unique to each phase. This dimension-based understanding provides a roadmap for program design, allowing agencies to target resources effectively, minimize drop-off, and ensure that decarbonization initiatives are accessible as well as culturally and operationally resonant with the communities they serve.

TABLE 5: PARTICIPANT QUESTIONS BY ENGAGEMENT DIMENSION

Dimensions of Engagement	Participant Questions
Learning: Awareness and Motivation	What is housing decarbonization? How do I engage with these programs? How can housing decarbonization benefit me? Are others satisfied with their energy upgrades? What do others say is important about these changes?
Capacity	What is the process for engagement? How do I fill out forms? How do I contact contractors? How do I compare bids? How do I know what my house needs? Do I have the time and energy? Can I find a reliable contractor?
Buildings and Neighborhoods	Does my house have hidden costs for health, safety, or energy infrastructure? Is the neighborhood energy infrastructure adequate?
Affordability (Ability to Cover Costs)	What incentives are available to offset project costs? Will switching from natural gas to electricity increase my energy bills?
Local Governance	Can I get approval from my HOA and permits from the city?
Post Implementation Outcomes	How do I use these new appliances? What is the impact on my energy bills? What is the impact on my thermal comfort? What is the impact on indoor air quality, health, and well-being?

Interviewees consistently described participation in decarbonization programs as a process rather than a discrete choice. Each dimension requires different forms of information, resources, and support. For the households in the sample, progress was not linear, and participants often encountered multiple, overlapping barriers that influenced whether they continued or dropped out. These dynamics were particularly pronounced for low- and moderate-income households, for whom constraints tended to compound over time and across dimensions.

Table 6 summarizes these dynamics, organizing the key factors that emerged from the interviews by dimension of engagement. Only those who were successful across all dimensions were able to complete implementation, underscoring the importance of addressing multiple barriers to participation.

TABLE 6: KEY FACTORS INFLUENCING HOMEOWNERS' ENGAGEMENT WITH DECARBONIZATION PROGRAMS

Dimensions of Engagement	Key Factors
Learning	Awareness: Knowledgeable network, knowledgeable workforce, community-based organizations (CBOs), online communities, public policy (e.g., energy assessment at the point of sale, reach codes) Motivation: Improved thermal comfort and indoor air quality, utilizing government incentives, fighting climate change, increased property quality and value, reduced maintenance costs and complaints, addressed landlord-tenant split incentives
Capacity	Organizational, technical, and administrative capacity, availability and affordability of skilled labor
Buildings and Neighborhoods	Retrofit needs in the home (e.g., lead/asbestos/mold remediation, electrical panel upgrade) and energy infrastructure (e.g., circuits, transformers)
Affordability (Ability to Cover Costs)	Low or covered project costs (including retrofit needs, labor costs, and equipment costs), access to financial resources (e.g., personal capital, financial incentives), future energy savings (dependent on energy use and energy rates)
Local Governance	Speed of permitting and HOA approval
Post Implementation Outcomes	Customer education on how to use and optimize the use of the new appliances for energy efficiency, impact on energy security, health, climate resilience, housing quality, and greenhouse gas (GHG)reductions

Below, we discuss the key factors influencing success in each dimension and how experiences varied between LMI and higher-income interviewees.

Learning

The learning dimension includes factors impacting awareness of decarbonization programs and technologies, and factors impacting the motivation to pursue and implement home energy retrofits.

Awareness refers to participants' knowledge of decarbonization programs. Respondents reported learning about decarbonization programs in multiple ways: personal networks - including colleagues, friends, and family, local contractors and demonstration projects, community-based organizations (CBOs), online communities, municipal mandates for energy audits at the point of sale, municipal policies (such as reach codes and natural gas bans) and state-level electrification policies such as appliance standards.

Learning about decarbonization from trusted sources proved to be the most effective in building awareness. Respondents shared that CBOs played a key role in building their awareness by hosting workshops and presentations that introduced the concept of decarbonization, explained its benefits, and connected them with resources and contractors. Respondents whose personal network included individuals who had already undertaken housing decarbonization measures found them to be a valuable source of information about technology and the process. Respondents who are members of online communities (e.g., Slack channels, Facebook groups) that focus on climate issues reported that these were important sources of information, including guidance on different technology options, incentives, and contractors. Lastly, some respondents noted that demonstration projects offering free energy audits to households helped raise their awareness of decarbonization programs.

The interviews reveal a stark divergence in the information ecosystems that LMI and higher-income households navigate when seeking decarbonization resources. While both groups utilize overlapping sources, such as CBOs and social circles, the primary distinction lies in the density and technical knowledge of their networks.

We found important differences between LMI and higher-income respondents in how people learn about decarbonization programs. High-income individuals reported hearing about decarbonization through multiple channels, including professional networks, friends, online communities, and CBOs. The quotes below from higher-income respondents illustrate the importance of knowledgeable networks and professional expertise in gaining awareness: *"I heard about [implementer name] from a Slack channel. There are over 30,000 people in that group. I heard about the Slack channel through a colleague at [high-tech company]. The [Slack] group helps people work with an implementation company that aligns with their values and helps with climate information."* Another respondent relied on her professional expertise: *"I work in the construction space and am aware that the goal is to upgrade everyone to be all-electric. I know that there are some incentives, but am not clear on when things will be available. I wanted to do it early so we are not waiting in line."*

In contrast, LMI households had less access to people with professional expertise and experience. LMI homeowners were more likely to learn about decarbonization through a single trusted source, such as a CBO or friend, and in most cases were prompted to pursue it due to a specific need, such as addressing energy insecurity. While both groups utilize CBOs and friends, the distinction lies in the density and level of knowledge of the network: high-income respondents had access to more people with professional knowledge and experience with these programs, which offer multiple reinforcing information pathways, whereas LMI respondents often had only one point of contact, and often with limited professional expertise. As one LMI household articulated: *"Over the years we have gone to a community meeting for energy upgrade programs, and I've been on a mailing list. Difficult and confusing to follow up on information. Made it look like it is easy to get an energy audit, I never figured out how to get the assessment done."*

Motivation refers to the factors that influence participants' desire to pursue a decarbonization project. The motivation to engage with decarbonization programs was significantly different between high-income and LMI respondents. For high-income interviewees, the primary motivation for engaging in housing decarbonization was related to concerns over climate change, closely followed by the desire to access government incentives, such as tax credits and rebates. This environmental commitment is exemplified by one interviewee who stated: *"I've been a strong advocate for solving the climate crisis, I'm a retiree, and this is my major passion in life – to create a better planet for my children. We have to get off of fossil fuels. I can't sit back and watch the planet destroyed; somebody needs to make sure that that doesn't happen."*

Interviews also highlighted that higher-income homeowners were more attuned to how changes in California's energy policy could impact them financially. For example, several high-income respondents noted that despite the high upfront costs, they rushed to install solar panels before the change in Net Energy Metering (NEM) policy[16]. NEM 2.0 offered significantly higher financial returns and a much faster path to system ownership. By locking in "grandfathered" status for 20 years, homeowners ensured their excess energy would be credited at near-retail prices, resulting in payback periods of just 5–7 years. In contrast, waiting for NEM 3.0 meant accepting a 75% reduction in export credits and a return on investment that is largely dependent on the additional expense of a battery storage system.

Beyond environmental and financial incentives, higher-income homeowners were also motivated by increased home quality and property value, the necessity of replacing end-of-life equipment, and improvements in thermal comfort and indoor air quality. In these cases, decarbonization was often a byproduct of prioritizing residential resilience and health. As one interviewee noted: *"From a health perspective, we wanted filtered air and air conditioning. In our previous apartment. it was smoky, and that's why HVAC was our first priority."*

Motivations among LMI respondents were primarily centered on enhancing residential habitability, specifically regarding health, safety, and thermal comfort, followed by the desire to access available government incentives. While environmental concerns were present, they were often secondary to more immediate priorities of home quality and financial affordability. For these respondents, decarbonization was viewed through a pragmatic lens of necessity rather than elective climate action. One respondent highlighted the intersection of financial and physical vulnerability: *"I was pregnant and worried about not having money and not having heating... We have two heaters. The one downstairs had asbestos ducting, so we never turned it on. The one upstairs had issues with turning on and off. We were trying to get away from gas. We wanted solutions for how to afford all of these all at once."*

[16] The transition from Net Energy Metering 2.0 (NEM 2.0) to the Net Billing Tariff (NEM 3.0) represents a fundamental shift from volumetric retail crediting to avoided-cost valuation. Under NEM 2.0, residential solar customers received credits for exported energy at rates nearly equivalent to retail prices. In contrast, NEM 3.0 reduces export compensation by approximately 75%, aligning credits with the utility's "avoided cost" rather than consumer retail rates. This policy evolution aims to incentivize behind-the-meter battery storage integration, encouraging ratepayers to consume their own generation during peak periods rather than exporting surplus energy to an increasingly saturated midday grid.

Furthermore, LMI interviewees demonstrated a heightened sensitivity toward the long-term operational costs of electrification. Their interest in heat pump technology, for instance, was driven by a desire to mitigate extreme indoor temperatures, and in some cases, to leverage existing solar assets to reduce utility bills. However, this interest was tempered by concerns regarding electrical capacity and the prohibitive capital costs associated with comprehensive infrastructure upgrades: *“We had many more days during the summertime heatwaves when it was unlivable... Even though we replaced furnaces in the past 8 years, the house is still too cold in winter and too hot in the summer. That’s why we were interested in heat pumps... we have become aware of health issues and because we have solar and want to reduce utility bills. We are concerned about not overloading the electric capacity. We are not interested in having a complete overhaul of electricity in the home because of the high costs.”*

Capacity

The third engagement dimension focuses on homeowner capacity: if a homeowner is aware and motivated to decarbonize their home, can they follow through? We define the capacity to engage across three dimensions: (1) the **organizational** capacity to manage a complex multi-step process; (2) the **technical** capacity to understand information about the energy technology, implementation process, and financial costs; and (3) the **administrative** capacity to fill out forms and take on the administrative burden of implementation.

All interviewees reported capacity challenges across the three dimensions described above. The persistence of capacity challenges, even among high-income homeowners, is an unexpected finding. Many implementers of incentive-based programs in the San Francisco Bay Area offer one-stop shops that are advertised to reduce these capacity challenges. Yet none of our interviewees were able to follow a streamlined process, even when they were working with one of these implementers. Instead, they reported needing to invest substantial time and resources in identifying which programs were available to them, finding contractors experienced in electrification, understanding and comparing bids, and completing forms.

The affordability and availability of skilled labor played a significant role in respondents’ ability to implement projects. Respondents who experienced long delays, last-minute cancellations, no-shows, and high labor costs decided to forgo electrification and instead replaced their natural gas equipment like-for-like. In contrast, respondents who trusted their contractor to complete the implementation were able to complete the installation, highlighting the importance of an affordable, knowledgeable workforce.

Organizational challenges involved difficulty in navigating the decarbonization process, with respondents reporting feeling overwhelmed and uncertain about where to begin or whom to contact. The lack of information about how to start and manage the engagement process was aggravated by the limited availability of skilled workers. Respondents reported long waiting times and communication issues with contractors, with delays of 3-6 months for an energy audit, making it difficult to replace end-of-life equipment promptly. As a result, some homeowners chose to replace their gas appliances with another one. The quotes below illustrate respondents’ frustration with engaging with the workforce:

“[The implementer] communication is horrible. They don’t let you know what is going on. You wait for months and months. I am tired of the way that they treat me. I am at the point of saying just forget about it…It makes me feel disrespected as a customer…It’s been a frustrating process. I don’t understand why they don’t communicate. I’d give them an F. They are just terrible. They can’t do the job. Because I am waiting for [implementer name], I am letting other opportunities go by.”

“We contacted [implementer name] for the induction stove. The contractor could do the electrical work but didn’t have a plumber. Later, they found a plumber, and they proposed doing the wiring but not the installation. So twice, people were offering to do only a partial job. This is why we haven’t installed it yet.”

Technical challenges were aggravated by the limited availability of skilled labor. Respondents reported that many contractors lacked knowledge of decarbonization technologies, leading them to recommend natural gas equipment or to struggle with new system design and installation. This lack of expertise extended to uncertainties around the recommended system size for Heating, Ventilation, and Air Conditioning (HVAC) systems and panel capacity sizing, causing some households to forgo recommended electrical upgrades. Further complicating the process, quotes and contracts were often unstandardized, with inconsistent itemization and pricing between contractors, making comparisons difficult. Finally, many households reported a lack of awareness of available incentives or received misleading information, which sometimes resulted in unexpected costs.

Below are quotes from several respondents to illustrate technical challenges:

> *“They said we could claim the roof replacement as an incentive but that wasn’t true. We had to take a loan. We were hoping to get less of a [financial] load. The contractor said ‘some people get it and some people don’t’ about the incentive for roof replacement. We learned that you can never trust contractors at face value.”*
>
> *“The [implementer name] provided an audit and a quote for all measures. The quote was not itemized. It was very hard to get a hold of the [implementer] agent, and I didn’t understand how to implement independent measures.”*
>
> *“If you get a proposal from different companies, they use different terminology. It’s not apples to apples. They recommend different places to put the air vent, with different reasoning. Each seems to have their own spin on what is the most effective way even for something as simple as a heat pump.”*

Respondents shared that they also faced **administrative challenges**, especially with filling out complex government forms that were required to access financial incentives. These tasks were often quite time-consuming. As one respondent described: *“There were a lot of forms pre/post, including pictures and copies of the permit. It took a lot of time and persistence because they asked for so much. I wasn’t working at the time and had the time to do that… I cannot imagine how someone who is working full time can do it, they are just going to give up. It’s a very time-consuming process.”*

Across the board, interviewees expressed a desire for trusted resources to help them overcome these capacity challenges. As one respondent articulated: *"It would have been helpful to have a community representative that we could learn from. We had to learn everything from scratch. It would have been so helpful to ask trusted people: "who are the contractors? Are they good contractors? It would be nice if we could plug into a community where people have done this. Trusted vendors. Industry experts."*

While getting through the process was hard for everyone, high-income households tended to have better capacity than LMI households across all dimensions. Higher-income respondents reported higher levels of education and work experience in technical or management fields, which allowed them to more easily overcome technical and administrative barriers. Higher-income households also had more opportunities to obtain trusted information. They often relied on personal networks, such as recommendations from friends, consulted online communities for advice, or even hired consultants to facilitate decision-making. These resources provided them with both an understanding of the process and the technical aspects of engagement and eased the complexities and time burdens of contractor selection, cost assessment, and incentive utilization.

Buildings and Neighborhoods

This dimension refers to the physical readiness of housing and neighborhood-level energy infrastructure for electrification, which shapes both the feasibility and cost of electrification. Factors impacting the physical condition of buildings include the home's structural integrity (e.g., roof condition, insulation), compliance with health and safety codes (e.g., presence of mold, lead, asbestos, gas leaks, pests), and the electrical panel's capacity to meet higher electrical loads. Factors impacting Neighborhoods include the adequacy of the electrical distribution grid, specifically whether local transformers and circuits possess the capacity to absorb concentrated increases in electrical load or handle new solar connections.

The interviews revealed how the existing conditions of the home impacted the cost and feasibility of implementing energy retrofits:

> *"The audit revealed that the home has structural problems that will impede decarbonization - The location of a central beam will make it difficult to install ductwork for the heat pump. The house has gas infrastructure."*
>
> *"[Energy utility] has a weatherization program - I qualify for that, but - after an audit they said that there are gas leaks from the water heater, so they didn't want to weatherize because they were afraid of concentrations of gas and methane."*
>
> *"Because it is state/federal money, they put parameters around what the appliance could be replaced with. The program only paid for the heat pump. We were told that asbestos removal would be paid for by another program, and we never got reimbursed. $2000 cost of remediation."*
>
> *"We have a 125 amp box that allows the electricity to come in. A change would cost $10,000…we were supposed to get a 17 solar panel system and we got a 16 solar panel*

> *system. We were told by the installer that to increase the number of panels we would have to get an electrical panel upgrade."*

Some of the interviewees also experienced challenges related to the local energy infrastructure. For example, one respondent had planned to replace natural gas space and water heaters with electric heat pumps but was informed by electrical engineers and electricians that it would be impossible to complete this project without upgrading the transformer to support higher electrical demand. Not only was the cost of replacing the transformer high (approximately $80,000), but the timeline for the upgrade was long. The respondent expressed concerns about the timeline: *"We want to do this now as a building before there is this really long line with [energy provider]. I work in construction, the cost of everything is very high. It's crazy how many of the projects I work on are finished and can't be occupied because [energy providers] haven't connected them. We're not sure what the plan is for the whole city or state, we want to do this now before everyone has to do this."*

Affordability (Ability to Cover Costs)

The fourth dimension of the framework focuses on the costs of electrification. Even when the awareness, motivation, and capacity to engage were there, for some homeowners, cost became the barrier to implementation. Homeowners' ability to cover the costs of housing decarbonization measures depends on three aspects:

(1) **Project cost** - includes equipment and labor costs, as well as any upgrades to the existing building or energy infrastructure that is a pre-requirement to install the new equipment. In general, the worse the existing conditions of the home and energy infrastructure, the higher the costs.

(2) **Personal capital and access to financial resources –** includes both the amount of available funds an individual is willing and able to invest in the retrofit project, and external sources of funding that individuals can access including tax incentives, rebates, loans, and grants.

(3) **Future energy savings** reflect the change in energy bills between the existing conditions and the retrofitted conditions. Despite the common perception that energy retrofits will lead to energy savings, that may not always be the case. Future energy savings depend on future energy use and energy rates. Since electricity rates in California are significantly higher than natural gas rates (Borenstein et al., 2023), switching to all electric equipment is not likely to lead to bill reduction unless the new equipment is far more energy efficient and/or the electrification is coupled with energy efficiency measures and/or solar panels. Further, households without air conditioning might suffer from extreme heat, which could be addressed through the installation of a heat pump, thereby increasing electrical demand to meet a previously underserved need. When these households exchange natural gas space heaters for heat pump space heating and cooling systems, they can experience an increase in electricity use and higher bills to meet cooling needs.

For a retrofit project to be financially viable, the sum of the present value of personal capital, financial incentives, and the net present value of future energy savings must be equal or larger than the present value of the cost of implementation. However, 90 percent of our interviewees did not integrate future energy savings into their cost calculation because that involved a high level of complexity and forecasting. Instead, in assessing their decision to decarbonize, most people focused on the relationship between project costs, incentives, and their available personal funds. This finding demonstrates how capacity challenges (discussed above) can affect participants' understanding of financial feasibility.

Project costs varied significantly between interviewees, based on the conditions of buildings and neighborhoods (described above). Those who lived in older housing were provided with higher cost estimates to remediate existing conditions in their homes, such as removing asbestos, addressing gas leaks, upgrading low-panel capacity, or fixing structural issues with the building or the roof. A couple of interviewees also needed to upgrade the local transformer, a process that is both expensive and requires long waiting time for permitting and service upgrade by the electric utility. None of these costs were covered by the available financial incentive programs, which led some of the LMI homeowners to abandon the decarbonization process.

High-income respondents in the cohort decided to pursue housing decarbonization despite the high uncovered costs because they were intrinsically motivated to fight climate change. But even among those households, costs remained a concern that they tried to mitigate. Several higher-income households reported chasing incentives or said they were waiting for the federal Inflation Reduction Act (IRA) incentives to become available. However, while they waited, rising labor costs diminished the value of those subsidies. Furthermore, all respondents who wanted to install solar panels reported "rushing" the project so that they could still benefit from the NEM 2 rates before they changed to be less financially attractive. These strategies demonstrate that even among higher-income and highly motivated homeowners, financial incentives play an important role in the ability to mitigate the cost of implementation.

Among LMI respondents, eligibility for no-cost installation was required to ensure implementation. Some interviewees did not qualify for financial incentives due to existing conditions in the home, or due to energy bills that were too low to qualify for solar. Several LMI interviewees struggled to bundle income-eligible programs due to differences in eligibility criteria and approved electrification measures. For one participant, trying to braid funding programs took over a year, during which she had no heating and suffered from heightened anxiety about the home retrofit process. In her words: *"We would spend most of the time in a small room that could be heated and avoid the colder other spaces. We sometimes used the kitchen stove for heating… It was very frustrating. I was pregnant with a son born in June. I wanted to finish before giving birth, but could only get it to work in November."*

Local Governance

From the homeowner's perspective, local governance affected their ability to move the project through permitting and approval processes. This included the timeline for obtaining city permits; and the speed and complexity of receiving Homeowners Association (HOA) approval (when relevant).

Interviewees reported long waiting times for permits, which significantly delayed their projects. They noted the lack of knowledgeable city staff to inspect and approve new technologies. Some interviewees were so discouraged by the permitting process that they decided to renew their natural gas equipment so they wouldn't have to engage with complex electrical permitting (since like-for-like gas replacements often only require simple over-the-counter permits). Others complained that the long waiting time for permitting meant that they were unable to wait for an electric replacement at the end-of-life of their existing appliances, forcing an emergency gas replacement instead.

Interviewees who lived in condominiums or multifamily properties with shared ownership of the roof and/or HVAC systems reported challenges in getting HOA approval. These interviewees invested a significant amount of time and effort in convincing their neighbors to participate in electrification. This often involved holding multiple meetings, conducting a cost-benefit analysis, educating neighbors about the new equipment, and reducing administrative load from others by having one person responsible for filling out forms and managing implementation for the entire building.

Post-Implementation Outcomes

Satisfaction with implementation depended on the quality of installation and knowledge of how to use the new technologies. Interviewees who completed the implementation process reported satisfaction, citing improved thermal comfort and indoor air quality. Some respondents shared that they needed education on how to use the new equipment. For example, heat pumps need to be turned on all the time at the desired temperature, which is different from gas furnaces that people typically turn on and off to heat their home. A few respondents reported dissatisfaction with the size of their water heater or heating/cooling pump system, saying that the contractor installed systems that were too big for their home, either taking up too much space or making too much noise.

Intersectional Barriers to Participation across Engagement Dimensions

Table 7 summarizes the factors impacting implementation by engagement dimension. By observing the multiple factors that affect decision making at each dimension, we show that public policies that rely only on financial incentives such as tax incentives and rebates can be insufficient in meeting homeowners' needs for two reasons: first, they only impact decision making at the motivation and ability to cover costs dimensions, ignoring challenges in other dimensions of engagement; and second, these financial incentives often do not include labor costs, or the cost of fixing existing conditions in the home. For example, one of the LMI respondents chose to forgo electrification of space heating because the rebates did not cover additional costs to install ductwork in the house, and those costs were prohibitive for a retired individual on a fixed income.

We also found that workforce readiness is a critical factor in all dimensions of engagement. A knowledgeable workforce can raise awareness of new all-electric technologies and discuss aspects that affect motivation with homeowners. Further, contractors who can explain the recommended new technologies, who know how to get incentives for their clients, and who can accurately estimate the costs of the project, can help bridge capacity gaps among homeowners. Finally, the ability to design and install energy measures in a home to the satisfaction of the client, and to provide education on how to use the new technology, will help not only the serviced client, but also others through word of mouth. In the interview cohort, none of the respondents were able to get this type of support from their contractors, leading them to invest time and resources to undertake decarbonization measures or to abandon the project. When faced with the challenge of finding reliable contractors, higher-income households were able to pay more or find someone in their network, while lower-income households reported more friction in finding contractors.

Trusted networks can mitigate gaps across several of the engagement dimensions, by supporting homeowners through building awareness, motivation, and increasing their capacity to undertake decarbonization. Interviews showed that when a person has access to someone in their network who raises their awareness of decarbonization programs, explains the motivation to engage, and answers questions about the process, costs, and technology, it significantly improves a person's ability to engage and implement decarbonization. This finding highlights the important role that community organizers serve in LMI communities, where there may be fewer friends or family members that can provide this information and assistance.

TABLE 7: INTERSECTIONAL FACTORS IMPACTING PARTICIPATION BY ENGAGEMENT DIMENSION

Factors Impacting Participation	Awareness	Motivation	Capacity	Costs	Implementation
Financial Incentives		X		X	
Public Policies (e.g. municipal building codes, zero NOx appliances)	X	X			
Workforce Readiness	X	X	X	X	X
Trusted Network (e.g., Community-Based Organizations, family, friends, online communities)	X	X	X		
Need for Remediation of Existing Conditions in the Home				X	
Need for Electrical Infrastructure Upgrades				X	X
Energy Rates		X		X	
Permitting and HOA Approval					X

Section 2: Energy Security Measurement

A fundamental pillar of equitable building decarbonization is ensuring that electrification delivers a clear net benefit to residents, particularly among priority populations. This raises the question of how to measure energy security in a way that captures both the financial and lived dimensions of energy insecurity, including affordability, physical comfort, and the strategies households use to cope with constraints. Research has increasingly moved toward multidimensional frameworks to capture the lived experience of energy insecurity beyond simple bill-to-income ratios. For example, using an expanded ten-indicator instrument, Siegel et al. (2024) operationalized energy insecurity through a combination of economic dynamics (utility debt and disconnection notices), physical conditions (extreme indoor thermal discomfort), and coping responses (the use of stoves for heat or the restricted use of air conditioning). Their citywide representative survey in New York City found that 28 percent of residents experienced three or more of these indicators, with a disproportionate burden falling on Black and Latino/a households, renters, and families with children. The study also found that high levels of energy insecurity are associated with significantly increased odds of respiratory, cardiovascular, and mental health conditions, illustrating that energy precariousness is a primary social determinant of health that requires targeted, context-specific policy interventions.

While existing literature underscores the broad environmental and health advantages of electrification, there remains a critical knowledge gap regarding its specific impact on the energy security of low- and moderate-income (LMI) households. To address this deficiency, we developed a composite Energy Security Score, a longitudinal metric designed to quantify shifts in household-level energy security following residential electrification projects. We build on existing measures in two critical ways. First, we transition from measuring **prevalence** to quantifying **severity**. Second, we apply this metric longitudinally to evaluate the efficacy of energy interventions. This approach allows us to determine whether a residential retrofit meaningfully moves a household from energy insecurity to security, providing a more granular assessment of how climate policy impacts household well-being over time. This diagnostic tool can provide program designers with actionable insights, identifying which initiatives most effectively bolster energy security for vulnerable populations.

Building on established definitions (Hernández, 2016; Hernández and Laird, 2025; Siegel et al., 2024), we categorized energy security into three dimensions: physical, economic, and coping. Each dimension was operationalized through specific indicators measured via survey questions. For ease of interpretation, we use a 0-100 scale, where 100 reflects an energy-secure household, and 0 describes the most energy-insecure households with deficits across all three dimensions. We employed a weighted scoring system (ranging from 10 to 20 points per indicator). The composite Energy Security Score is the total possible points (100), minus the sum of the weighted indicators. The dimensions are structured as follows:

The Physical Dimension. This dimension evaluates the structural and mechanical integrity of the home's thermal environment. Participants were assessed -20 points for the absence of functioning climate control or the use of hazardous secondary heating (e.g., kitchen stoves). Thermal discomfort, measured by how frequently respondents reported feeling too cold or too hot at home, was assigned a score of −20 if experienced frequently and −10 if experienced occasionally.

Economic Dimension. This dimension focuses on the affordability of energy in the home. If respondents reported being late in paying energy bills or receiving a utility disconnection notice, they were assessed -20 points if they experienced this every month or almost every month, and -10 points if they experienced this only once in a while.

Coping Dimension. This dimension captures the extent to which households adopt behavioral or material coping strategies in response to energy constraints and was assigned a maximum of 40 points. Coping is operationalized along two pathways. First, if respondents reported a constrained use of the home (e.g., restricting activities to one part of the house or leaving the home entirely due to energy problems), they were assessed -20 points. Second, if respondents reported making material trade-offs (e.g., foregoing basic needs like food or medicine to pay energy bills, or maintaining unsafe temperatures to reduce costs), they were assessed -20 points if they experienced these trade-offs every month or almost every month, and -10 points if they experienced them only once in a while.

Table 8 summarizes the dimensions, indicators, and weights in the Energy Security Index.

TABLE 8: RUBRIC FOR THE ENERGY SECURITY INDEX

Dimension	Indicator	Survey questions	Weight = 0 (Secure)	Weight = 1 (Moderate)	Weight = 2 (High Insecurity)
Physical	Functioning equipment	Unable to use the heater or AC; Use stove for heat	Able to use the heat or AC		Unable to use the heater or AC, or use the stove for heat
Physical	Thermal comfort	Sleep disturbed; Too cold/hot in home	Rarely/Never	Sometimes	Always / Very often
Economic	Financial strain	Late bills; Disconnection notice	Never	A few months	Every month / Almost every month
Coping	Constrained use of home	Restrict activities; Leave home	No		Yes
Coping	Trade-offs	Forgo basic needs; Unsafe temp to save money	Never	A few months	Every month / Almost every month

Section 3: Energy Security Impacts of Housing Decarbonization Programs

A central question for equitable building decarbonization is whether retrofit programs translate into meaningful improvements in household well-being, particularly for low- and moderate-income (LMI) households. While these households are often prioritized for program participation, they also face disproportionate energy insecurity, higher exposure to poor housing conditions, and greater financial vulnerability to changes in energy costs. Without careful evaluation, decarbonization investments risk exacerbating existing inequities rather than alleviating them. Assessing program impacts on household outcomes is therefore critical to understanding whether these interventions are delivering on their equity and public health goals.

To assess the impacts of housing decarbonization on household well-being, we designed a pre- and post-retrofit household level study, using the multidimensional Energy Security Score described above.

Methodology

The pre- and post-retrofit household study focuses on the experiences of households undergoing decarbonization retrofit projects that included Air Source Heat Pumps (ASHP) and Heat Pump Water Heaters (HPWH). Our study population included participants from the San Francisco Bay Area and Los Angeles, California. Eligibility criteria for participants to enroll in the study included a commitment to implement an energy retrofit the following year, primary responsibility for paying their energy bills, and being over 18 years old. We recruited 60 homeowners and renters into the pre-retrofit cohort. Nine homeowners were referred to the study team by project implementers in the San Francisco Bay Area. Fifty-one renters were referred by affordable housing developers in San Francisco and Los Angeles.

Surveys were conducted in person or by phone in English, Spanish, Mandarin, Cantonese, and Korean and lasted approximately 60 minutes. Pre-retrofit surveys were conducted during July 2023 - August 2024. Post-retrofit surveys were conducted between 6 and 12 months after project completion (June through December 2025) to ensure participants had time to use the new equipment in different seasons and to receive energy bills after retrofits were completed. Alongside standardized quantitative metrics, the survey included open-ended questions to capture participants' lived experiences with the new equipment. These qualitative responses were transcribed and analyzed using deductive thematic coding to capture the nuances of system usability and installation satisfaction.

Of the initial pre-retrofit participant group (N=60), 38 participants completed post-retrofit interviews. Of the 22 people who did not participate in the follow-up survey, 5 declined, and 17 did not respond. We compared key demographics between the full pre-retrofit cohort (n=60) to the full post-retrofit cohort (n=38), and found no significant differences across age, gender, race, education, or income (Table 9). The pre-retrofit and post-retrofit surveys included questions across the following domains: demographics, perceptions of home energy retrofits and electric appliances, experiences with the retrofit process and appliances, mental and physical health, physical conditions of the home and appliances, economic conditions of the households, and coping strategies with energy insecurity. Survey questions were derived from existing surveys on residential energy consumption (EIA, 2025), energy security (Siegel et al., 2024) and neighborhood health (Arcaya et al., 2018). Questions about perceptions and experience were developed by the study team in consultation with the study advisory committee. The survey instrument is available from the authors upon request. Study data were collected and managed using REDCap electronic data capture tools hosted at the University of California, Berkeley (Harris et al., 2019, 2009).

TABLE 9: PRE-RETROFIT AND POST-RETROFIT COHORT CHARACTERISTICS

Characteristic		Pre	Post
Total N	Participants	N=60	N=38
Referring Organization	Private Contractors in the SF Bay Area	10 (16.6%)	3 (7.9%)
	Affordable Housing developer in SF	26 (43.3%)	17 (44.7%)
	Affordable Housing developer in LA	24 (40%)	18 (47.4%)
Homeownership	Renter	51 (85%)	35 (92.1%)
	Homeowner	9 (15%)	3 (7.9%)
Age	18-29 years old	3 (5%)	2 (5.3%)
	30-44 years old	12 (20%)	8 (21.1%)
	45-60 years old	18 (30%)	8 (21.1%)
	over 60 years old	27 (45%)	20 (52.6%)
Nationality	Other	36 (60%)	23 (60.5%)
	U.S.	24 (40%)	15 (39.5%)
Language Spoken at Home	Other	21 (35%)	13 (34.2%)
	English	39 (65%)	25 (65.8%)
Gender	Female	40 (66.7%)	29 (76.3%)
	Male	20 (33.3%)	9 (23.7%)
Race and Ethnicity	Asian	15 (25%)	9 (23.7%)
	Black	13 (21.7%)	9 (23.7%)
	Latino/Latina/Latinx	22 (36.7%)	15 (39.5%)
	Multiracial	2 (3.3%)	1 (2.6%)
	White	8 (13.3%)	4 (10.5%)
Education	Less than a high school diploma or GED	12 (20%)	7 (18.4%)
	High school diploma or GED	19 (31.7%)	14 (36.8%)
	Some College or an Associate's degree	15 (25%)	11 (28.9%)
Education	College Degree/Bachelor's degree	9 (15%)	5 (13.2%)
	Graduate Degree	5 (8.3%)	1 (2.6%)
Employment	Employed full-time	14 (23.3%)	6 (15.8%)
	Employed part-time	5 (8.3%)	4 (10.5%)
	Not employed. Searching for work	11 (18.3%)	7 (18.4%)
	Not employed. Student	3 (5%)	2 (5.3%)
	Retired	27 (45%)	19 (50%)

Characteristic		Pre	Post
Rental Assistance	Yes	13 (26.5%)	8 (24.2%)
Income	$30k or less	26 (44.8%)	23 (63.9%)
	$30k-$60k	18 (31%)	7 (19.4%)
	$60k-$90k	6 (10.3%)	3 (8.4%)
	$90k-$150k	5 (8.6%)	2 (5.6%)
	$150k-$200k	3 (5.2%)	1 (2.8%)
Ability to Cover Expenses	Very hard	9 (15%)	9 (24.3%)
	Somewhat hard	27 (45%)	13 (35.1%)
	Easy	18 (30%)	10 (27%)
	Very easy	6 (10%)	4 (10.8%)

Our final analytical sample comprised 37 participants, as one respondent was excluded due to incomplete data.

In addition to providing a replicable approach to measuring the impacts of housing decarbonization programs, we utilize the Energy Security Score to analyze the outcomes of home retrofits among a sample of 60 people. The Energy Security Score serves as a continuous variable for our primary analysis, allowing for the comparison of baseline (pre-retrofit) and follow-up (post-retrofit) energy security levels. By aggregating these dimensions, the score captures not only the immediate physical state of the home but also the psychological and financial burdens placed on residents, providing a holistic view of the impact of housing decarbonization on public health outcomes.

In this section, we present the post-retrofit outcomes for our sample. We begin by analyzing who was able to use the new electric appliances post-implementation and then present how variations in use relate to energy security outcomes.

Post-Implementation Usability Outcomes

The well-documented health and economic benefits of housing decarbonization (Daouda et al., 2024; Gillingham et al., 2021; Jessel et al., 2019; Ryan and Campbell, 2012; Wilkinson et al., 2009; Willand et al., 2015) are strongly mediated by the user's ability to operate new technologies. If vulnerable populations receive physical upgrades but lack the knowledge to use and optimize them for affordability or proper installation, the intended public health intervention may inadvertently widen existing health disparities. Therefore, we operationalized 'usability' through two binary dimensions: knowledge and satisfaction with installation quality, based on the surveys and interviews we administered post-retrofit. The "knowledge" variable was coded as 1 if the participant reported the ability to operate and optimize the equipment for affordability (e.g., heat pumps, induction stoves), while the "satisfaction with installation quality" variable was coded as 1 if the participant reported satisfaction with the installation. These were combined into a composite usability variable: high-usability respondents were defined as those meeting both criteria (a cumulative score of 2), while low-usability respondents were those meeting only one or neither (a cumulative score of 0 or 1).

Table 10 describes the dimensions of knowledge and the level of satisfaction with the installation quality, and Table 11 describes the total number of respondents for each category. For the knowledge analytical variable, 21 respondents were coded as high knowledge if they were able to either follow the manufacturer's instructions or if they had learned how to use the equipment from others. In contrast, 16 respondents were coded as low knowledge (value=0) due to challenges across the following domains: did not know how to use the new equipment (e.g., which button to push to get heat), or how to optimize the new equipment (e.g., operating time and use of thermostat), didn't receive guidance in their native language, asked for help and didn't get it, and didn't use or constrained use of the new equipment due to concerns about cost.

Twenty-four respondents were satisfied with the installation quality, attributing satisfaction to reduced energy bills, improved air quality, health, and thermal comfort. Thirteen respondents were dissatisfied with the installation quality due to any of the following challenges: insufficient amount of hot water or long waiting time for hot water, heat pump installed in a location that doesn't allow air flow, leading to lack of thermal comfort in some rooms, malfunctioning equipment, unfinished installation, and an overloaded electrical panel that leads to power outages when the heat pump is in use.

TABLE 10: PARTICIPANT KNOWLEDGE OF AND SATISFACTION WITH RETROFIT

Code	Dimensions	Example Quote
High knowledge (=1)	Followed installer's instructions	"It works really well. The air conditioning works fine. I use the heater a lot. I turn it on when I come home and I turn it off when the house is warm. I set it for 77. I keep it on for a couple of hours and then turn it off."[17]
High knowledge (=1)	Asked for help and learned system	"I will turn it on for 2-3 hours before we go to bed to warm the whole house and we turn it off for the night. I set the temperature to 73. They set it up for 73 and I didn't touch it. ... When the temperature wasn't warm, I called maintenance and saw how they set the temperature up and down. Now if something happens, I know how to press the buttons up and down."
Low knowledge (=0)	Afraid to use due to bill concerns	"After the energy upgrade, the system is good, but I don't use the new appliances much because I worry about higher electricity bills."

[17] While general heat pump guidance often recommends continuous operation, in mild climates like the San Francisco Bay Area, targeted episodic use—warming the home only during critical periods of thermal comfort needs—can be a highly efficient and cost-effective strategy. These respondents demonstrate high operational knowledge by utilizing the system for sustained, multi-hour periods, which is significantly more efficient than users who incorrectly micro-cycle the equipment on and off for only a few minutes at a time.

Code	Dimensions	Example Quote
Low knowledge (=0)	Didn’t know how to optimize use of heat pump	"The installers gave me the remote control and how to turn it on and off. I wish they explained how to use it better. Maybe there's a new setting to make it work better. With the gas I would put the setting at 60, and now it's on 90 but it barely gives heat. We never feel the hot air coming out. I wish they would have explained it better.”
Low knowledge (=0)	Didn’t know how to use the heat pump	"The heater is when you push it up. There is another button for the fan; when he turns the fan on, the air conditioner turns on. He hits the wrong button, and the fans come on, and it gets cold. I don't know how to use the fan."
Low knowledge (=0)	Didn’t receive instructions in language spoken	Interviewer notes: Staff only explained how to use the equipment in English and the respondent didn't understand. The respondent only used the new heat pump once or twice. She didn't want to bother the staff so she didn't ask again.
Low knowledge (=0)	Asked for help and didn't get it	"I have never gotten that thing to work. When it was first installed they taught us how. I expected someone to come again to reiterate how it works. It was just one time and it's forgotten. It's not working for us."
High satisfaction with installation quality (=1)	Energy bill reduction	"I am very satisfied with the new appliances. They are much quieter and work so much better than the old ones and I am not afraid to use them compared to before as my bills are cheaper and they are of better quality."
High satisfaction with installation quality (=1)	Indoor air quality & health	"With the natural gas heater, when we used it, it also burned dust and created a strong smell. With the new electric heater, there's no problem. The air in the house is cleaner. Because the air is cleaner, we have less asthma attacks. I'm happy that the whole house is warm despite the expense. I am happy that the air is clean and I don't have to worry about leaking gas."
High satisfaction with installation quality (=1)	Indoor air quality & health	"Before, when I used the gas heating system, I often had headaches. Since the new indoor heating system was installed, I haven't had headaches, and the air feels better."
High satisfaction with installation quality (=1)	Thermal comfort	"I was satisfied with the energy upgrade. My first priority was home heating and indoor temperature, and it was accomplished."

Code	Dimensions	Example Quote
Low satisfaction with installation quality (=0)	Problems with temperature control (e.g., cold air when set to heating)	"[The] location in front of our bedroom is a bit noisy as we can hear it. It works well but in the bedroom, cold air comes in from the new heat pump instead of hot air. We notice that the electricity bill was higher in winter...my wife has difficulty sleeping due to problems and worries related to it"
Low satisfaction with installation quality (=0)	Long waiting time for hot water	"This project fixed our boiler, but we have an issue with the new water heater in that we have to wait one hour for hot water to come out after someone finishes showering."
Low satisfaction with installation quality (=0)	Not enough hot water	"The hot water doesn't last as long as the gas-heated water would last...I went out there several times, and someone turned it down, I had to adjust it. It doesn't last as long. I didn't even bother complaining. The whole thing was not put together."
Low satisfaction with installation quality (=0)	Not enough hot water	"We're not getting the water to the temperature we used to get...I have to warm water in the kitchen and bring that to the bathroom so that my children can have a bath. I brought up this issue several times, and they fixed it. It worked for a couple of days, and then it started to get lukewarm again. I wonder if they are trying to save money by keeping the temperature low and only increasing the temperature when people complain."
Low satisfaction with installation quality (=0)	Unfinished work	"We need a door frame and a seal. The cold is coming in through the door. I've complained three times already, and nobody has come. They haven't finished the work. We have holes in the wall. They ran out of funds. They never finished the plumbing and electrical work. We have holes in the bathroom and kitchen and papers covering it. I'm starting to have roaches. Two months with holes in the walls. "
Low satisfaction with installation quality (=0)	Electrical panel is insufficient	"Since the new indoor heating system was installed, the power in my home sometimes goes out. It can be inconvenient."
Low satisfaction with installation quality (=0)	Lack of thermal comfort	"The heat pump for heating doesn't work very well throughout the entire apartment. The heating is uneven - one room is significantly warmer than the other rooms."

As demonstrated in the quotes, poor installation or a lack of knowledge of how to use and optimize the use of the heat pump for affordability directly affect household behaviors (e.g., refusing to use the heat pump due to cost fears) and physical insecurity (e.g., enduring cold air or lack of hot water), effectively negating the intended benefits of the retrofit.

Overall, 16 participants (43%) met the criteria for 'high-usability' (demonstrating both high knowledge and high satisfaction). The remaining 21 participants (57%) were classified as 'low-usability', meaning they experienced either knowledge barriers, poor installation quality, or both—preventing them from fully benefiting from the upgraded systems (Table11).

TABLE 11: TOTAL NUMBER OF RESPONDENTS BY CONSTRUCTED VARIABLES

Variable	Value	Number of Respondents n=37 (%)
Knowledge	High (Value=1)	21 (57%)
Knowledge	Low (Value=0)	16 (43%)
Satisfaction with Installation Quality	High (Value=1)	25 (68%)
Satisfaction with Installation Quality	Low (Value=0)	12 (32%)
Usability (composite score)	High (Value=2, High Knowledge AND High Satisfaction)	16 (43%)
Usability (composite score)	Low (Value<=1, Low Knowledge OR Low Satisfaction)	21 (57%)

Energy Insecurity Outcomes by Usability Groups

Our findings indicate that improvements in energy security are strongly mediated by system usability (Figure 3 and Table 12). At baseline, both groups had low energy security scores: the low usability group had an average score of 50.5, and the high usability group had an average score of 61.9. The differences between the two groups at baseline are attributable to greater economic stress in the low usability group, who reported a higher frequency of being late in paying energy bills and receiving disconnection notices. Other indicators of energy security in the physical and coping domains were similar across both groups at the baseline.

FIGURE 3: BOX PLOTS OF ENERGY SECURITY SCORE PRE/POST RETROFIT BY USABILITY GROUP

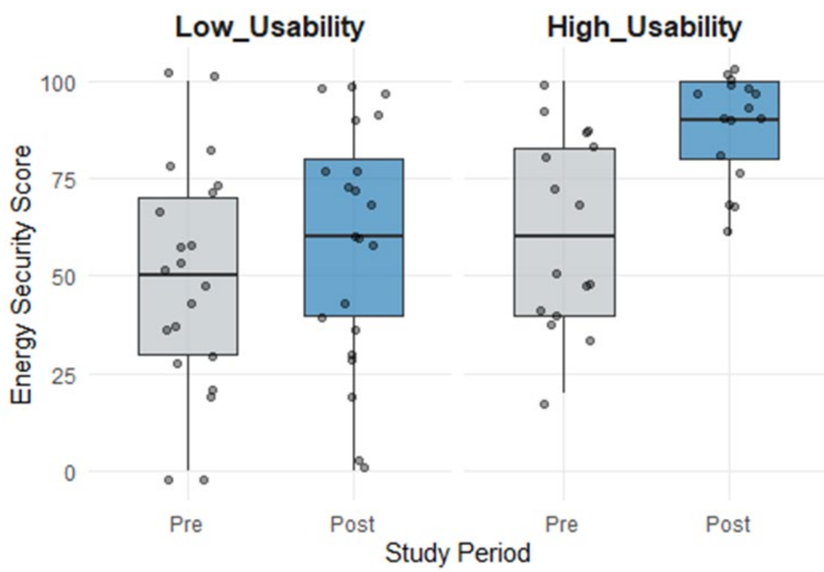


TABLE 12: MEAN ENERGY SECURITY SCORE PRE/POST RETROFIT BY USABILITY GROUP

Usability Group	Pre-Retrofit Mean	Post-Retrofit Mean	Mean Improvement	95% CI
High Usability (n=16)	61.9	88.8	26.9***	[12.35, 41.40]
Low Usability (n=21)	50.5	58.6	8.1	[-10.50, 26.70]

Following the intervention, only households that reported high usability of their new systems experienced a significant improvement in their Energy Security Score, an increase of 26.9 points (95% CI [12.35, 41.40], $p<0.001$). Conversely, in low usability households that struggled to operate the new equipment, there was only a small increase in the mean Energy Security Score (8.1 points, 95% CI [-10.50, 26.70], p=0.384).[18] Ultimately, this resulted in a large post-retrofit disparity between the two groups ($p<0.001$).

To isolate the effect of system usability on post-retrofit energy security, we estimated a difference-in-differences (DiD) regression model controlling for household and regional covariates (Table 13). The primary coefficient of interest, the DiD estimator (High Usability * Post-Retrofit), indicates that the decarbonization intervention improved energy security scores by an additional 19.97 points for the High Usability group compared to the Low Usability group (19.97, 95% CI [-1.036, 40.975], p = 0.062).

TABLE 13: DIFFERENCE IN DIFFERENCES ANALYSIS

Variable	Estimate [95% CI]	p-Value
DiD Estimator (High Usability * Post-Retrofit)	19.97 [-1.036, 40.975]	0.062

The results of the differences in means and difference-in-differences analyses suggest that while housing decarbonization holds significant promise for alleviating energy insecurity, its success is fundamentally contingent on ensuring high system usability. Upgrading physical infrastructure without parallel investments in resident education and quality assurance of installation risks leaving the most vulnerable households behind.

Conclusion

This chapter provides new evidence on both the barriers to participation in housing decarbonization programs and their impacts on household energy security. Taken together, the findings highlight that decarbonization is not a single intervention, but a complex, multi-dimensional process that requires sustained engagement, resources, and institutional support.

First, the analysis of participant experiences demonstrates that engagement is shaped by a cumulative "participation burden" spanning five dimensions: awareness, motivation, capacity, ability to cover costs, and implementation. Barriers at each dimension are distinct but interrelated, and even small frictions can compound over time to prevent project completion. While higher-income households often exit the process based on cost-benefit considerations, low- and moderate-income (LMI) households are more likely to be constrained by structural barriers—including limited access to information, administrative burden, workforce gaps, and insufficient financial resources. These findings underscore that financial incentives alone are insufficient; successful program participation depends on addressing barriers across the full engagement pathway.

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[18] Figure 3 shows a box plot comparing energy security scores before and after retrofit for low and high usability groups. Post-retrofit scores show increased median and reduced variability, with high usability group achieving higher overall scores and tighter distribution than low usability group.

Second, the chapter advances a multidimensional framework for measuring energy security, moving beyond traditional affordability metrics to capture physical conditions, economic strain, and coping behaviors. This approach provides a more comprehensive understanding of how households experience energy insecurity and offers a practical tool for evaluating program outcomes. By shifting from prevalence to severity and applying the metric longitudinally, the Energy Security Score allows for a more nuanced assessment of whether decarbonization interventions meaningfully improve household well-being.

Third, the impact analysis reveals that decarbonization can significantly improve energy security—but only under certain conditions. The results show that improvements are strongly mediated by system usability: households that understood how to operate new technologies and were satisfied with installation quality experienced large and statistically significant gains in energy security, while those facing usability challenges saw limited or no improvement. This finding highlights a critical gap in current program design: physical upgrades alone are not sufficient to deliver benefits if households lack the knowledge, support, or system performance needed to realize those benefits.

These findings have several key policy implications. First, program design should shift from a narrow focus on incentives to a more holistic, dimension-based approach that addresses barriers across awareness, enrollment, financing, and implementation. Second, investments in workforce development and contractor quality are essential—not only to expand capacity, but to ensure accurate system design, reliable installation, and effective communication with participants. Third, programs should prioritize trusted, community-based intermediaries to bridge information and capacity gaps, particularly in LMI communities where access to technical knowledge and networks is more limited. Fourth, usability must be treated as a core program outcome, requiring investments in resident education, language-accessible materials, and post-installation support. Finally, evaluation frameworks should incorporate multidimensional measures of energy security to ensure that programs are delivering tangible benefits and not unintentionally exacerbating inequities.

This study has several limitations that point to important areas for future research. The sample size is modest and geographically concentrated in the San Francisco Bay Area and Los Angeles, which may limit the generalizability of results to other regions with different housing markets, energy prices, and program structures. In addition, while the longitudinal design strengthens our ability to assess changes over time, the follow-up period is relatively short and may not capture longer-term impacts on energy costs, equipment performance, or household behavior. The analysis of usability also points to important heterogeneity in outcomes, but further research is needed to better isolate the relative contributions of system design, installation quality, and resident education. Future work should expand to larger and more diverse samples, incorporate longer-term follow-up, and examine how program design features shape both participation and outcomes. There is also a need for more rigorous evaluation of how decarbonization interacts with broader structural factors, including utility rate design, housing quality, and landlord-tenant dynamics, to ensure that interventions are both effective and equitable at scale.

Ultimately, this chapter shows that equitable decarbonization requires aligning technological change with the lived realities of households. Without addressing the full set of barriers that shape participation and outcomes, even well-funded programs risk falling short of their equity and public health goals.

5. Approaches to Policy Cost Analysis

Introduction

Equitable housing decarbonization is central to achieving California's climate and environmental justice goals. Over the past two decades, state legislators have tasked agencies such as the California Air Resources Board (CARB), the California Energy Commission (CEC), and the California Public Utilities Commission (CPUC) with implementing complementary building decarbonization and equity objectives (CARB, 2022a, 2022b.; CEC, 2024). The state's greenhouse gas (GHG) reduction trajectory—first established under the Global Warming Solutions Act (AB 32) and expanded through SB 32 and AB 1279—requires California to achieve an 85% reduction in GHG emissions below 1990 levels by 2045. Although California has made aggressive climate investments, these have often taken the form of consumer incentives targeted to early adopters who are typically higher income, in a state with substantial income inequality (California Climate Investments, 2024; LAANE, 2016; "Advancing Equity in California Climate Policy," 2020). As a result, the pursuit of ambitious emissions reductions has produced state-funded distributional inequities, leaving many lower-income households behind (LAANE, 2016; Maglicic & Vasconcelos, 2025; "Advancing Equity in California Climate Policy," 2020).This challenge is compounded by California's diverse climate zones, where a disproportionate share of low-income residents experience temperature extremes – such as intense inland heat or mountain cold – that many wealthier coastal residents do not face (California Department of Justice, 2017; Legislative Analyst's Office, 2022a, 2022b).

To meet these targets, CARB's *2022 Scoping Plan* outlines sector-specific goals, including the installation of six million heat pumps by 2030 and the creation of seven million climate-friendly homes by 2035 (CARB Scoping Plan, 2022). The plan also embeds equity considerations through strategies that prioritize residents in low-income, rural, disadvantaged, and tribal communities, ensuring that incentive programs address affordability, tenant protections, and small-landlord support while improving habitability, indoor air quality, and resilience to extreme weather events (CARB Scoping Plan, 2022). Indeed, California building decarbonization incentive programs are beginning to ground equity in their design as highlighted by the Equitable Building Decarbonization, which provides and installs energy-efficient electric appliances, energy efficiency measures, and related upgrades at no cost to low-income households in under-resourced communities.

This chapter focuses on recommendations for how to measure the distributional equity of the state's decarbonization programs. It begins by introducing frameworks for the evaluation of building decarbonization programs, including a brief review of Benefit-Cost Analysis (BCA), which has long been the foundation for regulatory and investment decisions by agencies such as the CPUC and CEC. The chapter then explores the suite of cost-effectiveness tests used in regulatory planning and program approval—including the Total Resource Cost (TRC), Societal Cost Test (SCT), Participant Cost Test (PCT), Program Administrator Cost (PAC), and Ratepayer Impact Measure (RIM). It highlights both the strengths of these measures and their limitations for measuring distributional equity. In the final section, we introduce a Distributional Equity Framework for

Building Decarbonization Programs. We present examples of how other states are analyzing distributional equity and offer recommendations for ensuring that California's decarbonization efforts deliver fair and tangible outcomes for priority populations and support the state's broader commitment to climate justice and equity.

Defining Distributional Equity in Housing Decarbonization

Equitable decarbonization is essential to California's climate goals because the state's housing and climate crises are intertwined: those most vulnerable to housing insecurity are often those most exposed to environmental hazards and least able to access clean-energy upgrades (CARB 2022, n.d.; SGC, 2024). Embedding equity within decarbonization policy ensures that climate investments do not deepen existing inequalities but instead close gaps in energy burden, health, and housing stability.

Historical housing and energy disparities underscore this imperative. Redlining, disinvestment, exclusionary lending, and environmental racism have concentrated low-income and racially marginalized populations in older, inefficient housing near pollution sources and heat islands (Frosch et al., 2018; González et al., 2023; Hernández et al., 2016; Jesdale et al., 2013). These households face higher energy costs, health risks, and climate vulnerabilities. As a result, achieving California's climate neutrality targets depends on making clean energy and housing upgrades accessible to those who have historically borne disproportionate burdens.

Within this context, distributional equity refers to the fair allocation of benefits, costs, and risks across populations, with explicit attention to those historically marginalized or burdened by environmental and housing inequities (Bednar & Reames, 2020; Hernández & Bird, 2010). For housing decarbonization, a focus on distributional equity ensures that public resources and program benefits—such as lower utility bills, healthier homes, and greater resilience—flow proportionately to households with the highest energy burdens and least access to capital. In California's diverse housing landscape—ranging from multifamily rental units to aging manufactured homes—distributional equity is particularly relevant. Renters, low- and moderate-income households, residents of disadvantaged communities, and tribes often live in housing stock most in need of retrofits yet face the greatest barriers to participation (Pigman et al., 2021; Sunter & Kammen, 2019). Addressing these inequities requires alleviating the participation burden, through strategies such as targeted funding, accessible financing mechanisms, multilingual outreach, and data-driven monitoring of program reach and outcomes (Al-Radaideh et al., 2025; Bednar & Reames, 2020).

Distributional equity is distinct from, but complementary to, *procedural equity*, which concerns fairness and inclusion in decision-making processes and *structural equity*, which involves addressing long-term systemic barriers (Morello-Frosch et al., 2025). Together, these three dimensions create a comprehensive framework for equitable decarbonization policy: structural reforms that correct historic injustices, procedural mechanisms ensure inclusive participation, and distributional design determines who takes on the costs, risks and benefits of decarbonization programs.

Overview of Benefit- Cost Analysis (BCA) and Cost-Effectiveness Frameworks

California's evaluations of building decarbonization programs focus on whether such investments deliver net long-term benefits, in addition to achieving emissions reductions. To do so, the CPUC relies on cost-effectiveness tests, most commonly the Total Resource Cost (TRC) test. Cost-effectiveness tests are best understood not as a single calculation, but as a framework for organizing and weighing the set of impacts a program is expected to have over time. It establishes what kinds of costs and benefits should be counted and prioritized as well as whose perspectives matter—not just those of utilities or program participants, but of society overall.

Within this framework, cost-benefit analysis tools such as net present value or benefit-cost ratios are used to compare costs and benefits that occur at different points in time (Table 14). Building decarbonization programs often involve substantial upfront costs, while many of the benefits, such as lower energy bills, avoided pollution, reduced strain on energy infrastructure, and public health improvements accrue gradually over years or decades. Cost-benefit analysis provides a way to translate these future impacts into comparable terms, allowing them to be evaluated alongside near-term expenditures. To assess whether a policy is economically justified, two metric benchmarks are commonly used: the benefit cost ratio (BCR) must exceed 1 or the net present value (NPV) must be greater than 0, indicating that the expected benefits outweigh the costs.

TABLE 14: BENEFIT-COST ANALYSIS METRICS

Metric	Definition	Decarbonization Context
Net Present Value (NPV)	The difference between the present value of all benefits and the present value of all costs.	The goal is to achieve an NPV > 0 for a project. This means the discounted value of future benefits (e.g., avoided climate damage, public health improvements) is greater than the discounted value of all costs (e.g., equipment, administration).
Benefit-Cost Ratio (BCR)	The ratio of the present value of total benefits to the present value of total costs.	A BCR > 1.0 indicates that every dollar spent yields more than a dollar in benefit to society, making the regulation or investment economically sound.

Direct costs generally include both the program and regulatory costs (e.g. administrative, implementation and evaluation expenses, as well as costs to participants (e.g. the cost of installing a heat pump). Benefits can include both direct and indirect benefits. Direct benefits--also sometimes referred to as avoided costs--include things like a reduction in the need for the utility to generate power, or build new transmission, distribution, or generation infrastructure, and/or direct savings on electricity or natural gas bills. Indirect benefits, also referred to as “co-benefits” or “externalities” include things like the long-term environmental benefits of decarbonization (e.g. avoided CO2 emissions or other air pollutants), public health benefits (e.g. the value of avoided morbidity and mortality costs due to reduced indoor and outdoor air pollution), and non-energy benefits (NEB), such as improved thermal comfort or increased productivity.

Benefit-cost analysis thus functions as a decision-support tool within different cost-effectiveness tests, by which policymakers judge whether decarbonization investments represent a sound use of public and ratepayer resources.

Cost-Effectiveness Tests

The CPUC applies cost-effectiveness evaluation to housing-sector and distributed-energy programs, principally under the California Public Utilities Commission’s Standard Practice Manual (SPM) and through analytic tools maintained for CPUC proceedings (e.g., the Avoided Cost Calculator). These frameworks (together with national guidance such as the National Standard Practice Manual) set out multiple tests that measure program value from different perspectives (CPUC, 2010; NSPM, 2017). Table 15 provides an overview of the primary cost effectiveness tests.

TABLE 15: OVERVIEW OF COST EFFECTIVENESS TESTS

Test Name	Primary Perspective	What it Measures
Participant Cost Test (PCT)	Program Participant	Does the customer who participates in the program save money (i.e., energy bill savings are greater than out-of-pocket costs)?
Ratepayer Impact Measure (RIM)	Ratepayers	How does the program affect utility rates? (Will utility rates go up for those who *don't* participate due to the need to recover lost revenue related to reduced energy demand?)
Program Administrator Cost (PAC); Also known as Utility Cost Test (UCT)	Utility/Program Administrator	Are the avoided supply costs greater than the costs incurred in running the program?
Total Resource Cost (TRC)	Service territory (Utility + Participants)	Does the program reduce the overall cost of providing energy services to the service territory? (Most common test for energy policy decision-making by CPUC.)

Test Name	Primary Perspective	What it Measures
Societal Cost Test (SCT)	Society at Large	Is the program beneficial to society as a whole? (Includes all benefits and costs, including externalities like the Social Cost of Carbon and valuing other non-energy benefits.)

The Total Resource Cost (TRC) test remains the primary benchmark in most CPUC and utility energy-efficiency proceedings. However, in Decision (D.) 24-07-015, the CPUC formally recognized the Societal Cost Test (SCT) as an "information-only" framework—a complementary tool that incorporates societal and environmental externalities into cost-effectiveness analyses (CPUC SCT, 2024) The Commission directed utilities and program administrators to report SCT results alongside the Total Resource Cost (TRC) and Program Administrator Cost (PAC) tests but clarified that the SCT will not yet be used to determine program approval or funding levels. The SCT inputs (e.g., use of Social Cost of Carbon values, air-quality impacts) were incorporated into the 2024 Avoided Cost Calculator (ACC)[19] update and are effective for SCT analyses beginning in 2025; nevertheless, the TRC remains the primary statutory benchmark for many Commission actions.

Although the Social Cost Test (SCT) comes closest to incorporating equity-relevant criteria, these factors are not evaluated in a distributional way, as the test was never intended to do so on its own and must therefore be complemented with explicit distributional approaches.

In the following section, we provide a brief overview of each of the tests outlined in Table 15, discussing their strengths and limitations for measuring the distributional equity of building decarbonization programs.

Total Resource Cost (TRC) Test

The TRC is a resource-efficiency test used in benefit–cost analyses of demand-side programs. It compares the monetized value of *total program benefits* (avoided generation, capacity, transmission and distribution costs, and other quantifiable benefits), to the *total costs* (program-administrator costs *plus* participant incremental costs). The TRC captures utility-side and participant-side costs, but the benefits are valued from the system/resource perspective (avoided utility costs), not as a full set of participant-side benefits (comfort, health, bill risk reduction, etc.),

[19] The CPUC's Avoided Cost Calculator (ACC) provides the marginal, hourly estimates of avoided electric and gas system costs (in $/kWh and $/therm) used to monetize benefits in the TRC, PAC, and SCT. The ACC methodology (developed by E3 under CPUC direction) models avoided generation, capacity, transmission and distribution, GHG impacts, and other values, and it has been updated on a roughly biennial cadence (2022, 2024) to reflect changing market conditions, IRP/decarbonization targets, and newly adopted SCT inputs (CPUC ACC 2024 documentation). The ACC translates program-level savings (hourly kWh or therm reductions) into monetized benefits for cost-effectiveness tests. (CPUC ACC 2024; E3 documentation).

except where specific non-energy benefit adders are separately adopted.[20] The TRC is used to assess whether a resource (e.g., energy efficiency, demand response) is a net benefit to the service territory (CPUC, 2010; NSPM, 2017).

- Typical measured benefits are drawn from CPUC's ACC and include:
  - Avoided electricity and gas costs (energy)
  - Avoided generation, transmission and distribution capacity costs,
  - Avoided ancillary services costs, where applicable.
  - Avoided greenhouse gas (GHG) compliance costs associated with meeting decarbonization policies.
- Typical measured costs[21] include:
  - Program administration costs (administration, implementation, Evaluation, Measurement, and Verification (EM&V), marketing, and incentive/rebate payments, plus any other utility costs that flow into revenue requirements)
  - Total Measure Cost (Equipment, labor and materials)

TRC tests have several strengths. First, TRC is a common metric across many jurisdictions, which facilitates cross-program and cross-state comparative analyses (EPRI, 2019; NSPM, 2017). This standardization also means that the TRC test is helpful for comparing programs and measures on an apples-to-apples basis when assessing system resource needs and overall efficiency (CPUC, 2010; E3, 2024).

However, the TRC test also has significant limitations. The TRC test often omits externalities (e.g. local air pollution health impacts, environmental justice concerns, and social cost of carbon) unless these are explicitly monetized and added (i.e., through a Societal Cost Test or modified TRC). This limitation can lead to significant underestimation of program benefits. Indeed, studies show that including health and environmental externalities materially changes benefit–cost outcomes for decarbonization measures (Buonocore et al., 2016; Maglicic & Vasconcelos, 2025; Tonn et al., 2018; Zhao et al., 2019).

TRC can also disadvantage programs targeted at low-income households. Because TRC includes participant costs, programs that require even modest participant contributions can appear less cost-effective—even when societal benefits or equity gains would argue for public support. In low-income housing, retrofit needs (e.g., fixing knob-and-tube wiring, mold, or roof leaks) are often a prerequisite for decarbonization. Because these costs are high and may not produce direct energy savings, they make programs appear to be cost ineffective under a strict TRC, even though these

[20] In a March 2025 audit of the CPUC, the California State Auditor critiqued the CPUC for not including participant benefits in the TRC: https://www.auditor.ca.gov/reports/2023-127/

[21] In practice, many TRC applications do not fully include major remediation costs (often ranging from $2,000 - $10,000 per installation), so the calculated TRC rations may not reflect the true costs faced by participants.

retrofits are critical to address safety issues in the home. Thus, unless the TRC evaluation framework is adjusted, it can systematically bias decision-making against decarbonization programs that are targeted to low-income households (ACEEE, 2024; Kushler et al., 2005).

Further, in a recent audit of the CPUC's oversight of energy efficiency programs, the California State Auditor found that while the TRC test includes costs that accrue to the utility and program participant, and benefits that accrue to the utility, the TRC does not consider non-energy-related benefits realized by program participants, such as cleaner air and/or improved health for occupants, nor their spillover benefits (CA State Auditor, 2025). For example, installing high-efficiency electric heat pumps and improving building envelopes can reduce indoor air pollution and dampness, which in turn can lower respiratory illness and reduce missed days of work or school, supporting healthier and more productive households and communities (Wyon, 2004). This omission leads to an undervaluation of direct install programs, may discourage utilities from pursuing deep retrofit projects, and contributes to utilities routinely falling short of assembling cost-effective program portfolios. In response, the State Auditor recommended that the CPUC embed non-energy benefits to the participant into the TRC (CA State Auditor, 2025).

In addition, TRC aggregates benefits and costs across populations and does not reveal who receives benefits; using TRC alone can mask inequitable distributional outcomes (Bednar & Reames, 2020). Finally, TRC outcomes are sensitive to assumptions (discount rate, avoided-cost forecasts, measure life, participant cost estimates). For example, low-income households with limited access to credit may face higher interest rates, which is not reflected in the established discount rate. Studies caution that lack of transparency about these inputs undermines comparability and can bias outcomes (ACEEE, EPRI, NSPM critiques).

Program Administrator Cost (PAC) Test

The Program Administrator Cost (PAC) test, sometimes referred to as the Utility Cost Test (UCT), assesses the cost-effectiveness of energy efficiency or demand-side management programs from the perspective of the program administrator, typically a utility or public agency. The PAC test evaluates whether a program is a least-cost resource compared to alternative supply-side investments, such as building new generation or procuring additional capacity.

The test focuses on the net costs and benefits experienced by the program administrator or utility (i.e., excluding participant costs). It is commonly used for budgeting and the utility's revenue requirement decisions because it shows the program effects on utility spending (CPUC, 2010; NSPM, 2017). Unlike the Total Resource Cost (TRC) Test, the PAC Test does *not* include costs borne by program participants (e.g., homeowners or renters).

- Typical measured benefits to the utility/program administrator include:
    - Avoided energy procurement costs (electricity and gas)
    - Avoided generation capacity costs
    - Avoided transmission and distribution infrastructure costs

  - Avoided greenhouse gas compliance costs associated with meeting decarbonization policies
  - Grid reliability and peak load reduction benefits
- Typical measured costs to the utility/program administrator include:
  - Program administration and implementation costs
  - Incentives paid to participants
  - Marketing, outreach, and evaluation costs

The PAC test is generally used during portfolio planning and program approval processes. Utilities must demonstrate that their proposed programs meet or exceed PAC thresholds unless they are exempt because the evaluated program is designed to serve equity goals or hard-to-reach populations. Because the PAC ignores the revenue the utility "loses" when a program participant reduces energy demand, it is a much "friendlier" test for energy efficiency than the Ratepayer Impact Measure (RIM) test (discussed below).

While the PAC test is valuable for regulatory budgeting and ensuring fiscal prudence, it does not account for participant-level out-of-pocket costs or non-energy benefits experienced by participants, such as improved air quality or health outcomes. Because the PAC test ignores the participant's financial burden, a program could appear highly 'cost-effective' to the utility while remaining financially inaccessible to a low-income resident who cannot cover a significant portion of the cost for an energy-efficient appliance. In addition, programs serving low-income renters or multifamily buildings may appear less cost-effective under PAC because the test counts their higher administrative and delivery costs but does not credit additional participant-side benefits, and these programs often yield lower measured energy savings per unit. Together, these factors make their utility-facing benefit-cost ratios look weaker even when they advance important equity and public-health goals. This can bias program selection toward short-term utility savings rather than long-term societal or equity-oriented outcomes. Finally, the PAC Test focuses on utility economics and may undervalue broader societal benefits of decarbonization. For example, it does not capture co-benefits such as improved indoor air quality, comfort, or emissions reduction beyond the utility boundary (Gillingham et al., 2015; Tonn et al., 2018).

Ratepayer Impact Measure (RIM) Test

The Ratepayer Impact Measure (RIM) test evaluates how an energy efficiency or decarbonization program affects utility revenues and, consequently, average electricity rates for all ratepayers, with particular attention to how costs and savings are shifted between participating and non-participating customers (National Standard Practice Manual [NSPM], 2017; CPUC, 2009). Unlike the TRC or PAC tests, which assess total system costs and benefits, the RIM test is explicitly concerned with whether cost recovery for programs will put upward or downward pressure on rates across the utility’s customer base, and how these changes affect customers who do not participate in programs.

The RIM test compares the utility's lost revenues from reduced energy sales to the avoided supply costs and program expenses. A RIM ratio below 1.0 indicates that average energy rates may increase, even if total system costs decline. This distinction is crucial in understanding the distributional impacts of decarbonization and electrification measures, especially in California's equity-focused policy landscape (Carley & Konisky, 2020).

In California, decoupling ensures utilities recover fixed costs regardless of energy sales, meaning any program that successfully reduces consumption triggers a mandatory rate increase to maintain authorized revenue levels. Because the RIM test treats these "lost revenues" as a primary cost to ratepayers, it often assigns a failing score to decarbonization programs even when they are socially or environmentally beneficial. This creates a technical paradox where successful energy reduction is viewed as a financial "cost" to the non-participating customers who must absorb the shifted revenue burden.

The CPUC historically requires utilities to report RIM test results alongside TRC and PAC results in annual portfolio filings (CPUC, 2023). For example, in an *Energy Efficiency Business Plan* filing, an IOU analyzed an HVAC upgrade program with the following outcomes:

- TRC ratio: 1.25 (cost-effective overall)
- PAC ratio: 1.10 (beneficial to the utility)
- RIM ratio: 0.75 (indicating a potential rate increase for non-participants)

This example illustrates that while a program may produce net societal or system-wide benefits, it can still result in higher rates for non-participating customers due to reduced utility sales and revenue recovery requirements (CPUC, 2010; NSPM, 2017). In California, RIM results are typically not used to reject programs outright, but to inform rate design discussions and cost recovery mechanisms (e.g., decoupling policies). For instance, under CPUC Decision D.22-09-026, the Commission reaffirmed the importance of mitigating adverse bill impacts while advancing equitable decarbonization.

Despite its focus on customer costs, the RIM test nevertheless also has limitations in capturing distributional equity. Importantly, it can misrepresent equity outcomes, as rate impacts may not align with total cost burdens across income groups (Carley & Konisky, 2020). A critical limitation is that the RIM test uses an 'average customer' model, which fails to account for the disproportionate impact on priority populations. Because low-income households often reside in inefficient housing with high energy loads and have energy costs that represent a higher proportion of their household income than wealthier households, even a marginal increase in energy rates can lead to a significant increase in their total energy burden. The RIM test masks these distributional realities by aggregating impacts into a single territory-wide average. In addition, RIM tests tend to penalize programs that reduce energy consumption, since lower sales decrease utility revenues (Carley & Konisky, 2020). And, as with many of the other benefit cost tests, RIM tests do not capture long-term or non-monetary societal benefits (e.g., GHG reductions, health gains).

Participant Cost Test (PCT)

The Participant Cost Test (PCT) evaluates the economic attractiveness of a program from the participant's perspective, comparing participant costs (e.g., net upfront investment, operations, and maintenance) with participant benefits (e.g., bill savings, rebates, or incentives) (NSPM, 2017). The PCT essentially answers: "Is this program financially worthwhile for customers who take part?" Unlike other cost tests that focus on system-wide efficiency or utility finances, the PCT provides direct insight into consumer adoption behavior and market uptake potential. It is therefore crucial for understanding the distributional equity and behavioral feasibility of electrification and energy efficiency initiatives (Carley & Konisky, 2020; Tonn et al., 2018).

California utilities routinely include PCT outcomes in program design and evaluation filings to assess the participant payback period and return on investment. For instance, in PG&E's *Residential Heat Pump Water Heater Program*, the utility found:

- Average participant investment: $3,500
- Average lifetime bill savings: $5,000
- Average incentive: $1,000
- PCT ratio: 1.7 (indicating participants gain $1.70 for every $1 invested)

The PCT test can therefore justify higher incentive levels in programs targeted toward low-income households, where upfront costs may otherwise deter participation despite favorable lifetime economics (Carley & Konisky, 2020). PCT tests can also support market transformation goals by quantifying at least a portion of the user-level value of participation.

However, in practice, the PCT often underestimates the true cost of program participation for priority populations. Traditional models rarely account for the costs of addressing remediation and deferred maintenance—such as electrical panel upgrades or mold removal—or the monetary value of the administrative burden and time off work required to oversee installations. Omitting these 'soft costs' leads to a PCT ratio that may not fully reflect the costs faced by low-income households.

Furthermore, the PCT typically relies on an 'average customer' model, which fails to represent the financial constraints faced by priority communities. First, retrofit costs may be higher in priority communities due to poor housing conditions and energy infrastructure, leading to higher remediation costs. Second, even when a program may show a positive return on investment, the PCT does not account for the lack of liquidity or credit access that makes even an apparently cost-effective upfront investment impossible for many low-income households.

Therefore, the PCT test on its own misses many important equity challenges related to the true costs of program participation. It includes a limited scope of participant financial costs and benefits, and it omits system-wide or societal impacts. It also fails to capture informational and other participation barriers that may result in disparate uptake of financially beneficial programs. It can also overstate benefits when bill savings depend on variable energy prices or use (Tonn et al., 2018).

Societal Cost Test (SCT)

The Societal Cost Test (SCT) expands traditional cost-effectiveness analyses by incorporating the broader social, environmental, and health impacts of energy and housing decarbonization programs—such as reductions in GHG emissions, improvements in air quality, public health co-benefits, and long-term social welfare gains (Carley & Konisky, 2020; Tonn et al., 2018).

These benefits are justified based on a growing literature that demonstrates that decarbonization investments yield substantial air-quality and public-health co-benefits—especially locally and for disadvantaged communities—which can materially alter benefit–cost outcomes when internalized (Gatto, 2022; Mailloux et al., 2022; Zhao et al., 2019). Programs that appear marginal or non-viable under traditional tests can deliver substantial net benefits when societal and environmental impacts are included. For example, studies that quantify avoided particulate and NOx exposures find large health benefit streams from displacing fossil generation and reducing in-building combustion (Buonocore et al., 2016; Zhao et al., 2019). Because many of these externalities disproportionately affect economically marginalized groups, incorporating them into cost effectiveness analyses (as the SCT does) can align program decisions with broader state objectives on health, environmental justice, and climate. (Buonocore et al., 2016; Mailloux et al., 2022; Zhao et al., 2019).

In California, the SCT is being integrated gradually into regulatory filings and planning tools. The CPUC's 2024 Avoided Cost Calculator includes SCT input values that monetize the social cost of carbon, account for methane leakage, and include a particulate-matter pollution adder and a lower social discount rate, reflecting long-term societal valuation of benefits (CPUC ACC, 2024). In addition, the 2025 Energy Savings Assistance (ESA) Non-Energy Impacts Study, commissioned by state IOUs and CPUC, provides an updated monetized estimate of societal co-benefits—including air quality, health, and climate impacts—for California's low-income energy efficiency programs, supporting integration into cost-effectiveness tests like the SCT.

Although SCT allows for stronger integration of societal co-benefits into cost-effectiveness tests, estimating health and environmental benefits involves methodological uncertainty and data gaps, which can affect comparability and reliability across programs (Carley & Konisky, 2020). Without standardization, SCT results may be applied inconsistently across utilities and program types.

In addition, while the SCT brings vital societal and environmental perspectives (non-energy benefits) into the evaluation, a focus on distributional equity is not clearly emphasized**.** The SCT quantifies how much benefit is created for society, but not where or to whom that benefit flows. For example, a program could pass the SCT based on global GHG reductions while failing to address improvements in local air quality in a specific frontline community. To truly serve equity goals, the SCT must be paired with geographic or demographic assessments to prioritize benefits that accrue directly to communities most impacted by energy pollution and energy burden.

Despite the growing sophistication of benefit–cost analysis (BCA) and cost-effectiveness frameworks such as the Total Resource Cost, Participant Cost Test, and Societal Cost Test, these methodologies often fall short in capturing how program benefits and burdens are distributed across different population groups. Traditional cost-effectiveness tests are primarily designed to assess aggregate efficiency and total system benefits, rather than to evaluate who gains and who bears the costs (Carley & Konisky, 2020). Because many programs remain designed around cost-optimal interventions and high-energy-use households, they often prioritize affluent homeowners and owner-occupied single-family units. Meanwhile, households with the highest health, housing and energy burden are underserved unless the program explicitly prioritizes equity in evaluation design and metrics, as well as outreach, and eligibility thresholds (Gatto, 2022; Tarekegne et al., 2021). These dynamics risk amplifying existing inequalities by failing to align investments with those who face the greatest burden.

Integrating Equity into Cost-Effectiveness Frameworks

Traditional cost-effectiveness tests are useful for judging whether building decarbonization programs deliver net benefits, but they say little about who benefits. In response, states and national initiatives are experimenting with practical ways to better reflect equity within or alongside BCA and cost-effectiveness tests. These strategies fall into two broad categories: adjustments to the BCA calculations themselves, and changes to how programs are screened, segmented, and governed.

Adjusting Benefit-Cost Calculations

- **Use of Equity Adders**: Several states, including Massachusetts and New York, are piloting "equity adders" in BCA—a dollar value or multiplier assigned to benefits delivered in identified priority communities or to historically underserved groups. This adjustment recognizes that the value of a unit of benefit (e.g., energy savings, improved thermal comfort, or avoided health costs) is greater for populations that have faced greater historic disadvantage, and incentivizes program implementers to prioritize those groups.
  For example, the Mass Save program applies an equity adder to cost-effectiveness screening to counteract the challenge of low energy savings among low-income households. Because low-income customers in Massachusetts often receive subsidized energy rates (similar to California's California Alternate Rates for Energy (CARE) and Family Electric Rate Assistance (FERA) programs), the monetary value of their avoided energy use is lower than that of standard-rate customers. Without an equity adder, this lower avoided cost can make efficiency investments in low-income homes appear less cost-effective. By applying a multiplier—for instance, valuing $1.00 of energy savings in a disadvantaged community as $1.20 in the benefit-cost analysis—equity adders ensure that programs serving low-income renters or multifamily buildings can pass cost-effectiveness screens despite lower per-unit monetary savings or higher delivery costs.
- **Assigning Value to Non-Energy Benefits**: Some states are expanding the monetization of non-energy benefits by categorizing impacts into distinct categories, such as improved indoor air quality, reduced asthma attacks, thermal comfort, fewer arrearages (which decrease administrative collection costs for utilities and financial stress for participants), and resilience

(the ability of a building to maintain habitable indoor temperatures and basic functionality during extreme weather events or grid outages), and adding these values to SCT or modified TRC calculations. California's ESA Non-Energy Impacts Study and the social cost of carbon and air-quality adders in the ACC provide a foundation for this approach.

- **Multi-Criteria Decision Analysis (MCDA) and Equity Weighting**: MCDA frameworks, increasingly used in regulatory and planning contexts, allow decision-makers to score and weight multiple criteria—such as TRC or PAC results, health and climate benefits, participation by priority populations, and qualitative feasibility—within a transparent decision matrix. Instead of relying on a single test to determine "go/no-go," MCDA explicitly elevates equity, health and resilience alongside economic efficiency, and can incorporate both quantitative outputs from BCA and qualitative community-informed evidence. States like California (in pilots[22]), Massachusetts, and Washington have begun using MCDA and participatory scoring to ensure funding and regulatory approval are linked not only to energy and cost efficiency but to measurable equity outcomes.
- **Changing How Programs are Screened and Governed.** Some jurisdictions exempt low-income or barrier-removal programs from strict TRC/PAC thresholds or place them in separate "equity" sub-portfolios with tailored expectations and dedicated budgets. Many states also layer equity metrics and processes on top of BCA requiring reporting by income, race/ethnicity, renter/owner status, and disadvantaged community status, and using equity advisory bodies or impact assessments when approving portfolios.

Taken together, these approaches show that equity can be integrated more directly into benefit-cost analysis and program governance alongside traditional cost-effectiveness tests. Equity adders and monetized non-energy benefits primarily modify benefit-cost analysis by changing what is counted and how it is valued. While carve-outs and sub-portfolios, and equity metrics change how benefit-cost analysis results are used. Multi-criteria decision analysis provides a structured way to weigh these elements when making decisions.

The next section turns to Distributional Equity Analysis, which focuses not on total net benefits but on how the benefits and burdens of building decarbonization are shared across households and communities, and how it can complement these cost-effectiveness tools to guide more equitable investments and outcomes.

[22] The CPUC's Microgrid Incentive Program (MIP) uses a multi-criteria scoring matrix to prioritize projects in Disadvantaged Vulnerable Communities (DVCs) based on historical reliability, socio-economic vulnerability, and community facility support. Similarly, the California Energy Commission (CEC) has introduced explicit equity scoring in its Gas R&D and Equitable Building Decarbonization (EBD**)** programs, where project approval is contingent on a weighted evaluation of community-based partnerships and localized health outcomes alongside technical performance.

Distributional Equity Analysis (DEA) Framework

Distributional Equity Analysis (DEA) frameworks provide a complementary way to evaluate equity within decarbonization programs. DEA asks explicitly how the benefits and burdens of clean energy and building decarbonization are distributed across demographic, geographic, and socio-economic groups, with particular attention to priority populations. By tracking outcomes such as energy-burden reduction, improvements in indoor air quality, and housing stability for specific groups, DEA makes equity outcomes visible and policy-relevant, rather than treating them as incidental.

Approaches to Distributional Equity Analysis

Lawrence Berkeley National Laboratory (LBNL) has developed a seven-step DEA framework for evaluating clean energy and building decarbonization programs (US Department of Energy, 2024), as a complement to traditional benefit-cost analysis (Table 16).

TABLE 16: KEY STAGES IN THE LAWRENCE BERKELEY NATIONAL LABORATORY DEA FRAMEWORK

1	2	3	4	5	6	7
Establish community and stakeholder process	**Articulate** the DEA context	**Identify** priority populations	**Develop** DEA metrics	**Apply** DEA metrics to priority populations	**Present and interpret** DEA results	**Make resource decisions** using DEA and benefit-cost analysis results
Community and Stakeholder Involvement						

Source: Adapted from: LBNL's Distributional Equity Analysis for Energy Efficiency and other Distributed Energy Resources – *A Practical Guide* (CPUC, 2009)

The framework begins by engaging communities and defining the decision context, then identifies priority populations and develops equity metrics. Those metrics are then applied to available data, results are interpreted to show how benefits and burdens are shared, and decision-makers then use DEA findings alongside BCA to decide whether to pursue, modify, or reject building decarbonization investments.

In the context of California's building decarbonization programs, we focus on three steps: identifying priority populations; selecting appropriate equity metrics; and applying them systematically to assess how program benefits and burdens are distributed across priority populations. This means linking clear definitions of priority populations to measurable indicators of access, affordability, health, energy savings, and housing stability, and evaluating outcomes across demographic, geographic, and socio-economic dimensions.

This section outlines how California defines and identifies priority populations, summarizes core DEA metrics used in decarbonization and energy policy, and describes approaches for applying these metrics in program evaluation. Drawing on examples from other states and national best practices, it highlights emerging DEA approaches that are not yet consistently captured in California's current frameworks.

Identifying Priority Populations

Identifying priority populations is a foundational step in DEA. It determines which communities' outcomes are tracked and whose benefits and burdens are considered most closely. In California, these groups are defined primarily through state and statewide climate-investment policy, and they are intended to ensure that public resources flow to communities that have been historically and disproportionately burdened by pollution, disinvestment, energy insecurity, and climate risk.

California's climate and equity statutes define "priority populations" as encompassing three groups:

- **Disadvantaged communities (DACs):** These are geographic areas identified by CalEPA as having high cumulative environmental, health, and socioeconomic burdens. Under Assembly Bill 1550 (2016), California is legally required to allocate at least 25 percent of Greenhouse Gas Reduction Fund proceeds to projects located within and benefiting DACs. Collectively, AB 1550 mandates that at least 35 percent of these investments benefit "priority populations," which include DACs and low-income households. CalEPA identifies DACs using the CalEnviroScreen tool.
- **Low-income communities:** These are census tracts whose median household income is at or below 80 percent of the statewide median income, or at or below the "low-income" threshold set by the Department of Housing and Community Development's (HCD) State Income Limits. They are treated as a distinct priority group even when they are outside CalEPA-designated DACs.
- **Low-income households:** These are individual households (anywhere in the state) with incomes at or below 80 percent of the statewide median income, or below HCD's low-income threshold, as defined in AB 1550 and used for California Climate Investments. Unlike low-income communities, they are not mapped as census tracts; eligibility is determined at the household level.

These statutory categories are operationalized using a combination of geospatial and demographic tools that help agencies to locate and identify priority populations:

- <u>CalEnviroScreen (CES):</u> Developed by Cal-EPA's Office of Environmental Health Hazard Assessment (OEHHA), CES evaluates cumulative environmental, health, and socioeconomic burdens at the census tract level. It incorporates indicators such as air pollution, traffic density, asthma rates, poverty, and linguistic isolation (OEHHA, 2021).
- <u>California Climate Investments Priority Populations Map</u>: This interactive map integrates CES data with income and housing data to identify DACs, low-income communities, and low-income households for CCI reporting and program targeting.
- <u>Program-Specific Data:</u> Programs like the Energy Savings Assistance (ESA) Program and TECH Clean California collect self-reported demographic data, housing type, and income eligibility to further refine targeting and allow administrators to track participation and outcomes for priority populations over time (CPUC SCT, 2024).

Research indicates that binary thresholds can create disparities in support for essentially similar households (Huynh et al., 2024). To mitigate these allocative harms, California already utilizes flexible boundaries in its priority population definitions; specifically, AB 1550 mandates that a portion of funding benefits low-income communities located within a 0.5-mile buffer of a designated DAC. Expanding this "buffer-zone" logic across more building decarbonization programs ensures that "nearly eligible" populations are not excluded by arbitrary census tract lines, allowing for a more continuous and equitable distribution of climate investment.

Other states often include additional factors – such as race/ ethnicity, renter status, displacement risk, and energy burden – on top of core income and place-based definitions (see Table 17).

TABLE 17: APPROACHES TO DEFINING PRIORITY POPULATIONS

State	Definition of Priority Populations	Key Distributional Indicators Used	Primary Data Sources
New York	Disadvantaged Communities (DACs) under the NY Climate Leadership and Community Protection Act (CLCPA)	Race/ethnicity, income, housing cost burden, health outcomes, pollution exposure, climate risk, energy burden	NYS DAC Criteria (2023), CEJST, NYSERDA GIS tools, US Census/ACS
Massachusetts	Environmental Justice (EJ) populations under state EJ statute and the Clean Energy and Climate Plan (CECP)	Income, race/ethnicity, English isolation, renter status, housing type, displacement and gentrification risk	MA EJ Block Groups, US Census/ACS, MassGIS, Metropolitan Area Planning Council (MAPC) displacement index
Washington	Highly Impacted Communities (HICs) under Clean Energy Transformation Act (CETA)	Income, race/ethnicity, tribal affiliation, health disparities, energy burden, pollution exposure	WA HIC Map, Washington Department of Health Health Disparities Map, US Census/ACS
Oregon	Environmental Justice Communities under HB 2021 and related energy policies	Income, race/ ethnicity, tribal affiliation, rurality, housing type, energy burden	Oregon EJ mapping tools, Oregon Health Authority, US Census/ACS

State	Definition of Priority Populations	Key Distributional Indicators Used	Primary Data Sources
Illinois	Equity Investment Eligible Communities (EIECs) under the Climate and Equity Jobs Act (CEJA)	Income, race/ethnicity, unemployment, housing cost burden, environmental burden, climate vulnerability	CEJA Equity Map, Illinois environmental and health data, US Census/ACS, USEPA EJSCREEN
Minnesota	Priority Populations under the Climate Action Framework and sector-specific plans (e.g., clean heat)	Income, race/ethnicity, renter status, manufactured housing, tribal affiliation, rurality	MN Compass, US Census/ACS, state health and housing data

Distributional Equity Analysis Metrics

California has begun to integrate DEA metrics in its building decarbonization and low-income energy programs, but these practices are evolving and are not yet applied consistently across the full portfolio. CPUC and CEC proceedings increasingly require reporting and evaluation of equity-relevant outcomes—such as program participation rates by income and geography, energy burden, and investment levels in disadvantaged communities—for specific equity programs, but the state lacks a unified framework for comparing participation across all programs. For example, the Equitable Building Decarbonization (EBD) program and recent CPUC equity requirements in distribution planning and energy-efficiency portfolios call for tracking how benefits and opportunities are distributed among priority populations, including metrics on participation, affordability, access, and selected non-energy benefits, yet similar tracking is not systematically required for mainstream decarbonization programs.

Table 18 summarizes a set of core distributional equity metrics including access, affordability, housing security, environmental health, and health outcomes that are emphasized in leading guidance from LBNL's DEA work, the American Council for an Energy-Efficient Economy (ACEEE), the 2035 Initiative, and California's Energy Savings Assistance Non-Energy Impacts (Evergreen Economics, 2025) Study (2025). These sources were selected because they (1) focus specifically on equity and building or energy decarbonization, (2) propose concrete, operational metrics, and (3) are already influencing policy and program design in California. Most of the metrics in Table 18 can be measured at the household level (for example, energy burden, participation, health outcomes) and then aggregated to community geographies such as census tracts or DACs for DEA.

TABLE 18: EQUITY AND HEALTH METRICS FOR MEASURING BUILDING DECARBONIZATION IMPACTS

Impact Category	Metric	Definition	LBNL	ACEEE	2035 Initiative	ESA NEI Study (2025)
Access & Inclusion	Program Participation	Uptake of programs by income, race, geography, housing type	X	X	X	
Affordability	Energy Burden	Percent of household income spent on energy bills, by income and place	X	X	X	X
Housing Security	Housing Stability	Changes in eviction risk, displacement risk, or tenure security for participants and their communities	X	X	X	
Environmental Health	Indoor Air Quality	Reductions in indoor pollutant exposure (e.g., NO_2, PM2.5) in homes and buildings	X	X	X	X
Health & Wellbeing	Health Outcomes	Changes in health indicators (e.g., asthma, respiratory hospitalization, heat-related illness, thermal comfort)	X	X	X	X

Note: Metrics can be derived from household-level data (for example, surveys, billing data, indoor air quality measurements) and/or community-level indicators (for example, census tracts, health or displacement indices).

California's SCT, adopted in CPUC Decision D.24-07-015, represents a major step forward in integrating equity and non-energy impacts, particularly climate and air-quality benefits, into cost-effectiveness analysis. However, SCT as currently implemented captures only a subset of the broader DEA metrics recognized in Table 18. It monetizes some environmental health and climate impacts but does not yet incorporate housing security, distributional energy-burden changes, or systematic participation metrics by priority population. Expanding SCT inputs and related reporting to include more of these metrics would better align California's cost-effectiveness framework with emerging best practices in distributional equity analysis.

Other states are increasingly capturing DEA metrics through targeted decarbonization and energy programs that go beyond California's current approaches in several key areas (Table 19). These examples show how participation, affordability, housing stability, environmental health and health outcomes can be tracked in ways that reveal whether priority populations are receiving benefits.

TABLE 19: APPROACHES TO MEASURING EQUITY IN BUILDING DECARBONIZATION PROGRAMS

Impact Category	Metric	Indicators	Examples	Metrics/Data Collected
Access & Inclusion	Program Participation	Enrollment and completion by income, race, housing type, geography	**Massachusetts**: Tracks participation and completion by renter status, income, and building type in its Mass Save plans	Share of participants by income bracket, tenure, building type; completion and drop-off rates by group
Affordability	Energy Burden Reduction	Pre/post percent income spent on energy; Bill savings by income and place	**Illinois**: CEJA mandates tracking of bill savings and energy burden by income and geography	Modeled or observed pre/post energy burden; average bill savings per household by income/tract
Housing Security	Housing stability	Service to renters vs. owners; changes in displacement or housing-cost burden indicators	**Maine**: Some weatherization and whole-home retrofit programs track renter share and use external displacement risk indices to assess risk	Share of renters served; linkage to external eviction or displacement-risk indicators at neighborhood level

Impact Category	Metric	Indicators	Examples	Metrics/Data Collected
Environmental Health	Indoor Air Quality (IAQ)	Changes in indoor PM2.5, NO_2, CO; ventilation upgrades; modeled IAQ improvements	**Washington**: Planning guidance for Highly Impacted Communities encourages reporting on IAQ improvements where data are available	Pre/post IAQ sensor readings or modeled pollutant levels; documentation of ventilation and equipment upgrades
Health & Wellbeing	Health Outcomes	Changes in asthma symptoms, heat related illness risk, or thermal comfort for participating households and communities	**Rhode Island**: Includes modeled estimates of avoided asthma events and survey-based comfort measures	Modeled avoided health events at household or tract level; thermal comfort scores from participant surveys

Note: In most cases, these metrics are derived from a mix of household-level data (for example, surveys, billing data, IAQ measurements) and community-level indicators (for example, census tracts, health or displacement indices), rather than from a single standardized data source.

Applying DEA Metrics to Priority Populations

Once priority populations and relevant DEA metrics are identified, the next step is to apply these metrics to assess how the benefits and burdens of building decarbonization programs are distributed. In practice, this involves a structured, data-driven process that links demographic and geographic information with program data.

- **Baseline Characterization**. Establish baseline conditions for priority populations -- such as energy burden, health status, housing tenure, and environmental exposures – using a combination of household-level data (e.g. surveys, billing records) and area-level tools (e.g. CalEnviroScreen, and other state-equity maps at the census-tract or block-group level). Area-level tools cannot measure household level impacts, so administrative or survey data are needed to understand baseline conditions at that scale. Specifically, household-level data is necessary to capture intra-tract variability and metrics that geographic proxies cannot detect. This includes objective energy burden via billing records, and qualitative aspects such as energy insecurity (thermal comfort, coping strategies, economic stress) via surveys.
- **Disaggregated Impact Tracking**. Analyze program outcomes—such as energy savings, bill changes, or participation rates – by income, race/ethnicity, housing type, and geography. This

disaggregation helps identify which groups are benefiting, which are left out, and where disparities persist (DOE, 2024; Langevin et al., 2023).

- **Counterfactual and Comparative Analysis**. Use pre/post comparisons to appropriate reference groups to assess whether benefits are equitably distributed. Key metrics to consider include enrollment and completion rates, energy consumption, energy bills, and energy security. For example, some states simulate retrofit completion rates by tenure and building type and then compare observed results to these baselines to identify whether renters or multifamily households face higher barriers.
- **Equity Weighting and Valuation**. Apply equity weights or assign higher monetary value to benefits received by priority populations when appropriate. For instance, non-energy impact studies for low-income programs in California monetize health and indoor air-quality benefits for low-income households and can be used as inputs to equity-sensitive benefit-cost analysis (Evergreen Economics, 2025).
- **Spatial Mapping and Visualization**. Use mapping tools to map participation, investment, and key outcomes (e.g., bill savings or indoor air quality improvements) across neighborhoods or census tracts. Mapping can reveal under-served high-burden areas and support targeted outreach or incentive redesign.
- **Stakeholder Validation**. Engage residents, community-based organizations, and program beneficiaries to interpret results and ground-truth the metrics. Community input can highlight issues that quantitative data lone may miss – such as hidden barriers to participation or unintended consequences – and can inform revisions to metrics, weights, and program design so DEA results better reflect lived experience. Although outreach strategies should be tailored to local conditions, prioritizing partnerships with community-based organizations already active in decarbonization programs can help reach communities most affected by program outcomes and ensuring that engagement is substantive rather than procedural.

Together, these practices illustrate how DEA can move beyond simple participation counts, providing a richer picture of who benefits from building decarbonization and informing program adjustments so that priority populations are not just eligible in theory, but served in practice.

Recommendations

In this section, we provide recommendations for how California could integrate DEA within its building decarbonization programs and regulatory frameworks, such as the proposed integration of distributional analysis into Standardized Regulatory Impact Assessments (SRIAs) under SB 1161, building on the literature review and state policy scan summarized above (Table 20). They are organized from approaches that can be implemented quickly using existing administrative and program data, to more resource-intensive strategies that require new data collection and analytical capacity. This graduated framework is intended to support near-term improvements while also laying the groundwork for more robust, equity-centered evaluation over a longer time period. Taken together, these recommendations reflect both current analytical constraints and the longer-term need for data collection systems that can better capture who benefits from decarbonization investments, how those benefits are distributed, and where equity gaps remain.

TABLE 20: SUMMARY OF DEA RECOMMENDATIONS BY IMPLEMENTATION TIMELINE

Timeframe	Recommendation
Immediate	Analyze the distribution of program delivery by tracking additional neighborhood-level data to understand which communities are being served and which are being left out.
Near-term	Expand non-energy and equity benefits in cost-effectiveness frameworks
Near-term	Require a standardized set of distributional indicators across all programs
Near-term	Require a standardized set of participant-level data for priority populations
Medium-term	Require pre- and post-implementation surveys of program participants to capture the full costs and benefits of decarbonization investments
Medium-term	Analyze the equity of funding sources to ensure burden of providing decarbonization programs does not fall on priority populations

Expand non-energy and equity benefits in cost-effectiveness frameworks. Limiting cost-effectiveness analysis to energy system benefits risks understating the full value of building decarbonization programs, especially for priority populations that experience large non-energy gains. A growing number of states now incorporate health, comfort, safety, and housing-related benefits into cost-effectiveness screening through non-energy benefit (NEB) adders and explicit valuation.

As of 2025, six states and the District of Columbia use NEB adder rates – such as fixed percentages added to the value of program benefits – to reflect non-energy benefits. Adders range from roughly five percent in Washington, DC and New Jersey to 30 percent in Vermont's low-income programs, with some states providing additional NEB value for low-income households. Other states like Rhode Island and New Hampshire assign specific monetary values to comfort, health, and other NEBs at the household level. These adders are typically established as fixed, statewide percentages to provide a consistent and administratively feasible method for bundling hard-to-quantify benefits such as health and comfort. While locational valuation is possible, the adder approach follows the National Standard Practice Manual (NSPM) framework, which favors jurisdictional-level consistency to ensure equitable program evaluation.

California's Social Cost Test (SCT) and Energy Savings Assistance (ESA) Non-Energy Impacts (NEI) Study already provide a foundation by monetizing climate, air-quality, and some health impacts for low-income programs. These methodologies differ from general population approaches by specifically valuing participant-level health and safety benefits that are often excluded from broader resource planning. We recommend that CPUC and CEC incorporate monetized health, comfort, and safety Non-Energy Benefits into the Social Cost Test (SCT) and, where appropriate, the Total Resource Cost (TRC) test for programs serving priority populations, using existing ESA NEI and related studies as inputs. They should also consider piloting NEB or equity adders (e.g., a higher benefit value when savings accrue to low-income households or DACs), as several other states have done, and report both “with” and “without” NEB or equity-adder results so decision makers can see how equity-relevant benefits affect program cost-effectiveness.

Require a standardized set of distributional indicators across all residential energy programs. California program administrators already collect much of the data needed to evaluate equity including participant counts, measures installed, incentive amounts, and costs, but generally report them only in aggregate. To assess equity outcomes, these indicators should be consistently reported across defined priority populations at either the neighborhood or household participant scale, allowing program administrators and policy decisionmakers to evaluate not only overall program activity, but how access to services and public investments varies across groups. While implementation may face barriers such as data privacy (PII) constraints and administrative tracking costs, these can be managed through standardized data-sharing protocols and phased reporting requirements.

We recommend that administering agencies require all major building decarbonization programs (not just equity-designated programs) to report the following core DEA metrics by priority populations (for example, DACs, low-income communities, low-income households) and, where feasible, by income, tenure, race/ethnicity, and housing type:

Inclusion:

- Number of participants by population segment (for example, income band, renter/owner, DAC vs. non-DAC).
- Types of decarbonization improvements installed by population segment (for example, heat pumps, envelope upgrades, panel upgrades).
- Program completions and drop-off rates by priority population segment. They show whether households can get all the way through the process, not just enroll.
- Average time-to-completion (from application to final install) by population segment. Long timelines can be a meaningful barrier for low-income renters and small landlords even when participation counts look strong.

Distribution of Program Dollars Spent:

- Total and average incentive amount by population segment. This can help program designers understand the distribution of financial incentives across different population groups and structure incentives to reach an equitable distribution within priority populations.
- Share of total program incentives flowing to priority populations.

Participant Costs:

- Total and average participant costs with and without incentives by population segment can help program designers understand the share of incentives out of total costs for different population segments, support financial analysis of barriers to participation, and improve incentive structure.

We recommend that program implementers collect and analyze these DEA metrics at the portfolio-level across all programs they oversee. For the purposes of this report, we distinguish between program-level analysis (individual initiatives) and portfolio-level analysis (the aggregate of all programs in a utility's service area). Evaluating equity at the portfolio level, rather than for individual programs in isolation, recognizes that different programs are designed to serve different population segments. A portfolio-level approach therefore provides a more accurate assessment of how services and investments are distributed overall, and whether the full suite of programs collectively reaches priority populations. This comprehensive approach ensures that the true reach of energy investments is captured, as reporting on only a sub-selection of programs can obscure the overall distributional impacts.

Analyze the distribution of program delivery by tracking additional neighborhood level data to understand which communities are being served and which are being left out. Currently, California lacks a consistent approach for evaluating who is served by building decarbonization programs. For example, the CPUC requires reporting on project counts in Disadvantaged Communities (DACs) only for equity-designated programs, rather than across the full portfolio of decarbonization investments. At the same time, all programs already collect participant address data, creating a clear opportunity to report on key distributional equity indicators in a more systematic way. Implementers could provide participant addresses that are geocoded and linked to census tracts or block groups to generate these indicators, or the State could develop a standardized, tract-level tool that allows program implementers to report DEA metrics by priority populations.

For each of the four DEA metrics listed above, the State or program administrators should report results disaggregated across the neighborhood-level indicators summarized in Table 21. Although DACs are one important dimension of distributional equity, the state has other frameworks in place that could provide additional insights into which communities are served and not. Analysis across these various domains would be easy to implement because the analytical frameworks already exist, and many are updated regularly. However, the State could also consider using other neighborhood-level analyses, for example, there are other approaches to measuring displacement which could also be adopted.[23]

[23] For example, see https://www.mdpi.com/1660-4601/16/12/2246 or https://pmc.ncbi.nlm.nih.gov/articles/PMC11420692/.

TABLE 21: DEA PRIORITY POPULATIONS: NEIGHBORHOOD-LEVEL ANALYSIS

Equity Measure	Resource
Disadvantaged Communities/Cumulative Burden	California EPA CalEnviroscreen DAC Designation https://oehha.ca.gov/calenviroscreen/sb535
Income Disparities	The Community Reinvestment Act defines low-, moderate-, middle- and upper-income communities to help direct community investments.[24] Federal Financial Institutions Examination Council: https://www.ffiec.gov/data/census/median-income
Opportunity and Resource Distribution	California's Tax Credit Allocation Committee's Opportunity Map is designed to identify disparities in housing needs and in access to opportunity. TCAC Opportunity Designation https://www.treasurer.ca.gov/ctcac/opportunity.asp
Displacement Risk	California's Tax Credit Allocation Committee's Neighborhood Change Map identifies tracts racial/ethnic changes (growth in the non-Hispanic white share of the population) and economic changes (growth in median household income), as well as markers of disproportionate housing needs (rising median rents and the home value/income percentile gap). https://www.treasurer.ca.gov/ctcac/opportunity.asp
Climate Risk	Governor's Office of Land Use and Climate Innovation (LCI) Vulnerable Communities Platform identifies California communities most sensitive to the impacts of climate change. https://lci.ca.gov/news/2025/10-14.html

Standardize participant-level data collection for priority populations. Neighborhood-based analysis can capture aggregate equity trends, but it cannot reliably identify the individuals or households reached by decarbonization programs within a census tract. To complement areal-level metrics, California should standardize a common set of program participant data that all building decarbonization programs must collect at the point of implementation (with appropriate privacy protections). (Table 22) Standardizing these measures across programs would enable consistent, individualized assessment of who is being served by the state's decarbonization investments, rather than relying solely on program-level or place-based proxies. A standardized set of metrics would also allow results to be compared across programs and aggregated statewide,

[24] Low: tract median family income less than 50% of area median family income; Moderate: tract median family income greater than or equal to 50% and less than 80% of area median family income; Middle: tract median family income greater than or equal to 80% and less than 120% of area family median income.

improving transparency, accountability, and the ability to identify gaps in participation among priority populations. Participant level data collection should include all the DEA metrics outlined above.

TABLE 22: DEA PRIORITY POPULATIONS: PARTICIPANT-LEVEL DATA

Priority Populations	Data to Collect
Population Characteristics: The literature has identified that certain population groups, including low-income, people of color, and renters are less likely to participate in decarbonization programs. In addition, structural racism has led to disproportionate exposure to pollution and underinvestment in communities of color.	• Race/Ethnicity • Household Income • English Language Proficiency • Household Size • Low-income status (CARE/FERA or LIHEAP eligibility)
Housing Types: Residents of multifamily or manufactured housing often face barriers to participation in decarbonization programs. Older buildings are more likely to expose occupants to adverse environmental conditions and often require more extensive retrofits, increasing barriers to decarbonization.	• Renter/Owner • Single-Family or Multi-family Property • Manufactured housing • Year Built • Percent Income Spent on Rent/Mortgage • Renters only: Subsidized v. non-Subsidized Rent • Basic building attributes relevant to retrofit costs
Energy Insecurity[25]: Households with high energy burdens, disproportionately low-income renters and residents of older or inefficient buildings, have less capacity to absorb upfront costs, bill volatility, or temporary disruptions associated with retrofits. Evaluating decarbonization outcomes through an energy-burden lens helps determine whether programs are meaningfully reducing cost pressures for those most at risk.	• Pre-retrofit household energy costs • Energy burden (Percent Income spent on energy costs) • Energy insecurity 10-point questionnaire (available from authors upon request)

Require pre- and post-implementation surveys of program participants to capture the full costs and benefits of decarbonization investments. Point-in-time data cannot fully capture how building decarbonization programs affect households, particularly with respect to ongoing energy bill impacts, comfort, health, and other non-energy benefits. Requiring implementers to conduct

[25] The US doesn't have an established metric for energy insecurity. The REC survey uses 5 questions to establish energy insecurity at the census tract level every 5 years. Federal and state programs use income level and participation in means-tested programs (CARE, FERA, SNAP, etc.) as a proxy for energy insecurity. Other countries, for example the UK, have established methodologies for energy insecurity.

standardized pre- and post-implementation surveys would allow the State to assess how costs and benefits are experienced by different households over time, and whether those experiences vary across income levels, housing types, or communities. These surveys are essential for understanding whether decarbonization programs are delivering intended benefits equitably, identifying unintended burdens, and informing program design improvements that better align incentives, supports, and outcomes for priority populations. At a minimum, surveys should be conducted one year after implementation (to cover one year of different seasons and energy needs), but longer-term follow-up surveys (e.g. at three years) are also recommended to understand impacts.

As part of this project, the Research Team has implemented a pre- and post-survey to low-income renters whose homes underwent a decarbonization retrofit. This survey could be used or modified to collect data on program impacts. The survey covers five key themes: household renovation priorities and perceptions of home energy retrofits (including heat pumps and induction stove technologies), household energy needs, health, financial security, and household demographics. We identified 10 key questions that inform the household energy insecurity score. This new measure can help program designers understand how housing decarbonization programs impact energy insecurity and critical health outcomes.

Analyze the equity of funding sources to ensure burden of providing decarbonization programs does not fall on priority populations. California's building decarbonization programs are financed through a mix of ratepayer surcharges, California Climate Investments (CCI) funds, state tax revenues, and federal grants. Different funding sources have different distributional implications: volumetric rates and fixed surcharges can be regressive, especially if gas system costs are concentrated on households that cannot electrify quickly, while CCI and broad-based tax revenues may be more progressive. Unlike utility rates, which are regressive because they absorb a higher share of income for low-earning households, tax-based funding scales with income levels.

We recommend that the state evaluate the distributional equity of major funding sources for building decarbonization and develop guidance on a preferred hierarchy of funding from an equity perspective. To maintain independence from program administration, this analysis should be performed by an entity such as the Legislative Analyst's Office, the California State Auditor, or a designated office within the Governor's administration charged with cross-cutting climate and equity evaluation. The analysis should:

- Compare the incidence of different funding mechanisms (e.g., ratepayer surcharges, CCI proceeds, state tax revenues, and federal grants) across income groups and priority populations (following precedents set by states like New York and Massachusetts in evaluating ratepayer impacts);
- Identify funding mixes that minimize regressivity while sustaining decarbonization investment; and
- Provide guidance to the Legislature and relevant agencies on prioritizing more progressive funding sources when designing or expanding building decarbonization programs.

Options such as building-sector carbon pricing (for example, Local Law 97-style performance standards or fees) can be considered in this context, but any such mechanism would need sensitivity modeling during the design phase to avoid shifting costs onto low-income renters and to ensure that resulting revenues are reinvested in ways that advance equity.

Conclusion

These recommendations offer a practical roadmap for embedding equity into building decarbonization programs while remaining grounded in existing data and administrative capacity. By standardizing a core set of distributional and process metrics, disaggregating results for priority populations, and pairing quantitative indicators with community-driven interventions, agencies can better understand who is being left out and why, and adjust program design accordingly. While it is difficult to prescribe a single “good” performance benchmark across diverse programs, systematically tracking these metrics over time, including differences in experience for priority populations, will allow agencies to identify emerging gaps and refine program design in context-appropriate ways. Implemented consistently, this framework can help ensure that decarbonization investments not only reduce emissions, but also deliver tangible, measurable benefits to the households and communities that need them most.

6. Policy Recommendations

Meeting California's decarbonization targets will require large-scale adoption of residential energy upgrades, driven by incentives, policy mandates, and market transformation. Yet these strategies alone are unlikely to deliver equitable outcomes. Our research, bolstered by the literature on this topic (Brown et al., 2019; Reames, 2016), shows that higher investment in outreach and program navigation is essential in communities that suffer from compounding burdens and a legacy of distrust in government programs. Without targeted strategies, disadvantaged communities—who face higher levels of energy insecurity, older housing stock, and constrained access to capital—risk being excluded from the benefits of the energy transition.

To ensure equitable residential decarbonization in California, the state must invest in intentionally designed, equity-centered models that proactively address barriers to participation and integrate coordinated support across program design, implementation, and evaluation.

This section presents policy recommendations designed to overcome the structural barriers that drive low participation rates and exacerbate socio-economic disparities in decarbonization program adoption. These recommendations are grounded in a robust, multi-method research framework. Our insights are synthesized from a statewide analysis of residential energy programs, household interviews, and a pre- and post-retrofit household level survey measuring the impact of decarbonization on energy security. This empirical evidence is supported by a literature review exploring equity considerations in program design, implementation, and evaluation, as well as a critical review of integrating equity measures in benefit-cost analyses. (A summary of the recommendations can be found in Appendix D.)

We find that current decarbonization efforts transfer the responsibility of implementation onto households, requiring them to navigate a complex system to access residential energy programs. Within this system, low- and moderate-income households struggle to participate not only due to individual-level constraints, such as time, information access, and limited capital, but also due to systemic community-level factors, such as the availability of knowledgeable contractors, the existing quality of their homes (older buildings typically require costly upgrades as a prerequisite to electrification) and the capacity of the energy infrastructure (disadvantaged communities have lower panel, electric circuit and transformer capacity). To bridge these gaps, we propose aligning efforts across the policy and program cycle. This chapter is organized into three strategic pillars:

The **Program Design** section focuses on strategies to bridge the coordination gap among government agencies, engage meaningfully with community partners, increase affordability, and establish effective pathways to build participant capacity to engage with decarbonization programs.

The **Program Implementation** section focuses on building the local capacity of local governments, the workforce, and community organizations, and addressing the combined challenges of upgrading both buildings and energy infrastructure (i.e., electrical panels, transformers, circuits). Although these are not typically within the purview of the decarbonization program designers, they are nevertheless critical to advancing equitable implementation.

The **Program Evaluation** section includes recommendations for incorporating equity into budget planning and provides guidance on how to collect and report on equity metrics. This section describes strategies for embedding non-energy benefits into cost-effectiveness tests and for integrating distributional equity analysis into program evaluations.

Program Design

Coordination

Create an interagency working group to improve program coordination

Lack of coordination across government agencies creates significant challenges, including the difficulty of braiding funds to address substandard housing and systemic bottlenecks like energy infrastructure delays and protracted permitting. To address these challenges, we recommend that California form an interagency working group to improve coordination of program design, implementation, and evaluation among state agencies and local representatives, and to report on progress towards climate, energy, and equity goals. The interagency working group would:

- Include state agencies that directly design policies and programs for housing decarbonization or that have responsibility over key issues impacting housing decarbonization, such as workforce development, financing programs, or the identification of priority communities. (See Appendix E for Agency Matrix.)
- Create task forces dedicated to core areas such as program design and evaluation (including health and safety considerations), building and appliance standards, energy rates and infrastructure, workforce, licenses and certifications.
- Include representatives from priority communities across the state. These roles should be compensated. Our advisory committee recommends including members of the Building, Energy, Equity, and Power (BEEP) coalition, which represents priority communities across California, as well as members of Healthy Homes Working Groups.
- Develop clear public processes to solicit input from actors across sectors and geographies across the state.
- Hire a third-party contractor to facilitate the interagency group's work and to be responsible for reporting. A third-party facilitator can help build trust among the different actors and support coordination and alignment across agencies that have distinct missions.
- Meet on a regular cadence and publicly report every two years on progress.

The interagency working group would have oversight responsibility for the following areas:

<u>Program design and evaluation</u>

- Ensure sufficient funding and attention to integrating participant support in priority communities, including outreach, support in program navigation, and post-implementation education and quality control

- Ensure that decarbonization programs meet the needs of different property owners and building types, with a special focus on affordable multi-family housing and manufactured homes.
- Track progress towards creating tenant protection guidelines and enforcement mechanisms.
- Coordinate eligibility criteria across energy, housing, and health programs to ensure incentives can be stacked.
- Create a list of means-tested programs for auto-enrollment in income-eligible decarbonization programs.
- Conduct a study on how to improve green financing mechanisms such as Go-Green financing and Inclusive Utility Investment (IUI) programs.
- Coordinate and standardize reporting requirements and evaluation metrics for incentive programs across state agencies to ensure equity metrics are consistently tracked across programs and to reduce the administrative burden associated with different reporting requirements and formats across programs.
- Evaluate progress towards streamlining permitting at the local level.
- Offer legislative recommendations to synchronize program goals and timelines.
- Coordinate data access/sharing across agencies.
- Coordinate with local governments to ensure they can support program implementation

Energy rates and infrastructure

- Evaluate the impact of high electricity rates on the financial feasibility of electrification.
- Track how the California Energy Commission (CEC) and California Public Utility Commission (CPUC) coordinate electrical infrastructure upgrades with electrification projects in priority communities.

Workforce, licenses and certifications

- Evaluate progress towards developing the decarbonization workforce and supporting small-scale businesses
- Evaluate progress towards streamlining decarbonization licensing and certifications.

SB X1-2 provides an example of this type of interagency collaboration, directing the California Air Resources Board (CARB) and the CEC to jointly develop the Transportation Fuel Transition Plan (Skinner, 2023). A third-party contractor UC Berkeley's (Center for Law, Energy, and the Environment) facilitates the process by convening state agencies and stakeholders, including community organizations and businesses, to deliberate on key issues. Each agency retains distinct responsibilities but coordinates closely with the other agencies and the advisory group.

Leverage cross-sector partnerships

Currently, there is limited support for people who live in older homes that require health and safety upgrades (such as remediation of mold, asbestos, or lead) as a prerequisite for electrification. There is an opportunity to leverage cross-sector partnerships among energy service providers, housing agencies, and healthcare partners to strategically align funding for the combined health, safety, and electrification work necessary to bring energy and health benefits to people who live in the worst housing conditions.

- Pilot programs that create a seamless pipeline from home repair to decarbonization have proven especially effective. For example, several low-income weatherization programs pair basic health-and-safety repairs (like electrical upgrades or roof stabilization) with heat-pump installation, allowing the housing program to address habitability issues while the energy program covers energy equipment.
- Health-focused initiatives also offer promising models: some counties partner closely with local health departments to identify household members with asthma or chronic obstructive pulmonary disease (COPD), referring them to healthy-homes interventions that integrate mold remediation, ventilation improvements, and electrification measures. Additional opportunities lie in aligning lead remediation programs with decarbonization efforts and exploring how California Advancing and Innovating Medi-Cal (CalAIM) Community Supports (e.g. asthma remediation) could be braided with energy funds to finance health and safety upgrades that are necessary prerequisites for electrification.

Prioritize deep engagement with Community-Based Organizations (CBOs)

CBOs play a crucial role in implementing decarbonization programs in priority communities, primarily through established trusted relationships with target communities and an understanding of community needs in program engagement. To optimize housing decarbonization programs, state and local government agencies should transition from treating CBOs as mere outreach channels to integrating them as fully compensated strategic partners throughout the program lifecycle. By leveraging the deep-rooted trust and diverse networks these organizations hold within specific cultural and linguistic segments, agencies can ensure that program design and messaging are tailored to community needs. Effective coordination requires a shift toward sustainable funding models that prioritize capacity building and long-term engagement over task-specific stipends, allowing CBOs to act as expert consultants in design, implementation, and evaluation of decarbonization programs.

For each program in priority communities, we recommend that decarbonization programs:

- **Form a Community Advisory Board** to guide program design, implementation, and evaluation. This advisory board can include members from several CBOs that are active in the target communities, and can provide valuable insights into community needs, effective implementation strategies, and which metrics to track to ensure effective implementation in the target communities.

- **Engage with multiple CBOs to ensure broad engagement across different priority groups.** It is critical to identify those CBOs and Non-Governmental Organizations that are familiar with the target community to ensure that they have the necessary network and trusted relationships to be effective messengers. In a specific geographic area, there could be several CBOs serving different segments of the population (e.g., Latinx community, Chinese community, faith-based communities, etc.), requiring contracts with several CBOs. The ideal partners are CBOs that have long-standing relationships and networks in priority communities, with the capacity to identify how to meet households where they are at.
- **Invest in capacity and expertise:** Provide dedicated funding and training for CBOs to hire staff and develop decarbonization expertise, particularly in geographies where energy-specific knowledge is currently limited. Contracts that span several years can ensure that CBOs have the financial resources necessary to build capacity for decarbonization projects, which translates into broader community education and motivation for residential energy retrofits.
- **Integrate full-cycle partnership:** Utilize CBOs as vendors or consultants across all program stages, from initial participatory design and geographic targeting to ongoing feedback loops and outcome evaluation.
- **Implement sustainable compensation:** Move away from small, project-based stipends toward longer-term contracts that fairly compensate CBOs for their time, expertise, and sustained participation.

Affordability

Participants' ability to afford housing decarbonization measures depends on project costs, personal capital, access to financial incentives, and the change in energy bills post-implementation. Low-Moderate Income (LMI) households face known constraints: they are more likely to live in older homes that require higher costs to electrify, they have limited or no access to capital, and they are exposed to volatility in electricity rates that threatens the financial viability of electrification. To address these challenges, program designers can take several actions to ensure sufficient funding for the remediation of pre-existing conditions, scope projects to reduce or avoid increases in energy bills, align the incentive structure with participant needs, and ensure enrollment in rate plans that fit household needs.

Address building readiness for electrification

Program designers should integrate retrofit needs into decarbonization programs in priority communities through either coordination with health/housing programs or direct provision of these services. Retrofit needs include home health and safety upgrades and code compliance issues such as lead/asbestos/mold abatement, electrical system and wiring upgrades, and roof replacement. In retrofits of subsidized affordable housing, program designers need to include funding for tenant relocation costs in case there is a need to address significant health/safety/code compliance issues. Since retrofits can require substantial funding, there is a need to improve program efficiency and coordinate funding across sectors. If retrofit funding can be built into a single decarbonization program (e.g., like the CEC Equitable Building Decarbonization program), this would improve program efficiency by reducing the administrative burden of coordinating different funding streams on program administrators, implementers, and participants. Alternatively, funding could be provided through formal coordination (including eligibility criteria and reporting requirements) with housing, health, and transportation programs.

Align eligibility criteria to enable incentive stacking

Program designers create eligibility criteria for programs based on the demographic and geographic profile of their jurisdictions. While this process is intended to meet the goals of local programs, this fragmentation creates a macro-level "patchwork" that complicates the decarbonization landscape. The resulting lack of alignment across federal, state, and local levels increases administrative burdens and obscures the path for participants attempting to stack multiple incentives across programs. This challenge creates the highest burden for people living in older homes that require the combination of multiple programs to afford electrification.

Coordination of eligibility criteria can ensure the ability of households to stack incentives for different equipment across programs (e.g, utilize the incentive from program A for an induction stove and from program B for a heat pump). Across sectors, coordination of energy programs with housing habitability programs (e.g., home repair, lead remediation) can support households by streamlining services in the home and removing barriers to participation.

To streamline verification, we recommend that decarbonization programs:

- **Implement categorical eligibility:** Automatically qualify households already enrolled in other means-tested programs like SNAP or Medi-Cal.
- **Enable CBO-led verification:** Programs should consider allowing CBOs to verify low-income status to address documentation gaps and correct for the appearance of higher income in crowded homes.
- **Consider self-eligibility declarations:** Implementers should evaluate trust-based systems for local programs where the administrative cost of document collection exceeds the potential cost of providing incentives to an occasionally ineligible participant.
- **The CPUC should coordinate the statewide eligibility verification tool (Concurrent Application System) with the interagency working group** to ensure fit for program needs across agencies and for needs in priority communities.

Match incentive structure and financing strategies to household needs

Financial barriers vary significantly across income groups, requiring differentiated program design. For low-income households, no-cost direct install programs remain the most effective funding approach, as upfront costs, credit constraints, and high housing cost burdens make other funding approaches such as rebates largely inaccessible.

Moderate-income households, in contrast, often fall outside eligibility thresholds for fully funded subsidies but still lack the liquidity or credit access needed to finance retrofits. This “financing gap” has been widely documented in the energy equity literature, which finds that reliance on rebates and tax credits disproportionately benefits higher-income households with greater upfront capital (Carley and Konisky, 2020; Forrester and Reames, 2020). To close this gap, California should expand financing tools that reduce upfront costs and align repayment with energy savings, including on-bill financing, Go-Green financing, and Inclusive Utility Investment (IUI) models. Evidence suggests these approaches can overcome credit barriers and improve access, but remain underutilized at scale (Campbell, Lamm and Hoff, 2023). The interagency working group should assess how to improve and expand access to these tools to ensure that moderate-income households are not excluded from participation.

Scope projects to reach energy bill neutrality or savings

Program designers should structure decarbonization projects to achieve energy bill neutrality—or ideally, bill savings—for participating households, particularly in priority communities. While single-measure electrification programs work in environments ready for electrification, in older buildings they risk increasing energy bills when implemented in isolation, especially in high electricity cost environments.

To mitigate this risk, electrification should be bundled with energy efficiency improvements (e.g., insulation, air sealing), distributed energy resources such as solar and storage, and access to affordable or protected electric rates. Further, program designers should ensure that program administrators use right-sizing strategies for load optimization, including measures such as meter socket adapters, circuit splitters, and low-voltage appliances.

Programs should also incorporate safeguards to prevent unintended cost increases. These may include pre-project bill impact assessments, standardized modeling tools, and requirements for implementers to disclose expected bill changes to participants with written acknowledgment, similar to provisions in the HOMES program. In cases where electrification increases energy use to meet previously unmet needs (e.g., adding cooling in homes without air conditioning), modest bill increases may be appropriate. However, these increases should be explicitly evaluated in the context of overall housing affordability and accompanied by targeted rate protections or subsidies. Ensuring energy bill neutrality is critical not only for household affordability, but also for building trust and supporting sustained adoption in disadvantaged communities.

Help participants enroll in energy bill assistance programs

Program implementers should integrate enrollment in energy bill assistance programs into the intake process. Because many eligible households are unaware of available programs or face barriers to enrollment, implementers in priority communities should provide direct support in enrolling participants in programs such as California Alternate Rates for Energy (CARE) and Family Electric Rate Assistance (FERA). In addition, implementers should assist Low-to-moderate-income households in selecting energy rate plans that align with their usage patterns and provide guidance on demand response programs where available.

Participant Education and Capacity

Households in priority communities may not be aware of decarbonization programs, understand their benefits, or have the capacity to participate in a complex and multi-step process, including managing multi-step processes and engaging with contractors, technical understanding (assessing technologies, incentives, and bids), and administrative bandwidth (completing complex paperwork). They may also not know how to use and maintain new appliances.

Program designers must create dedicated programs tailored to the unique needs of LMI homeowners and renters, landlords, and residents of manufactured homes and parks. Different ownership structures and building types require different approaches to building the knowledge and capacity to navigate programs from start to finish.

Strengthen participant support systems in priority communities

Findings from this research (Chapters 2, 3, and 4) highlight that households in priority communities face a cumulative “participation burden” that spans awareness, enrollment, financing, and implementation. These barriers are often interrelated and cannot be addressed through incentives alone. Instead, effective program design must include robust participant support systems that reduce friction at each stage of engagement. In priority communities, this support must be culturally competent, accessible, and sustained over time. Program designers should dedicate funding for participant support across four key areas:

- **Awareness:** Build awareness through deep engagement via trusted messengers, including CBOs with multilingual staff and professional translations of program engagement materials.
- **Motivation:** Adapt messaging to local needs (e.g., focus on health, safety, and comfort), and use trusted messengers such as CBOs, community leaders, and community members who are past program participants. Motivation is also tied to removing structural and financial barriers and ensuring that program offerings align with participants’ needs.
- **Capacity:** Fund an energy navigator, who can provide guidance through all stages of program engagement to ensure participants can complete the process. Navigators can serve as a key point of contact to explain the program, technologies, and financial implications. They can also help with filling in the necessary forms, provide guidance throughout the process, and answer questions as they arise, including ensuring participants know how to operate equipment once installed.
- **Post Implementation Quality Control and Education:** Structure quality control and post-implementation follow-up into program design to ensure appliances are properly installed and to provide guidance on how to use and maintain the new appliances. Quality control should be conducted upon completing installation, and guidance on how to use the appliances should be provided several times throughout the first year of using the new equipment, preferably through the energy navigator model.

Our research identified two scalable models to provide participant support:

- **Local Government Resource Hubs:** Municipalities and regional agencies can establish "one-stop-shop" resource centers that act as a single, consistent point of contact for residents and contractors to navigate diverse incentive programs, understand costs, and connect households with qualified local contractors. Examples include the San Francisco Climate Equity Hub and the Sacramento Contractor Network.
- **Implementer-Led Energy Navigators:** Program administrators can provide participants with dedicated, non-sales-oriented "Energy Navigator" who offers personalized guidance from initial project scoping and form completion through long-term post-installation troubleshooting. These roles should be integrated into the program budget.

Address the needs of different property ownership structures in the residential sector

Different property ownership structures and building types complicates outreach and program design, particularly given owners' and occupants' varying capacities to engage in decarbonization. Renters are especially vulnerable, as they disproportionately experience poor housing quality yet face the risk that energy upgrades could drive up rents and heighten housing insecurity. In residential programs that target affordable multi-family properties or manufactured home parks, interventions should be tailored to address the split incentives between landlords and tenants.

- **Adopt tenant protections in all housing decarbonization incentive programs impacting renters and clarify their enforcement.** The interagency team should develop standardized Tenant Protection Agreements (TPAs) that landlords sign as a condition of receiving subsidies, coupled with transparent enforcement mechanisms. These protections should include rent stabilization, bans on usurious cost pass-throughs, safeguards against evictions related to substantial remodels, and requirements to inform renters of these protections and how they are enforced. By establishing clear oversight and habitability standards during retrofits, California can ensure that financial incentives for property owners do not compromise the housing stability of low-income renters.
- **Plan utility allowances in affordable housing to support decarbonization.** California's current utility allowance system effectively penalizes affordable housing owners for decarbonizing because standard HUD averages prevent them from capturing energy savings to offset the cost of high-efficiency upgrades. To bridge this gap, regulatory pathways should allow properties to transition to consumption-based models like the California Utility Allowance Calculator (CUAC) during retrofits and for local housing authorities to establish tiered "high-efficiency" schedules. Such adjustments would enable owners to increase net operating income or service solar-related debt without increasing the total out-of-pocket housing costs for low-income tenants.
- **Target Manufactured Housing Infrastructure:** The CPUC and the CEC should build on the Mobilehome Park Utility Conversion Program Electrification Pilot Initiative (CPUC, 2025) to address the unique electrical deficits and split incentives between lot owners and

homeowners in mobile and manufactured home parks, where master-metered systems and aging panels currently make individual electrification impractical.

- **Equalize Multifamily Solar Access:** The CPUC should reform metering strategies to ensure that solar and storage benefits are distributed equitably across all units in multifamily buildings, rather than being restricted to a single meter or the property owner. Since solar and storage are key to the affordability of electrification projects, ensuring that solar benefits can be shared across all units is essential for project viability in priority communities.
- **Engage Homeowners Associations (HOAs):** State agencies should provide technical assistance and information to HOAs to remove administrative barriers, such as "no energy production" clauses, and encourage the adoption of shared heating and cooling equipment.

Program Implementation

Local Capacity for Implementation

Building local implementation capacity in priority communities involves transferring the burden of program management from the individual participant to local organizations. In these communities, California must bolster support for local governments, program implementers, and community organizers to provide dedicated participant support services to facilitate engagement with complex programs. These organizations can also create critical feedback loops that allow program designers to continuously refine policies based on ground-level local needs.

Build the capacity of local governments to support decarbonization efforts

- **Provide standard, statewide guidelines for local building departments** on new electrification technologies to provide clarity on health and safety requirements, reduce confusion, and streamline permitting. This can involve written guidelines, training for inspectors, and models for simplified online forms for same-day approvals. The State could require streamlined permitting for electrification projects, following the example of AB2128 which required local governments to adopt a streamlined process for solar panel permitting. Developing model permitting processes and requirements for common clean energy technologies would reduce complexity and training needs while enabling contractors to work efficiently across multiple areas.
- **Offer training programs for building department staff**. Regular education initiatives should focus on the unique characteristics and safety considerations of heat pumps, induction stoves, EV charging systems, and other emerging technologies to ensure appropriate and consistent review processes.
- **Support the creation of local resource hubs to support participants.** Local governments, at the municipal level for densely populated areas and at the county or multi-county level for rural areas, should be encouraged to establish local resource centers for the coordination and implementation of decarbonization programs. San Francisco, for example, co-developed a hub with community partners to provide a one-stop shop for

decarbonization actions for both participants and contractors. In rural areas or areas with a small local government, a resource hub can be established at the regional level.

- **Create a local contractor network.** One promising local solution is to develop a contractor network that provides contractors with technical assistance and customer leads, while connecting households to verified, high-quality providers. For example, in Sacramento, a contractor network links contractors with residents, offers technical and administrative support, and conducts quality assurance (https://www.smudcontractornetwork.org/). Contractors must meet certification requirements and demonstrate positive customer reviews to participate, and receive training on program offerings, incentives, and reporting. An on-staff energy advisor supports contractors with system design and installation questions, improving quality outcomes. Contractor performance is monitored through quarterly scores based on customer surveys and field checks; while these scores are not public, higher-performing contractors are more likely to receive referrals, creating incentives for high-quality work.

Invest in the decarbonization workforce

Interviews suggest that the residential decarbonization sector faces a critical workforce shortage, particularly in rural regions where contractors lack the certifications required for electrification and hazardous material remediation. This gap is exacerbated by a technical and administrative divide: while large-scale firms possess specialized in-house expertise, small-scale contractors often lack the training necessary to navigate both the installation of heat pump technologies and the complex reporting requirements of state-funded programs.

Coordination across state agencies is needed to advance workforce development. The California Workforce Development Board and the Department of Industrial Relations should take the lead on standardizing curricula and creating high-road training partnerships that prioritize disadvantaged workers. Simultaneously, the California Community Colleges Chancellor's Office is best positioned to scale technical courses and offer them in multiple languages to increase accessibility. To ensure contractor buy-in, the CEC and CPUC could provide financial incentives, such as through the CEC's CA-TREC Program, including aid training and childcare support, to offset the costs of learning new skills. By collaborating with community-based organizations and large-scale program implementers, these agencies can create streamlined apprenticeship and placement paths that turn training into stable employment within priority communities.

Expanding the decarbonization workforce will require targeted investments in workforce development, including the creation of public training programs that broaden access beyond workers employed by large contractors with in-house training capacity.

- Create decarbonization courses in trade schools and colleges, following the successful examples of the Technology and Equipment for Clean Heating (TECH Clean California) grant for workforce development. The State should take the responsibility for standardizing the curriculum, certification, and provide administrative support.

- Collaborate with community partners and labor unions to create workforce development programs in priority communities. These programs could help to ensure sufficient labor to expand policies that encourage hiring of Disadvantaged Workers (DAW).
- Make programs available in languages other than English.
- Create financial incentives for experienced contractors to learn new decarbonization skills, such as paid training and childcare support. Interviewees noted that to get contractor buy-in to invest time and effort in training, there's usually a need to either compensate contractors for their time or promise a certain amount of work to offset the costs of learning new skills.
- Collaborate with large-scale program implementers for apprenticeships, fellowships, and placements, so that those acquiring new skills will have a streamlined path to getting a job.
- Establish multi-year program commitments (3-5 years) to provide contractors with reliable business prospects that justify investments in specialized training and equipment.

Streamline certifications for housing decarbonization

The State should either develop one standard housing decarbonization certificate or streamline the training and certification process for housing decarbonization. Standardizing certification requirements would make it easier to develop a trained workforce and would benefit small contractors. At a minimum, the State should integrate lead and asbestos remediation training and certification into the same place that certifies other construction programs.

As an example of a streamlined process, the Electric Vehicle Infrastructure Training Program (EVITP), established by California law (AB 841; Pub. Util. Code § 740.20) is the industry-recognized gold standard for training and certifying licensed electricians to install, maintain, and commission electric vehicle supply equipment (EVSE). The curriculum focuses on technical standards, load calculations, and national electrical codes specific to vehicle power systems. This certification is a common requirement for publicly funded infrastructure projects to guarantee a high-quality workforce and long-term network performance.

Address financial barriers for small contractors

Creating a bridge capital program can help small contractors access capital to implement projects before receiving reimbursements. Programs that provide or lend specialized equipment (like insulation blowers) to new contractors who lack the capital or credit relationships to purchase equipment independently can also overcome workforce barriers.

Prioritize local, small-scale contractors in program implementation

In programs that are first-come first-serve (e.g. TECH), large-scale contractors that can more easily move fast can claim all available rebate money before small-scale contractors are able to place their applications. Reserving a portion of incentives for local small-scale contractors will enable them to participate and potentially expand the reach of programs to areas underserved by large contractors and contribute to local economic development.

Address capacity barriers

Growing small contractor business capacity to engage with decarbonization programs requires support beyond technical training, to include business operations and administrative knowledge. Decarbonization programs should include additional pay and technical assistance for small businesses on administrative tasks (data collection, reporting, permitting) related to these programs.

Convene a task force of CBOs and small contractors to study wages in the decarbonization sector

While all interviewees agreed that jobs need to pay a living wage[26], views on prevailing wages[27] were mixed. While they ensure higher wages and benefits, they can also introduce higher costs and administrative reporting burden, especially for small contractors. In some cases, the high costs of prevailing wage and the administrative burden of complying can make projects infeasible, especially given limited subsidies. The State should conduct a study, in consultation with organizations that have direct experience with workforce development in priority communities (such as Emerald Cities), to explore wage guidance strategies (e.g., prevailing wage, living wage).

Energy Infrastructure Readiness

Coordinate panel and circuit capacity programs

The CPUC and CEC should coordinate panel and circuit capacity programs with local electrification efforts to align projects with grid infrastructure. Where feasible, programs should promote low-capacity planning to avoid costly panel upgrades and support grid stability. This will require workforce training on maximizing existing panel capacity and properly sizing equipment to household needs. When electrical upgrades are necessary, decarbonization programs should cover the associated costs.

Establish transparency about grid capacity

The CEC and CPUC should establish transparency about grid capacity through mandatory, public-facing reporting on granular electric grid capacity to identify infrastructure gaps in priority communities. In partnership with community-based organizations, the CEC and CPUC should design a community education campaign to support understanding of the state of electric infrastructure in priority communities and the infrastructure upgrades needed to achieve electrification goals. While the CPUC and energy utilities study electrification loads across service areas, there is a need for publicly available, granular information on infrastructure readiness in disadvantaged and priority communities, including both circuit capacity and loads.

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[26] Living wage refers to the minimum income a worker needs to meet basic life necessities (like housing, food, and healthcare) in their specific location, often serving as a voluntary ethical benchmark.

[27] Prevailing wage is a mandatory hourly rate set by law for workers on government-funded public works projects.

Align capital improvement plans with local decarbonization projects

The CPUC should require utilities to align capital improvement plans with local decarbonization projects, ensuring that grid constraints do not stall community-level energy transitions. This should include investments in energy infrastructure in priority communities, including faster panel capacity, transformer upgrades, and solar connections to the grid, ahead of anticipated demand. In addition, coordinating electric grid upgrades with the decommissioning of natural gas pipelines creates an opportunity to redirect avoided gas system costs toward needed electric infrastructure investments, as per Senate Bill 1221.

The CPUC should also optimize regulatory oversight on energy infrastructure upgrades to provide faster panel capacity, transformer upgrades, and solar connections to the grid. Strengthen the enforcement of existing mandates to eliminate administrative delays. While AB 2861 (2016) and AB 643 (2023) established the Expedited Interconnection Dispute Resolution (EDR) process and significant fines for negligence, waiting times remain a barrier to decarbonization.

Housing and Energy Conditions

Conditions of the built environment vary significantly across communities, reflecting long-standing patterns of disinvestment and cumulative disadvantage. These differences shape both the feasibility and cost of electrification. In some areas, households reside in newer, code-compliant homes with sufficient panel, circuit, and transformer capacity, where targeted outreach and financial incentives may be sufficient to drive adoption. In others—particularly in historically disinvested communities—households face older housing stock requiring costly remediation (e.g., mold, asbestos, lead, gas leaks), often alongside constrained energy infrastructure. These overlapping barriers significantly increase the complexity and cost of electrification and require more comprehensive, place-based program approaches. Program design and delivery should therefore be tailored to the conditions and needs of the communities being served.

Scale single-measure programs in places where home and community conditions allow for straightforward adoption

Single-measure programs—such as heat pump or induction stove rebates—can be effective in contexts where homes are in good condition and energy infrastructure has sufficient capacity to support electrification without additional upgrades. In these settings, streamlined program design focused on reducing administrative burden, ensuring affordability, supporting workforce readiness, and simplifying permitting can enable rapid and cost-effective scaling. Prioritizing these programs in well-suited markets can accelerate overall adoption while preserving resources for more complex interventions in higher-need communities.

Expand place-based approaches in priority communities

Priority communities characterized by the cumulative burden of poor building and energy infrastructure, coupled with little access to credible information and limited availability of a knowledgeable workforce, could benefit from coordinated place-based strategies that address multiple challenges at once.

Prior neighborhood-level projects, such as The San Joaquin Valley (SJV) Disadvantaged Communities Pilot (Opinion dynamics, 2021; Abigail Solis, 2022; Evergreen Economics, 2022; SCE, 2023) and the Green Impact Zone (GIZ) in Kansas City (Reames, 2016), demonstrate that combined strategies that shift away from an individual self-referral approach are essential in reaching priority communities.

Place-based strategies combine several or all of the following elements:

- Deep engagement with community partners across the entire program cycle to ensure fit to participant needs and utilize existing networks for trusted messaging.
- Participant support to build awareness, motivation, capacity, and knowledge of how to use the appliances post-implementation
- Financial mechanisms to pay for readiness upgrades in older buildings.
- Workforce development to train local contractors in decarbonization skills.
- Electricity infrastructure upgrades, inclusive of panels, circuits, and transformer upgrades.
- Decommission natural gas service, avoiding future capital investment in aged gas distribution lines, which is reflected in rates.

California is currently advancing neighborhood-scale decarbonization through Senate Bill (SB) 1221 (Min, 2024), a landmark policy that shifts the strategy from individual appliance replacement to coordinated, block-level gas decommissioning. Regulated by the CPUC, the State has established over 150 priority zones to pilot up to 30 projects through 2029, targeting areas where aging gas infrastructure would otherwise require costly replacement. Our recommendations for place-based strategies build on this regulatory framework and provide guidance for how to implement this framework in priority communities.

Program Evaluation

Benefit-Cost Analysis Tests

These recommendations build on the research described in Chapter 5. Limiting cost-effectiveness analysis to energy system benefits risks understating the full value of building decarbonization programs, especially for priority populations that experience large non-energy benefits. A growing number of states now incorporate health, comfort, safety, and housing-related benefits into cost-effectiveness screening through non-energy benefit adders and explicit valuation. California's SCT and ESA Non-Energy Impacts (NEI) Study provides a foundation to move in this direction by monetizing climate, air-quality, and some health impacts for low-income programs. We recommend that the CPUC and CEC:

- Systematically incorporate monetized health, comfort, and safety non-energy benefits into the Social Cost Test (SCT) – and, where appropriate, into the Total Resource Costs (TRC) test – for programs serving priority populations, using existing ESA NEI and related studies as inputs.

- Consider piloting NEB or equity adders (for example, a higher benefit value when savings accrue to low-income households or DACs), as several other states have done, and report both “with” and “without” non-energy benefit/equity-adder results so decision makers can see how equity-relevant benefits affect cost-effectiveness.

Equity adders and monetized non-energy benefits primarily modify benefit-cost analysis by changing what is counted and how it is valued. These changes are essential in providing an accurate description of program benefits in priority communities, where there is often a need for higher upfront investment to remedy poor housing conditions, and in return, higher public health benefits when investments in energy upgrades target those who need thermal comfort, clean air, and energy affordability the most.

Equity Metrics

Standardizing reporting requirements across residential energy incentive programs can increase efficiency, reduce administrative costs associated with compliance with different reporting requirements, and ensure that the State has the data it needs to advance its equitable decarbonization goals.

Report on equity data that is routinely collected at the community level

California program administrators already collect much of the data needed to evaluate equity – for example, participant counts, measures installed, incentive amounts, and costs – but generally report them only in aggregate. To assess equity outcomes, these indicators should be consistently reported across defined priority populations at either the neighborhood or household participant scale, allowing program administrators and policy decision-makers to evaluate not only overall program activity, but also how access to services and public investments varies across groups.

We recommend that administering agencies require all major building decarbonization programs (not just equity-designated programs) to report the following equity metrics by priority populations (for example, the CalEnviroScreen disadvantaged community (DAC) designation[28]) and, where feasible, by income, renter/homeowner status, race/ethnicity, and housing type.

Inclusion

- Number of participants by population segment (for example, income band, renter/owner, DAC vs. non-DAC).
- Types of decarbonization improvements installed by population segment (for example, heat pumps, envelope upgrades, panel upgrades).
- Type and cost of housing readiness (e.g., remediation of mold/asbestos/lead/gas leaks, fixing roofs, etc.)

[28]The State could also consider using other neighborhood level analyses, for example, there are other approaches to measuring displacement which could also be adopted.

- Program completions and drop-off rates by priority population segment. They show whether households can get all the way through the process, not just enroll.
- Average time-to-completion (from initial application to final installation) by population segment. Long timelines can be a meaningful barrier for low-income renters and small landlords even when participation counts look strong.

Distribution of Program Dollars Spent

- Total and average incentive amount by population segment. This can help program designers understand the distribution of financial incentives across different population groups and structure incentives to reach an equitable distribution within priority populations.
- Share of total program incentives flowing to priority populations.

Participant Costs

- Total and average participant costs with and without incentives by population segment can help program designers understand the share of incentives out of total costs for different population segments, support financial analysis of barriers to participation, and improve incentive structure.

We recommend that program implementers collect and analyze these equity metrics at the portfolio level across all programs they oversee. Evaluating equity at the portfolio level, rather than for individual programs in isolation, recognizes that different programs are designed to serve different population segments. A portfolio-level approach therefore provides a more accurate assessment of how services and investments are distributed overall, and whether the full suite of programs collectively reaches priority populations.

Collect participant-level equity metrics

Neighborhood-based analysis can capture aggregate equity trends, but it cannot reliably identify the individuals or households reached by decarbonization programs within a census tract. To complement area-level metrics, California should standardize a common set of program participant data that all building decarbonization programs must collect at the point of implementation (with appropriate privacy protections). Standardizing these measures across programs would enable consistent, individualized assessment of who is being served by the state's decarbonization investments, rather than relying solely on program-level or place-based data.

Conduct pre-post decarbonization intervention surveys in priority communities

Point-in-time data cannot fully capture how building decarbonization programs affect households, particularly with respect to ongoing energy bill impacts, comfort, health, and other non-energy benefits. Requiring implementers to conduct standardized pre- and post-implementation surveys would allow the State to assess how costs and benefits are experienced by different households over time, and whether those experiences vary across income levels, housing types, or communities. These surveys are essential for understanding whether decarbonization programs are delivering intended benefits equitably, identifying unintended burdens, and informing program design improvements that better align incentives, supports, and outcomes for priority populations. At a minimum, surveys should be conducted one year after implementation (to cover a year of different seasons and energy needs), but longer-term follow-up surveys (e.g. at three years) are also recommended to understand impacts.

Analyze decarbonization program funding sources

Analyze the equity of funding sources to ensure the burden of providing decarbonization programs does not fall on low-income/priority populations. California's building decarbonization programs are financed through a mix of ratepayer surcharges, California Climate Investments (CCI) funds, state tax revenues, and federal grants. Different funding sources have different distributional implications: volumetric rates and fixed surcharges can be regressive, especially if gas system costs are concentrated on households that cannot electrify quickly, while CCI and broad-based tax revenues may be more progressive.

We recommend that the state periodically evaluate the distributional equity of major funding sources for building decarbonization and develop guidance on a preferred hierarchy of funding from an equity perspective. To maintain independence from program administration, this analysis should be performed by an entity such as the Legislative Analyst's Office, the California State Auditor, or a designated office within the Governor's administration charged with cross-cutting climate and equity evaluation. The analysis should:

- Compare the incidence of different funding mechanisms (for example, ratepayer surcharges, CCI proceeds, state tax revenues, federal grants) across income groups and priority populations;
- Identify funding mixes that minimize regressivity while sustaining decarbonization investment; and
- Provide guidance to the Legislature and relevant agencies on prioritizing more progressive funding sources when designing or expanding building decarbonization programs.

Options such as building-sector carbon pricing (for example, Local Law 97-style performance standards or fees) can be considered in this context, but any such mechanism would need careful design to avoid shifting costs onto low-income renters and to ensure that resulting revenues are reinvested in ways that advance equity.

Appendix A: Memorandum of Understanding

As part of the Participatory Action Research (PAR) process guiding the Equitable Housing Decarbonization project, we established a Memorandum of Understanding with the Advisory Committee members.

We discussed our motivation to participate in this research, research priorities, how participation might align with other efforts the Advisory Committee members have underway, the expectations we have for each other, how we will meet and communicate, make decisions, and how we will share information about the study. Below is a summary of the discussion.

Motivation

- Community-based organizations can benefit from increased research capacity to support their advocacy efforts for ongoing regulatory and legislative conversations.
- Policy designers and advocates can benefit from ground truthing the needs, barriers, and concerns for priority households.
- The rigor, relevance, and reach of research are enhanced by the expertise of community partners.
- Appreciation for the PAR framework and ability to build relationships across organizations.

Research Priorities

- Identifying equitable funding mechanisms.
- Developing tenant access/protections.
- Better visual map of existing programs, their eligibility criteria overlaps, their gaps, and how they measure equity.
- Create an effective frame for climate action that integrates equity goals with greenhouse gas (GHG) reduction goals.
- Learning to navigate the tension between ensuring that priority households are not overburdened with adopting climate solutions (that might not be their priority) and making sure that they are not left behind in terms of access to the benefits of decarbonization policies.
- Policy and program design should be informed by feedback and learnings from on-the-ground implementation to increase effectiveness and positive outcomes.

Alignment

- Building Energy, Equity and Power (BEEP) coalition members are currently supporting the following state efforts: California Energy Commission (CEC) equitable building decarbonization program, California Air Resources Board (CARB), and the new Southern California Edison (SCE) pilot supported by the California Public Utilities Commission (CPUC).
- Other organizations working towards equitable decarbonization: e.g., San Francisco (SF) building decarbonization demonstration projects, National - Community Climate Shift, California Environmental Justice Alliance (CEJA).

- There is concern over competing demands for decarbonization. On one hand, households are required to electrify, and on the other hand, gas and oil power plants are greater contributors to air pollution and it's unclear if/when they will be discontinued.
- There is concern over the pace of housing decarbonization. Many government plans have dedicated a considerable amount of funding to decarbonization over the next few years, but there is a lack of knowledge of how to do equitable housing decarbonization and research needs more time.

Expectations

- Create a safe space that enables all Advisory Committee members to participate by establishing norms of respect, honesty, transparency, credit-giving, and trust.
- Share information as it becomes available so it can inform community action projects.
- Create a peer network - all members of the Advisory Committee are researchers and contribute expertise.
- Transparency about the process.
- Attribution of ideas and ensuring that funding opportunities are broadly shared are critical steps to building the field.
- While we all try to avoid them, mistakes can happen. If anyone feels uncomfortable, or wants to improve the collaborative process, they will let the academic team know immediately to ensure a timely response.

Logistics

- Create a Google Drive folder and share all documents for review as links in this folder.
- To make sure everyone can come to the PAR workshop prepared, share materials in advance and offer pre-meeting briefs/calls.
- The academic team will convene the Advisory Committee in key moments of the research: (1) collaborative research design; (2) collaborative interpretation of the results; (3) collaborative knowledge dissemination.
- Most meetings will be via Zoom and under 2 hours. Once a year we will convene in person.
- Advisory Committee members will have two weeks to respond to questions/requests for feedback on this project. If more time is necessary, Advisory Committee members will notify the academic team in advance that they need additional time to review materials.

Decision Making

- If there's a red light or veto from an environmental justice (EJ) representative who works with communities, that's a stop-the-presses moment.
- We will strive to make decisions by consensus, and we will deliberate on big decisions so that everyone will have a chance to weigh in.
- In some cases, reports and/or materials may need to state that the group was unable to come to consensus. In these cases, the full range of perspectives will be shared.

Process for Developing Reports

Across all formats of knowledge sharing, we will take special care to note the level of agreement of Advisory Committee members. If there is content that an advisory member does not agree with, we will have a conversation about the disagreement and discuss ways to revise the report to reach consensus. If consensus can't be reached, we will note in the report that not all points were agreed upon by the Advisory Committee members. This clarification will provide an honest representation of diverse points of view on a complex and challenging topic.

Authorship of CARB Reports

- We are required to write the following reports as part of our CARB contract: a literature review, an interim report, and a final report.
- The main authors/preparers are the research team.
- Advisory Committee members have the opportunity to provide feedback on the draft of each of the required reports.
- All Advisory Committee members will be listed the CARB report.
- If the committee member contributes significantly to the writing of journal articles derived from the research, co-authorship can be considered and discussed.
- CARB and state agency staff will also provide feedback on the reports. If CARB or agency staff make comments that don't align with the research team's views, the requirement is to respond to all comments with reasoning/rationale as to why the report was or was not revised based on the feedback.

Authorship of Academic Papers

- Academic papers are subject to expert peer review, and authorship is subject to journal guidelines, which typically require authors to substantially contribute to the study design, protocol development, data collection, analysis, and writing of the paper.
- Research team will track papers in-progress and share drafts with the Advisory Committee.
- The Advisory Committee will be given the opportunity to provide feedback on paper drafts.
- People interested in being a co-author on a paper can reach out to the research team to discuss roles and responsibilities of co-authorship.
- Journals have requirements for authorship: https://www.elsevier.com/researcher/author/policies-and-guidelines/credit-author-statement
- All Advisory Committee members will be acknowledged in all papers.

Presentations / Conferences

- All members of the Advisory Committee and research team can present at community gatherings, conferences, and webinars.
- We will coordinate presentations and knowledge dissemination via a Google signup sheet to which Advisory Committee members can add presentations/conferences.
- We will have a repository of slide decks that anyone on the team can (re)use.

- We will acknowledge collaborative work. Presenters will credit the entire project team and CARB grant when presenting findings from this work.
- Logos of all member organizations will be included in an acknowledgment slide.

Appendix B: Interview Guide for the Statewide Analysis

Policy Makers and Program Designers

Part 1: Organization, Role, Coordination

1. Can you describe your role and responsibilities in [organization name]?

Part 2: Program Design

2. We are reaching out to you because of your [program or policy]. Could you give me a bit of background on the program?
    a. What led to the creation of the program?
    b. How does the program work?
    c. Where does your program fit within the broad spectrum of state programs designed to achieve the decarbonization goal across all sectors?
3. Can you describe the process for designing this program?
    a. What is the information that informed policy design?
    b. Who participated in making decisions about this program?
    c. What are the considerations for including community-based organizations in program design?
    d. Are the people who participated in program design involved in program implementation and evaluation?
4. What source(s) of capital does your program(s) use and need? (taxpayer funding, ratepayer funding, federal funding, private residential capital/credit)
5. Is this program coordinated with other programs in [your organization] or with other government agencies?
    a. If so – how?
    b. If not, what are the barriers for coordination? What would you suggest to overcome those barriers?
6. What is the target audience for this initiative?
    a. How was the target audience determined?
7. What does [your organization] know about the barriers for participation among the target audience?
    a. Existing conditions in the home
    b. Electricity infrastructure and rates

    c. Landlord/tenant split incentives
    d. Capacity to engage
    e. Access to credit and financing
    f. Knowledge and motivation
    g. Social factors (income, race, gender, age, immigration status, language, disability, people who use life-assisting devices)

8. What role do you see community-based organizations playing in design and implementation of EBD programs?

<u>Part 3: Program Implementation</u>

9. Can you describe how the program is implemented?
    a. Who is implementing? What are the considerations for choosing a provider?
    b. What are the considerations for contracting with community-based organizations?
    c. What is the procedure for participation?
    d. How is outreach conducted?
        i. Are there specific strategies to engage with hard-to-reach residents (undocumented immigrants, communities with limited trust in government programs)
    e. What kind of follow-ups should be designed into these programs? (Is installation the end goal of these programs?)
10. Since [your organization] first started implementing this program, did you make any changes to program design or implementation?
    a. Why?

<u>Part 4: Program Evaluation</u>

11. How does [your organization] define the success of this program?
12. What are the data and metrics that your organization collects about this program?
    a. Is there a strategy to track benefits (energy bills, costs, health) for the long term?
    b. Are non-energy benefits measured? (if so – how?, if not – why?)
13. Is the funding and staffing of this program sufficient to meet program goals?
14. Does this program have any specific goals relating to environmental justice, energy justice, or equity?
    a. How are those goals being evaluated and measured?

    b. What do you see as the key metrics to assess success for equitable building decarbonization?

15. What type of resources or system change would you need to happen in order to move to more equitable decarbonization programs?

Is there anything else you would like to share with us about this program?

Energy Providers

(In addition to questions from the program designer section)

<u>Energy Infrastructure for Electrification</u>

1. Can you describe the ability of the current energy infrastructure to support higher electricity demand due to the electrification of homes and personal vehicles?
    a. What are the barriers and opportunities?
    b. Is there a plan for upgrading neighborhood level capacity?
2. What are the equity implications of the current energy infrastructure for electrifying homes and personal vehicles?
    a. Can all customers participate in electrification?
3. Can you describe your process for evaluating equity in energy infrastructure maintenance and upgrades?
4. What changes are necessary to support equitable housing electrification?

<u>Implementation Process</u>

5. Can you describe the process for upgrading home panel capacity?
    a. What are the stages for engagement?
    b. How long does it take to provide service?
    c. What are the costs?
    d. What barriers and opportunities exist in upgrading panel capacity to support home electrification?
6. Can you describe the process for upgrading the neighborhood-level circuit capacity?
    a. What are the stages for engagement?
    b. How long does it take to provide service?
    c. What are the costs?
    d. What barriers and opportunities exist in upgrading neighborhood-level circuit capacity to support home electrification?

Is there anything else you would like to share with us?

Program Implementers

<u>Part 1: Organization, Role, Network</u>

1. Can you describe your role and responsibilities in [organization name]?
2. Which decarbonization programs is [your organization] engaged with, and in what capacity (e.g., program design, management, implementation, community outreach, evaluation)?
3. Which agencies or organizations do you work with most closely on this work (for example, state government agencies, local housing departments, NGOs, academic institutions, CBOs), and in what capacity?

<u>Part 2: Target Audience, Outreach, and Workforce</u>

4. What is your target audience?
    a. How was the target audience determined?
5. How do you conduct outreach to your target audience?
    a. What strategies have been successful? What did you find as important motivators among your target audience?
    b. Are there strategies you found ineffective?
    c. Are there specific client segments that are harder to reach? (Why)
    d. Do you conduct outreach in a language other than English?
6. What are the critical workforce needs to help [your organization] reach the target population and implement retrofits?
    a. Is there an effort to recruit people from the target population?
7. What is your recruitment strategy for new installers, electricians, and auditors?
    a. What are the qualifications you are looking for in installers and auditors (certification, experience, etc.)?
8. Does [your organization] provide workforce training?
    a. If yes:
        i. What is included in the training? (technical capabilities, marketing, education)
        ii. Which components are readings and which are “hands-on”?
        iii. Do you provide certification for installers?

<u>Part 3: Procedures + Coordination</u>

9. Talk me through how a client works with you, from outreach to implementation?

10. What are the stages of engagement? (forms, energy audit, financial planning)
    a. How long does it take from initial engagement to program completion?
    b. Which aspects take the longest? (why?)
    c. Do you have a process for quality assurance?
11. Among those who reached out to receive service, how many end up receiving service?
    a. At what steps in the process are potential clients likely to disengage? (why)
12. Have you made any changes to your process? (Why?)
13. Do you coordinate funding and services across different programs?
    a. Why?
    b. What are the benefits?
    c. What are the challenges?
14. Does [your organization] provide education to your clients before, during, or after implementation?
    a. If yes - How is education provided to the consumer? (pamphlet left on the property, hands-on, etc.)
    b. Do you have a process to ensure customers understand how to use the new appliances after installation?
    c. Do you provide education in a language other than English?
15. What are the main barriers to participation that you experience when trying to engage with or provide services and programming to your target population?
    a. How does [your organization] work to address or overcome these barriers to participation actively?
16. Have you been able to do a whole home retrofit for low-income residents? If yes, what has enabled you to do that, and if not, what were the barriers?

<u>Part 4: Evaluation</u>

17. How does [your organization] define a successful project?
18. What are the metrics that your organization collects about each project?
19. What recommendations do you have for program designers to overcome barriers to implementation?

Is there anything else you would like to share with us?

Community Based & Advocacy Organizations

Part 1: Role, Organization, Mission

1. Can you describe your role and responsibilities in [organization name]?
2. How do housing decarbonization activities fit within other activities led by [your organization]?

Part 2: About the Community

3. What prompted [your organization's] interest in housing decarbonization, housing repair, or healthy housing?
4. [Ask only CBOs] How would you describe the level of interest in your community for engagement with housing decarbonization, housing repair, or healthy housing?
    - How do they learn about it?
    - What would motivate people?
    - What is a concern?
5. What are the most critical housing decarbonization programs among the people served by your organization?
    - In what ways are local and state/federal programs similar, and in what ways are they different?

Part 3: Actions

6. How does [organization name] promote housing decarbonization, housing repair, or healthy housing? (i.e. education, outreach, technical assistance, organizing, policy advocacy, litigation, implementation of actual decarbonization and/or electrification initiatives, etc.)
    - What are the issues [your organization] is responding to?
    - [Ask only CBOs] How do people in your community respond to these actions?
    - What works well?
    - What are the challenges you encounter?

7. Which agencies or organizations do you work with most closely on this work (for example, state government agencies, local housing departments, energy providers, NGOs, academic institutions, CBOs), and in what capacity?
    - What is the process for engagement?
    - Do you feel like your contributions are respected and addressed?
    - Do you get compensation for your contribution?
    - What is the outcome of engagement?
8. Is your organization engaged with policy/program advocacy?
    - Who are your policy allies (local, regional, statewide)?
        - Who do you trust, don't trust? And why?
    - Who do you wish were more involved in policy and program design? Why aren't they able to be involved?

9. Who are the implementers that you see as allies in equitable decarb efforts? What is it that they do differently?
10. What recommendations do you have for program designers to overcome barriers to implementation?

Is there anything else you would like to share with us?

Appendix C: Homeowner Interview Guide

We are interested in better understanding the factors you considered in making decisions about home energy upgrades.

1. When did you move into your house? How old is the house? Conditions of the house?

2. What motivated you to consider home energy upgrades?
    a. What are your households needs? Priorities? With regards to making energy-related changes in the home?

3. Why have you reached out to this specific program?
    a. Have you also contacted other programs?

4. Can you describe the process of engagement with this program?
    a. Did you understand the process?
    b. Was it easy to ask questions and get in touch with the program administrator?
    c. Were there any red flags?
    d. Do you feel like you can trust this implementer? Why?

5. What information did the project administrator provide you with?
    a. Energy status of the home?
    b. Health impacts?
    c. Financial impacts?
    d. Financial planning?

6. Considering your households needs, what did you prioritize in making a decision about home energy upgrades?
    a. What factors affected your prioritization?

7. Thinking about your engagement with this program:
    a. What were the greatest obstacles to deciding to implement a project?
    b. What were the greatest strengths of this program?

8. Is there anything else you would like to share with us about your experience with this program?

Appendix D: Summary of Recommendations – Statewide Analysis

Table 233: Summary of Recommendations from Statewide Analysis

Domain	**Challenge** in priority communities	**Recommendations** for priority communities
Governance: coordination	Fragmentation and misalignment across programs	• Establish a dedicated interagency working group to coordinate program design (including eligibility criteria and measures), implementation strategy, data sharing, and evaluation.
Governance: coordination	Lack of coordination between programs for home retrofits across sectors exacerbates funding constraints for health and safety upgrades	• Improve coordination between the housing and health sectors. Coordination with the housing sector—such as creating a seamless pipeline from home repair to decarbonization—or with the health care sector—such as referring asthma patients to decarbonization programs—are proven successful models.
Governance: coordination	Administrative burden and higher costs for reporting compliance	• Standardize reporting requirements across programs to reduce administrative burden, increase coordination, and efficiency.
Governance: deep engagement	Mismatch between decarbonization programs and on-the-ground needs	• Form a Community Advisory Board to guide program design, implementation, and evaluation.
Governance: deep engagement	Limited awareness, trust, and capacity	• Contract with community-based organizations (CBOs) that are trusted in the target community to support all stages of the decarbonization program (design, implementation, evaluation).
Governance: deep engagement	Lack of sufficient funding to CBOs	• Fund CBOs as consultants/vendors to support all stages of the program. • Provide adequate compensation for ongoing consultation instead of solely for a specific task such as outreach. • In areas with active CBOs that lack energy expertise, provide capacity-building funds and training on decarbonization programs.

Domain	**Challenge** in priority communities	**Recommendations** for priority communities
Governance: local permitting	The fragmentation of permit requirements across jurisdictions creates an unpredictable landscape, compounded by inconsistent knowledge of local governments' staff with decarbonization technologies. The challenge in obtaining permits leads to costly delays and inappropriate rejections.	• Provide standard, statewide guidelines for local building departments on new electrification technologies to provide clarity on health and safety requirements, reduce confusion, and streamline permitting. This can involve written guidelines, training for inspectors, and models for simplified online forms for same-day approvals. • Offer training programs for building department staff. Regular education initiatives should focus on the unique characteristics and safety considerations of heat pumps, induction stoves, electric vehicle charging systems, and other emerging technologies to ensure appropriate and consistent review processes.
Learning	Less access to informational resources about decarbonization programs, and marketing often doesn't relate to their priorities	• Contract with local trusted messengers such as CBOs, ensure language access across the entire process, and highlight program impacts that are of interest to priority communities, such as improved thermal comfort, indoor air quality, and health.
Capacity: participant support	Limited time, technical knowledge, and capacity to engage	• Dedicate funds for participant support in priority communities. • Include support in the following aspects: build awareness, motivation, and capacity, and provide post-retrofit education • Create support models within local governments (e.g., local resource centers) and implementers (e.g., energy navigator role).
Capacity: ownership structure and housing type	Utility allowances can prevent decarbonization	• Plan utility allowances in affordable housing to support owners' financial ability to undertake decarbonization.
Capacity: ownership structure and housing type	Tenants face risks of increased rents and eviction	• Adopt tenant protections in housing decarbonization programs impacting renters and clarify their enforcement.

Domain	**Challenge** in priority communities	**Recommendations** for priority communities
Capacity: ownership structure and housing type	Multi-family buildings face physical constraints and regulatory challenges in distributing solar benefits equally	• The California Public Utilities Commission (CPUC) should ensure residents of multi-family buildings can enjoy solar benefits equally through a regulation that enables Virtual Net Metering (VNEM) and addresses the imbalance between buying and selling rates.
Capacity: ownership structure and housing type	Regulation challenges for community solar	• The CPUC should ensure community solar is viable in priority communities.
Capacity: ownership structure and housing type	Mobile and manufactured home communities face unique housing and energy conditions that hinder decarbonization	• The California Energy Commission (CEC) and CPUC should establish dedicated decarbonization programs for mobile and manufactured homes.
Capacity: ownership structure and housing type	Homeowners Associations (HOAs) can delay or block decarbonization projects	• Local governments should provide information and technical assistance to HOAs to encourage electrification.
Capacity: workforce	Trade schools typically don't teach the specialized skills required for weatherization and electrification work	• The interagency working group should coordinate strategies to make it easier to acquire decarbonization skills by investing in workforce development. There is a need to create public training programs for decarbonization.
Capacity: workforce	Fragmentation of certification programs	• The interagency working group should coordinate the streamlining of certifications for housing decarbonization. Create one standard housing decarbonization certificate or consolidate housing decarbonization certification by integrating lead and asbestos remediation training and certification into the same agency that certifies other construction programs.

Domain	**Challenge** in priority communities	**Recommendations** for priority communities
Capacity: workforce	Entry barriers for small businesses	• Program designers should establish multi-year program commitments (3-5 years) to provide contractors with reliable business prospects that justify investments in specialized training and equipment. • Address financial barriers for small businesses. Creating a bridging capital program can help small contractors access capital to implement projects before receiving reimbursements. • Prioritize small-scale contractors in program implementation. • Create a contractor network to ease market access. Address capacity barriers: business operations, administrative burden, and technical knowledge.
Capacity: workforce	Low wages and job insecurity	• Convene a task force of CBOs and small contractors to study wages in the decarbonization sector.
Buildings and neighborhoods	Programs often don't fund critical prerequisites, such as health and safety upgrades, effectively disqualifying the households most in need of assistance.	• Program designers should integrate retrofit needs into decarbonization programs in priority communities through either coordination with health/housing programs or direct provision of these services. Allocate adequate funding for retrofit needs such as lead/asbestos/mold abatement, electrical system and wiring upgrades, and roof replacement.
Buildings and neighborhoods	Inadequate electricity infrastructure hinders electrification due to high upfront costs and very slow times to upgrade electrical panels, transformers, or to connect solar to the grid.	• The CEC and CPUC should establish transparency about grid capacity through mandatory, public-facing reporting on granular electric grid capacity to identify infrastructure gaps in priority communities.

Domain	**Challenge** in priority communities	**Recommendations** for priority communities
Buildings and neighborhoods	Inadequate electricity infrastructure hinders electrification due to high upfront costs and very slow times to upgrade electrical panels, transformers, or to connect solar to the grid.	• The CPUC should mandate that utilities proactively invest in energy infrastructure in priority communities, including faster panel capacity, transformer upgrades, and solar connections to the grid, ahead of anticipated demand.
Buildings and neighborhoods	Inadequate electricity infrastructure hinders electrification due to high upfront costs and very slow times to upgrade electrical panels, transformers, or to connect solar to the grid.	• The CPUC should optimize regulatory oversight on energy infrastructure upgrades to provide faster panel capacity, transformer upgrades, and solar connections to the grid.
Affordability: eligibility criteria	Fragmented and inconsistent eligibility criteria across federal, state, and local levels lead to widespread confusion among recipients and administrators alike, increase administrative burdens, and complicate the ability to "stack" funding from complementary programs.	Inclusion: • The interagency working group should provide guidance on inclusion criteria and track alignment/coordination among programs. • Policymakers and implementers should coordinate the eligibility criteria across programs at the regional level. • Program administrators should track and report enrollment by eligibility criteria and use those data to refine program design.

Domain	**Challenge** in priority communities	**Recommendations** for priority communities
Affordability: eligibility criteria	Fragmented and inconsistent eligibility criteria across federal, state, and local levels lead to widespread confusion among recipients and administrators alike, increase administrative burdens, and complicate the ability to "stack" funding from complementary programs.	Verification: • Program designers should use categorical eligibility for low-income households, automatically qualifying households already enrolled in other means-tested programs. • Program designers should introduce more flexible income and geographic verification processes to reach underserved populations more effectively. • Program designers could consider self-eligibility declarations.
Affordability: incentive structure	Most programs rely on tax credits or rebates that require upfront capital, which most low- and moderate-income households do not have, while fully funded direct-install options operate at a scale far too small to meet demand.	• Combine measures to reach bill neutrality or bill savings (e.g., electrification needs to be combined with efficiency, clean energy measures, or electrification rates). Some bill increases should be tolerated when providing new air conditioning. • Address panel capacity limitations. Educate workforce on low-capacity planning and fully fund upgrades where needed
Affordability: incentive structure	Most programs rely on tax credits or rebates that require upfront capital, which most low- and moderate-income households do not have, while fully funded direct-install options operate at a scale far too small to meet demand.	• The interagency working group should conduct a study on how to expand access to green financing mechanisms such as Go-Green financing and Inclusive Utility Investment (IUI) programs.
Affordability: scope and efficient delivery	Electrification alone can lead to a bill increase	• Program designers should combine measures to reach bill neutrality or bill savings.

Domain	**Challenge** in priority communities	**Recommendations** for priority communities
Affordability: scope and efficient delivery	Priority communities are more likely to suffer from the compounding burden of both poor housing conditions and inadequate energy infrastructure	• Program designers should adopt place-based strategies that combine program outreach, workforce training, infrastructure improvements, and community development within a specific geographic area to improve efficiency and reduce costs.
Affordability: scope and efficient delivery	Priority communities are more likely to suffer from the compounding burden of both poor housing conditions and inadequate energy infrastructure	• The CPUC and CEC should coordinate panel capacity and circuit capacity programs with local electrification programs to ensure projects align with the capacity of the energy infrastructure.
Affordability: energy rates	High electricity rates relative to natural gas hinder the ability of electrification to be cost effective	• Program implementers should help participants enroll in bill assistance programs as part of program intake.

Appendix E: State Agencies with a Role in Building Decarbonization

Our analysis identified the following state agencies as directly impacting housing decarbonization. This list is provided to assist in an initial identification of agencies to consider for the recommended interagency working group. It is not prescriptive and should be expanded as needed to include other relevant entities such as local governments.

- The **California Air Resources Board (CARB)** influences decarbonization through its clean air regulations, which shape how energy is produced and consumed by end users.
- **The California Energy Commission (CEC)** oversees electrical demand forecasts and designs and evaluates programs for clean energy and decarbonization, including electrification, efficiency, demand response, load management, and PV-distributed generation. The CEC also establishes building energy efficiency standards, appliance efficiency standards, flexible demand appliance standards, and load management standards, and funds research on building decarbonization.
- **The California Public Utilities Commission (CPUC)** regulates energy rates and utility-mandated energy efficiency and electrification programs.
- **The California Housing and Homeless Agency (CHHA)** oversees housing funding programs and participates in building code development. This new agency now includes the Housing and Community Development department.
- **The California Department of Community Services and Development (CCSD)** implements state and federal programs to retrofit homes and provide energy bill assistance.
- **The California Department of Public Health (CDPH)** advises other agencies (e.g., CEC, CARB) on how to integrate public health into their programs, trains and certifies professionals for lead remediation, and administers lead abatement programs.
- **The California Workforce Development Board** (CWDB) administers workforce development programs such as High Road Training Partnerships (HRTP) and High Road Construction Careers (HRCC).
- **The California Department of Public Affairs**, through the Contractors State Licensing Board (CSLB) certifies contractors to do construction and decarbonization projects.
- **The California Department of Industrial Relations (CDIR)** certifies contractors to remediate asbestos and other hazardous materials (excluding lead).
- **The California Treasurer's Office** funds housing decarbonization and financing programs.
- **The California Environmental Protection Agency through the Office of Environmental Health Hazard Assessment (Cal-EPA OEHHA)** is responsible for identifying disadvantaged communities that should be prioritized for decarbonization programs.

Table 24 summarizes areas of overlap between different government agencies across different decarbonization responsibilities.

TABLE 24: STATE AGENCY ROLES IN BUILDING DECARBONIZATION

	Program Design & Evaluation	Habitability: Health & Safety	Building & Appliance Standards	Energy Rates & Infrastructure	Workforce, Licenses & Certifications
CARB			X		
CEC	X		X		
CPUC	X			X	X
CHHA		X	X		X
CCSD	X	X			
CDPH		X			X
CWDB, CSLB, CDIR					X

Appendix F: References

ACEEE. (2024). Summer Study on Energy Efficiency in Buildings. Retrieved from: https://www.aceee.org/summer-study-2024-proceeding

Arcaya, M.C. et al. (2018) “Community change and resident needs: Designing a Participatory Action Research study in Metropolitan Boston,” Health & Place, 52, pp. 221–230. Available at: https://doi.org/10.1016/j.healthplace.2018.05.014.

Al-Radaideh, A., Martinez, A., & Verdaguer, B. (2025). Understanding the challenges and barriers of decarbonization instruments: An approach for the building sector. IOP Conference Series: Earth and Environmental Science, 1568, 012032. https://doi.org/10.1088/1755-1315/1568/1/012032

Armstrong, S., Stone, N., & Dryden, A. (2022). The impact of the California Utility Allowance Calculator and the benefits of standardization within California Title 24 software. 2050 Partners and Southern California Edison. Retrieved from: https://calbem.ibpsa.us/wp-content/uploads/2022/07/CUAC-Whitepaper-Final-Draft-4-28-22.pdf

Balazs, C.L. and Morello-Frosch, R. (2013) “The Three Rs: How Community-Based Participatory Research Strengthens the Rigor, Relevance, and Reach of Science,” Environmental Justice, 6(1), pp. 9–16. Available at: https://doi.org/10.1089/env.2012.0017.

Bednar, D. J., & Reames, T. G. (2020). Recognition of and response to energy poverty in the United States. *Nature Energy*, 5(6), 432–439. https://doi.org/10.1038/s41560-020-0582-0

Borenstein, S., Fowlie, M. and Sallee, J. (2023) Designing Electricity Rates for An Equitable Energy Transition. Next 10 and the Energy Institute at UC Berkeley’s Haas School of Business. Available at: https://www.next10.org/publications/electricity-rates.

Borenstein, S., Bushnell, J., & Mansur, E. (2023). The economics of electricity reliability. *Journal of Economic Perspectives,* 37(4), 181–206. https://doi.org/10.1257/jep.37.4.181

Brockway, A.M., Conde, J. and Callaway, D. (2021) “Inequitable access to distributed energy resources due to grid infrastructure limits in California,” Nature Energy, 6(9), pp. 892–903. Available at: https://doi.org/10.1038/s41560-021-00887-6.

Brown, A.F. et al. (2019) “Structural Interventions to Reduce and Eliminate Health Disparities,” American Journal of Public Health, 109(S1), pp. S72–S78. Available at: https://doi.org/10.2105/AJPH.2018.304844.

Buonocore, J. J., Luckow, P., Norris, G., Spengler, J. D., Biewald, B., Fisher, J., & Levy, J. I. (2016). Health and climate benefits of different energy-efficiency and renewable energy choices. *Nature Climate Change*, 6(1), 100–105. https://doi.org/10.1038/nclimate2771

California State Auditor. (2025). The California Public Utilities Commission (Report No. 2023-127). Retrieved from: https://www.auditor.ca.gov/reports/2023-127

CAEATFA. (2024). 2023 Annual Report to the California State Legislature. California Alternative Energy and Advanced Transportation Financing Authority. Retrieved from: https://www.treasurer.ca.gov/caeatfa/annual/2023.pdf

California Climate Investments. (2024). 2024 Annual Report to the Legislature on California Climate Investments using Cap-and-Trade auction proceeds. California Air Resources Board. Retrieved from: https://ww2.arb.ca.gov/sites/default/files/auction-proceeds/cci_annual_report_2024.pdf

California Department of Justice. (2017). Climate change's unequal impacts. State of California, Office of the Attorney General. Retrieved from: https://oag.ca.gov/environment/climate-change/unequal-impacts

Campbell, A., Lamm, T., & Hoff, K. (2023). The future of California consumer energy finance. Center for Law, Energy, & the Environment. Retrieved from: https://www.law.berkeley.edu/wp-content/uploads/2023/06/Future-of-CA-Consumer-Energy-Finance.pdf

CARB. (2022a). Equitable building decarbonization. https://ww2.arb.ca.gov/sites/default/files/2022-03/BEEP%20Letter%20and%20Report_Equitable%20Decarb%20March%202022.pdf

CARB. (2022b). 2022 scoping plan for achieving carbon neutrality. https://ww2.arb.ca.gov/sites/default/files/2023-04/2022-sp.pdf

Carley, S., & Konisky, D. M. (2020). The justice and equity implications of the clean energy transition. *Nature Energy*, 5(8), 569–577. https://doi.org/10.1038/s41560-020-0641-6

Carr, M. F., & Boyd Kramer, D. (2022). Homeowners' associations: Barriers or bridges to more sustainable residential development? *Landscape and Urban Planning*, 224, 104419. https://doi.org/10.1016/j.landurbplan.2022.104419

CEC. (2024). Assembly Bill 209 clean energy programs—2024 Annual Report. Retrieved from: https://www.energy.ca.gov/publications/2025/assembly-bill-209-clean-energy-programs-2024-annual-report

Kirk, C. (2021). Los Angeles building decarbonization: Tenant impact and recommendations. Strategic Actions for a Just Economy. Retrieved from: https://www.saje.net/resources/reports/building-decarbonization/

CPUC. (2025). Decision 25-11-009: Establishing an electrification initiative for mobile home parks. Retrieved from: https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M588/K329/588329387.PDF

CPUC ACC. (2024). Updated 2024 Avoided Cost Calculator (ACC) Documentation (Version 1b). Retrieved from: https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/documents/demand-side-management/acc-models-latest-version/updated-2024-acc-documentation-v1b.pdf

CPUC SCT. (2024). Societal Cost Test Documentation [PDF]. Retrieved from: https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M535/K822/535822173.PDF

CPUC. (2023). Decision 23-06-055 authorizing energy efficiency portfolios for 2024–2027 and business plans for 2024–2031. Retrieved from: https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M512/K907/512907396.docx

CPUC. (2022). Decision 22-09-026: Decision building decarbonization phase II. California Public Utilities Commission. Retrieved from: https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M497/K247/497247754.PDF

CPUC. (2009). Adopting cost-benefit methodology for distributed generation. Retrieved from: https://docs.cpuc.ca.gov/published/FINAL_DECISION/105926-03.htm

CPUC. (2010). California Standard Practice Manual: Economic Analysis of Demand-Side Programs and Projects. In *Sustainable Communities Design Handbook* (pp. 277–312). Elsevier. https://doi.org/10.1016/B978-1-85617-804-4.00018-5

Farrell, D., Mah, J., Sussman, R., & Specian, M. (2025). Estimating the impacts of weatherization readiness programs. American Council for an Energy-Efficient Economy. Retrieved from: https://www.aceee.org/research-report/b2504

Daouda, M. et al. (2024) "Out of Gas, In with Justice: Findings from a gas-to-induction pilot in low-income housing in NYC," Energy Research & Social Science, 116, p. 103662. Available at: https://doi.org/10.1016/j.erss.2024.103662.

DOE. (2024). Decarbonizing the U.S. economy by 2050: A national blueprint for the buildings sector. U.S. Department of Energy. Retrieved from: https://www.energy.gov/eere/decarbonizing-us-economy-2050-national-blueprint-building-sector

Dolfie, D., Quiroz, P., Lemei, E., & Czworniak, B. (2026). Energy efficiency in California's public power sector. California Municipal Utilities Association, Northern California Power Agency, & Southern California Public Power Authority. Retrieved from: https://ncpapwr.sharepoint.com/sites/publicdocs/Compliance/2026%20POU%20Energy%20Efficiency%20Report.pdf

Dunsky Energy + Climate Advisors. (2024). Joint tariff on-bill proposal assessment. California Public Utilities Commission. Retrieved from: https://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M562/K975/562975610.PDF

E3. (2020). The challenge of retail gas in California's low-carbon future: Technology options, customer costs, and public health benefits of reducing natural gas use (Publication No. CEC-500-2019-055). California Energy Commission. Retrieved from: https://www.energy.ca.gov/sites/default/files/2021-06/CEC-500-2019-055-F.pdf

E3. (2022). E3 undertakes analysis of targeted decommissioning of natural gas infrastructure in California. Retrieved from: https://www.ethree.com/e3-undertakes-analysis-of-targeted-decommissioning-of-natural-gas-infrastructure-in-california/

E3. (2024). ACC for DER. Retrieved from: https://www.ethree.com/public_proceedings/energy-efficiency-calculator/

EIA (2023) U.S. energy insecure households were billed more for energy than other households. Washington, DC, USA: U.S. Energy Information Administration. Available at: https://www.eia.gov/todayinenergy/detail.php?id=56640 (Accessed: June 19, 2023).

EIA (2025) "Residential Energy Consumption Survey (RECS)." Washington DC: U.S. Energy Information Administration. Available at: https://www.eia.gov/consumption/residential/about.php (Accessed: March 18, 2026).

EPRI. (2019). The total value test: A framework for evaluating the cost effectiveness of efficient electrification. Retrieved from: https://www.epri.com/research/products/000000003002017017

Evergreen Economics. (2022). SJV DAC pilot projects process evaluation. California Public Utilities Commission. Retrieved from: https://www.calmac.org/publications/SJV_DAC_Process_Evaluation_Final_Report_102022.pdf

Evergreen Economics. (2025). Energy Savings Assistance Program non-energy impacts study. Prepared for Southern California Edison. California Measurement Advisory Council (CALMAC). Retrieved from: https://www.calmac.org/publications/2025_ESA_Non-Energy_Impacts_Study_-Final_Report-_SCE0498.01.pdf

Ferguson, J., Bickel, S., Lachman, H., Cillo, P., & Hummel, H. (2022). Pay as you save system of inclusive utility investment for building efficiency upgrades: Reported and evaluated field experience in the United States. Retrieved from: https://drive.google.com/file/d/1PQyY8-ltjLjqiLThOcUF9tdfSjCxnUqB/view

Forrester, S. P., & Reames, T. G. (2020). Understanding the residential energy efficiency financing coverage gap and market potential. *Applied Energy*, 260, 114307. https://doi.org/10.1016/j.apenergy.2019.114307

Fournier, E. D., Cudd, R., Smithies, S., & Pincetl, S. (2024). Quantifying the electric service panel capacities of California's residential buildings. *Energy Policy*, 192, 114238. https://doi.org/10.1016/j.enpol.2024.114238

Frosch, R. M., Pastor, M., Sadd, J., & Shonkoff, S. (2018). The climate gap: Inequalities in how climate change hurts Americans and how to close the gap. In *Planning for climate change: A reader in green infrastructure and sustainable design for resilient cities* (pp. 138–150).

Gatto, A. (2022). The energy futures we want: A research and policy agenda for energy transitions. *Energy Research & Social Science*, 89, 102639. https://doi.org/10.1016/j.erss.2022.102639

Gillingham, K.T. et al. (2021) "The climate and health benefits from intensive building energy efficiency improvements," Science Advances, 7(34), p. eabg0947. Available at: https://doi.org/10.1126/sciadv.abg0947.

Gillingham, K., Rapson, D., & Wagner, G. (2015). The rebound effect and energy efficiency policy (FEEM Working Paper No. 107.2014). Fondazione Eni Enrico Mattei. Retrieved from: https://doi.org/10.2139/ssrn.2550710

González, D. J. X., Morton, C. M., Hill, L. A. L., Michanowicz, D. R., Rossi, R. J., Shonkoff, S. B. C., Casey, J. A., & Morello-Frosch, R. (2023). Temporal trends of racial and socioeconomic disparities in population exposures to upstream oil and gas development in California. *GeoHealth*, 7(3), e2022GH000690. https://doi.org/10.1029/2022GH000690

Green & Healthy Homes Initiative (2023) Integrating Health-Related Services into Electrification Upgrades: Feasibility Study for BlocPower. Green & Healthy Homes Initiative. Available at: https://live-blocpower-api.pantheonsite.io/wp-content/uploads/2024/01/GHHI_Feasibility_Study_BlocPower_June_2023.pdf (Accessed: June 4, 2024).

Guo, S., & Kontou, E. (2021). Disparities and equity issues in electric vehicles rebate allocation. *Energy Policy*, 154, 112291. https://doi.org/10.1016/j.enpol.2021.112291

Harris, P.A. et al. (2009) "Research electronic data capture (REDCap)—A metadata-driven methodology and workflow process for providing translational research informatics support," Journal of Biomedical Informatics, 42(2), pp. 377–381. Available at: https://doi.org/10.1016/j.jbi.2008.08.010.

Harris, P.A. et al. (2019) "The REDCap consortium: Building an international community of software platform partners," Journal of Biomedical Informatics, 95, p. 103208. Available at: https://doi.org/10.1016/j.jbi.2019.103208.

Hernández, D. (2016) "Understanding 'energy insecurity' and why it matters to health," Social Science & Medicine, 167, pp. 1–10. Available at: https://doi.org/10.1016/j.socscimed.2016.08.029.

Hernández, D., & Bird, S. (2010). Energy burden and the need for integrated low-income housing and energy policy. *Poverty & Public Policy*, 2(4), 5–25. https://doi.org/10.2202/1944-2858.1095

Hernández, D. and Laird, J. (2025) Powerless: The People's Struggle for Energy. New York: Russell Sage Foundation. Available at: https://www.russellsage.org/publications/powerless

Hernández, D., Phillips, D., & Siegel, E. L. (2016). Exploring the housing and household energy pathways to stress: A mixed methods study. International Journal of Environmental Research and Public Health, 13(9), 916. https://doi.org/10.3390/ijerph13090916

Jesdale, B. M., Morello-Frosch, R., & Cushing, L. (2013). The racial/ethnic distribution of heat risk–related land cover in relation to residential segregation. *Environmental Health Perspectives*, 121(7), 811–817. https://doi.org/10.1289/ehp.1205919

Jessel, S., Sawyer, S. and Hernández, D. (2019) "Energy, Poverty, and Health in Climate Change: A Comprehensive Review of an Emerging Literature," Frontiers in Public Health, 7. Available at: https://www.frontiersin.org/article/10.3389/fpubh.2019.00357 (Accessed: April 15, 2022).

Ju, Y., Cushing, L. J., & Morello-Frosch, R. (2020). An equity analysis of clean vehicle rebate programs in California. *Climatic Change*, 162(4), 2087–2105.

Kirk, C. (2023). Decarbonizing California equitably: A guide to tenant protections in building upgrades/retrofits throughout the state. Strategic Actions for a Just Economy. Retrieved from: https://www.saje.net/wp-content/uploads/2023/09/Decarbonizing-California-Equitably-Report-1.pdf

Kirk, C., Carpenter-Gold, D., & Hut, G. (2025). Tenants at the center: An equitable path to building decarbonization. Strategic Actions for a Just Economy; Public Health Law Center at Mitchell Hamline School of Law. Retrieved from: https://www.saje.net/wp-content/uploads/2025/03/Tenants-at-the-Center-Equitable-Decarbonization-Report-2025.pdf

Kresowik, M., Subramanian, S., Specian, M., Bradley-Wright, F., Ghosh, D., Mooney, P., Fraser, A., Sosa-Kalter, S., Fadie, B., & Mauer, J. (2025). The 2025 State Energy Efficiency Scorecard. American Council for an Energy-Efficient Economy. Retrieved from: https://www.aceee.org/research-report/u2502

Kushler, M., York, D., & Witte, P. (2005). Examining the potential for energy efficiency to help address the natural gas crisis in the Midwest (Report No. U051). American Council for an Energy-Efficient Economy.

LAANE. (2016). Advancing equity in California climate policy. Retrieved from: https://drive.google.com/file/d/1ChyCagl4LHqm7ubz4jISaRc1u45y8XJO/view

Langevin, J., Satre-Meloy, A., Satchwell, A. J., Hledik, R., Olszewski, J., Peters, K., & Chandra-Putra, H. (2023). Demand-side solutions in the US building sector could achieve deep emissions reductions and avoid over $100 billion in power sector costs. *One Earth*, 6(8), 1005–1031. https://doi.org/10.1016/j.oneear.2023.07.008

Legislative Analyst's Office. (2022a). Climate change impacts across California: Crosscutting issues. Retrieved from: https://lao.ca.gov/Publications/Report/4575

Legislative Analyst's Office. (2022b). Climate change impacts across California: Housing. Retrieved from: https://lao.ca.gov/Publications/Report/4584

Energy Efficiency Institute. (2022). 2022 PAYS status update. Retrieved from: https://www.eeivt.com/wp-content/uploads/2022/03/2022-PAYS-Status-Update_3_29_22.pdf

Maglicic, M., & Vasconcelos, V. V. (2025). Income inequality in the uptake of environmentally friendly products. *iScience*, 28(4), 112277. https://doi.org/10.1016/j.isci.2025.112277

Mailloux, N. A., Abel, D. W., Holloway, T., & Patz, J. A. (2022). Nationwide and regional PM2.5-related air quality health benefits from the removal of energy-related emissions in the United States. *GeoHealth*, 6(5), e2022GH000603. https://doi.org/10.1029/2022GH000603

McKinny, J., Williams, M., Smith, C., Rasool, H., & Bohan, D. (2024). Zero-emission vehicle workforce training and development strategy: A roadmap for clean transportation program funding. California Energy Commission. Retrieved from:

https://www.energy.ca.gov/publications/2024/zero-emission-vehicle-workforce-training-and-development-strategy-roadmap-clean

Min, D. (2024). SB-1221: Gas corporations: Ceasing service: Priority neighborhood decarbonization zones. California Legislature. Retrieved from: https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=202320240SB1221

Miller et al. (2019) Equitable Building Electrification: A Framework for Powering Resilient Communities. California: Greenlining and Energy Efficiency for All. Available at: https://greenlining.org/publications/reports/2019/equitable-building-electrification-a-framework-for-powering-resilient-communities/ (Accessed: August 17, 2022).

Morello-Frosch, R., Caballero-Gomez, H., Shankar, M., & Cushing, L. J. (2025). Forging just futures: A path from climate crisis to climate solutions. *Annual Review of Public Health*. https://doi.org/10.1146/annurev-publhealth-071723-040657

New York State Climate Justice Working Group. (2023). Disadvantaged Communities Criteria. New York State. Retrieved from: https://climate.ny.gov/Resources/Disadvantaged-Communities-Criteria

Norton, R.A. and Brown, B.W. (2014) “Green & Healthy Homes Initiative: Improving Health, Economic, and Social Outcomes Through Integrated Housing Intervention,” Environmental Justice, 7(6), pp. 151–157. Available at: https://doi.org/10.1089/env.2014.0033.

NSPM. (2017). National standard practice manual for assessing cost-effectiveness of energy efficiency resources. National Efficiency Screening Project. Retrieved from: https://nationalefficiencyscreening.org/wp-content/uploads/2017/05/NSPM_May-2017_final.pdf

OEHHA. (2021). CalEnviroScreen 4.0. California Environmental Protection Agency, Office of Environmental Health Hazard Assessment. Retrieved from: https://oehha.ca.gov/calenviroscreen/report/calenviroscreen-40

Opinion Dynamics. (2021). SJV DAC data gathering plan findings report. California Public Utilities Commission. Retrieved from: https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/documents/infrastructure/disadvantaged-communities/sjv_dac_data-gathering_findings-report_vol1_final.pdf

Pigman, M., Deason, J., & Murphy, S. (2021). Who is participating in residential energy efficiency programs? Exploring demographic and other household characteristics of participants in utility customer-funded energy efficiency programs. Lawrence Berkeley National Laboratory. Retrieved from: https://doi.org/10.2172/1831426

Reames, T. G. (2016). A community-based approach to low-income residential energy efficiency participation barriers. *Local Environment*, 21(12), 1449–1466. https://doi.org/10.1080/13549839.2015.1136995

Ryan, L. and Campbell, N. (2012) Spreading the Net: The Multiple Benefits of Energy Efficiency Improvements. Paris: OECD. Available at: https://doi.org/10.1787/5k9crzjbpkkc-en.

SCE. (2023). Southern California Edison's San Joaquin Valley pilots quarterly progress report. Retrieved from: https://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M507/K387/507387423.PDF

Siegel, E.L. et al. (2024) "Energy Insecurity Indicators Associated with Increased Odds of Respiratory, Mental Health, And Cardiovascular Conditions," *Health Affairs*, 43(2), pp. 260–268. Available at: https://doi.org/10.1377/hlthaff.2023.01052.

SGC. (2024). Council Priority 3 on housing, climate, and equity: 2024 progress report. Strategic Growth Council. Retrieved from: https://sgc.ca.gov/wp-content/uploads/20240626-6_AttachmentA_Priority_3_Progress_Report.pdf

Skinner, N. (2023). SB X1-2: Energy: Transportation fuels: Supply and pricing: Maximum gross gasoline refining margin. California Legislature. https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=202320241SB2

Solis, A. (2022). Heat pump programs and implementation: San Joaquin Valley disadvantaged communities pilot projects. Self-Help Enterprises.

Solis et al. (2022) Preliminary Report: Community Priorities for Equitable Building Decarbonization. California: Building Energy, Equity, and Power (BEEP) Coalition. Available at: https://ww2.arb.ca.gov/sites/default/files/2022-03/BEEP%20Letter%20and%20Report_Equitable%20Decarb%20March%202022.pdf.

Sunter, D. A., Castellanos, S., & Kammen, D. M. (2019). Disparities in rooftop photovoltaics deployment in the United States by race and ethnicity. *Nature Sustainability*, 2(1), 71–76.

Tarekegne, B., Pennell, B., Preziuso, D., & O'Neil, R. (2021). Review of energy equity metrics (Report No. PNNL-32179). Pacific Northwest National Laboratory. https://doi.org/10.2172/1830804

Tonn, B., Rose, E., & Hawkins, B. (2018). Evaluation of the U.S. Department of Energy's weatherization assistance program: Impact results. *Energy Policy*, 118, 279–290. https://doi.org/10.1016/j.enpol.2018.03.051

UC Berkeley Labor Center. (2020). Advancing equity in California climate policy: A new social contract for low-carbon transition. Retrieved from: https://laborcenter.berkeley.edu/advancing-equity/

US Department of Energy. (2024). Distributional equity analysis for energy efficiency and other distributed energy resources: A practical guide. Retrieved from: https://www.energy.gov/sites/default/files/2024-05/bto-distributed-equity-analysis-guide_may2024.pdf

US EPA. (2024). Inclusive utility investments: Tariffed on-bill programs. Retrieved from: https://www.epa.gov/statelocalenergy/inclusive-utility-investments-tariffed-bill-programs

Walker, I., Casquero-Modrego, N., & Less, B. (2023). Challenges and opportunities for home decarbonization. Lawrence Berkeley National Laboratory. Retrieved from: https://escholarship.org/uc/item/60x7310p

Wilkinson, P. et al. (2009) “Public health benefits of strategies to reduce greenhouse-gas emissions: household energy,” The Lancet, 374(9705), pp. 1917–1929. Available at: https://doi.org/10.1016/S0140-6736(09)61713-X.

Willand, N., Ridley, I. and Maller, C. (2015) “Towards explaining the health impacts of residential energy efficiency interventions – A realist review. Part 1: Pathways,” Social Science & Medicine, 133, pp. 191–201. Available at: https://doi.org/10.1016/j.socscimed.2015.02.005.

Wyon, D. P. (2004). The effects of indoor air quality on performance and productivity. *Indoor Air,* 14(s7), 92–101. https://doi.org/10.1111/j.1600-0668.2004.00278.x

York, D., Cohn, C., Morales, D., & Tolentino, C. (2022). Building decarbonization solutions for the affordable housing sector. American Council for an Energy-Efficient Economy. Retrieved from: https://www.aceee.org/research-report/u2204

Zhao, B., Wang, T., Jiang, Z., Gu, Y., Liou, K.-N., Kalandiyur, N., Gao, Y., & Zhu, Y. (2019). Air quality and health cobenefits of different deep decarbonization pathways in California. *Environmental Science & Technology*, 53(12), 7163–7171. https://doi.org/10.1021/acs.est.9b02385

Appendix G: Literature Review

The literature review for this study was published prior to the final report and can be accessed on the California Air Resources Board website: https://ww2.arb.ca.gov/equitable-housing-decarbonization-implementation-approaches. To ensure that its findings are accessible alongside the rest of the research, we have also appended it here.

Equity Implications for the Design, Implementation, and Outcomes of Housing Decarbonization Programs

A Scoping Literature Review

December 14, 2025

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Equitable Housing Decarbonization Project Team

Prepared for:

California Air Resources Board

1. Contents

1. Executive Summary

This report synthesizes existing literature on equity considerations in housing decarbonization programs for existing buildings. In this report, we focus on housing decarbonization strategies that reduce the carbon emissions of residential buildings. These strategies drive housing decarbonization by decreasing energy demand through energy efficiency measures, transitioning household energy use away from combustible fuels through electrification, and where possible, producing local electricity from renewable sources.

Energy retrofits of residential buildings support the achievement of California's climate and environmental justice goals.[1] In support of these state goals, the California Air Resources Board (CARB) partnered with researchers from the University of California, Berkeley, as well as community and environmental justice organizations, to conduct a study on equitable implementation pathways for housing decarbonization. This literature review provides state and federal agencies with insights on the promise, perils, and equity implications of housing decarbonization program design, implementation, and evaluation.

This report is structured as follows: the introduction describes the project and team, California state goals and policy alignment, housing decarbonization measures, and their impact on public health. The chapter on equity implications for program design discusses existing conditions in the home and opportunities to meet retrofit needs; electricity rates and infrastructure readiness; landlord/tenant split incentives; access to technology, capital and financing; and perceptions, knowledge, and concerns about decarbonization; the workforce; and social factors. The chapter on equity implications for program implementation discusses welfare approaches, market-based incentive and regulatory approaches, and community-based approaches. Lastly, the chapter on equity implications for program outcomes discusses greenhouse gas emissions and electric grid stability, climate resilience, housing security, energy security, and health equity.

Equity Implications for Program Design

Housing decarbonization program designers, often staff in state or local governments and energy utilities, need to address a complex set of conditions that affect the ability of households to participate in decarbonization programs. Evidence shows that priority

[1] Relevant legislation includes AB 32: https://ww2.arb.ca.gov/resources/fact-sheets/ab-32-global-warming-solutions-act-2006; SB32: https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160SB32; AB1279: https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=202120220AB1279; SB 350: https://www.energy.ca.gov/rules-and-regulations/energy-suppliers-reporting/clean-energy-and-pollution-reduction-act-sb-350; SB535: https://legiscan.com/CA/text/SB535/id/179871; AB1550 https://digitaldemocracy.calmatters.org/bills/ca_201520160ab1550; AB197: https://digitaldemocracy.calmatters.org/bills/ca_201520160ab197.

communities (e.g., low- to moderate-income households, renters, and disadvantaged communities, as defined by Senate Bill 535 and the U.S. Department of Energy through the Justice40 Initiative), are disproportionately affected by conditions that limit their ability to participate in housing decarbonization programs. Often, households face several barriers simultaneously, demonstrating the need for comprehensive program designs that take the following known barriers into consideration:

- **Existing Conditions in the Home (Retrofit Needs):** 56 percent of housing units in California were built before 1980.[2] Older homes are more likely to have irregular construction, structural issues related to the roof, a roof orientation unsuitable for solar panel installation, hazardous materials (e.g., asbestos siding or insulation, vermiculite insulation, and lead paint), unsuitable electrical systems, mold, pests, or other issues often related to deferred maintenance. Even though remediation of these conditions is often a prerequisite for implementing decarbonization measures, funding for retrofit needs is often not included in existing programs.
- **Electricity Infrastructure and Rates:** 70 percent of California households use combustible fuels (e.g., natural gas, propane, wood) for heating and cooking.[3] Transitioning to electric appliances will increase demand on the electric grid, and in some cases, will require upgrades to the distribution infrastructure. Ratepayers can face long waiting times to get a cost estimate for the required upgrades and are required to pay out of pocket for the upgrades between the transformer and the home. Acknowledging these challenges, the California Public Utilities Commission (CPUC) is piloting a new program to relieve low-income ratepayers of these costs. At the same time, it is still unclear how many people will have access to this pilot. There remain unanswered questions about who should be paying for grid upgrades as well as what the impacts will be for ratepayers, including low- and moderate-income households. Furthermore, the higher the electricity rates compared to natural gas rates, the less likely electrification will be financially feasible. Disadvantaged communities disproportionately live in areas with low circuit capacity (Brockway et al., 2021), which limits solar adoption, and pay higher energy bills per square foot of living space (EIA, 2023), thus hindering their ability to adopt decarbonization measures. Therefore, there is a need to consider electricity price and infrastructure influences on the feasibility and affordability of housing decarbonization projects.
- **Access to Capital and Financing:** Most market-based incentive programs rely on the fact that investment in home energy efficiency pays for itself over time. However, low- and moderate-income households may not have the financial ability to finance the upfront costs of decarbonization projects and upgrades. Electrification retrofits may not be cost-effective without further investment in

[2] 2022 American Community Survey, Table B25034.
[3] 2022 American Community Survey, Table A10034.

energy efficiency, solar panels, or both. While low-income households should be targeted for no-cost direct install programs, among moderate-income households there is a need to address the green financing gap.

- **Landlord/Tenant Split Incentives:** 45 percent of households in California are renters who have lower levels of income compared to homeowners[4]. Renters face barriers due to split incentives with landlords, where neither party has sufficient motivation to invest in energy efficiency upgrades. This can lead to two different negative outcomes for renters: (1) if their home is excluded from retrofitting, they could incur higher energy bills as a result of energy inefficiency in their units and increasing utility prices, or (2) if their home is retrofitted by the landlord, the landlord might try to recover the cost of the investment via higher rents, which could displace low-income residents. Policy designers must include strategies to both financially incentivize landlords to undertake retrofits and protect renters from rising costs and displacement pressures.
- **Capacity to Engage:** The capacity of households to engage with a decarbonization project depends on a variety of factors, including the ability to make changes to the housing unit, language and cultural access, knowledge about the program, ability to find and connect with opportunities, ability to navigate bureaucracies, an understanding of the benefits and risks of program participation, time and capacity for project management, the ability to conduct a cost-benefit analysis and access financing, and the ability to manage a construction project. Limited capacity in one or more of these areas can undermine the capacity of a household, property owner, or both to participate in complex decarbonization programs. Integrating technical assistance and project management support throughout the process into program design can address these barriers.
- **Perceptions and Concerns:** Concerns about utility bills, electricity reliability, and lack of knowledge about new technologies influence household decisions regarding decarbonization. Adapting programs to the specific needs of target communities can help overcome this barrier.
- **Social Factors:** Structural racism, age-related limitations, immigration status, and language barriers contribute to disparities in housing quality and participation in decarbonization programs. Adapting programs to the specific needs of target communities can help overcome this barrier.

Equity Implications for Program Implementation

In this literature review, we identify three distinct implementation approaches and discuss their equity implications:

[4] 2022 American Community Survey, Table B25003.

Welfare approaches involve government initiatives that directly install no-cost energy retrofits for low- and moderate-income (LMI) households to reduce energy demand and costs. One of the challenges for these programs is identifying who is eligible for assistance. There has been a shift away from using income as the sole criterion and towards using multiple indicators to determine a household's eligibility for assistance. Lessons from programs in the United Kingdom (UK) and the U.S., including the Weatherization Assistance Program (WAP) and utility-operated programs, highlight other common challenges:

- Income-based targeting is ineffective at reaching energy-burdened, priority households.
- The metrics chosen for program evaluation often exclude non-energy benefits such as improvements in human health, leading to an incomplete assessment of societal benefits.
- Lack of funding for retrofit needs precludes participation for those living in the worst housing conditions.
- Complex engagement processes raise administrative costs and burdens.
- In some cases, low-income households might consume more energy post implementation due to latent demand.
- Racially and ethnically marginalized groups have disproportionately lower participation rates in welfare-based decarbonization programs.

Despite these challenges, the literature shows that for households that do participate, most welfare programs contribute to reduced energy demand, improved housing quality, and better health, demonstrating the potential for approaches that target LMI households that experience the worst housing and energy conditions.

Market-based incentive and regulatory approaches refer to government interventions that incentivize the transition to low-carbon homes through regulation (e.g., appliance standards, building codes, benchmarking, utility regulation) and financial incentives (e.g., rebates, tax credits). These predominant interventions are designed to address market failures (e.g., unpriced externalities, imperfect information, principal-agent problems, credit constraints) and consumer decision-making barriers that hinder energy efficiency and decarbonization efforts.

These strategies have significant equity implications. While building standards have improved the overall quality of new buildings, in some cases, they have also increased the costs of development and raised the price premium for homes with energy-efficient features. Appliance standards and eco-labels have improved the energy efficiency of appliances. However, lower adoption among renters and LMI households due to lack of information about benefits, cost and credit barriers, and split incentives between landlords and renters limit their contribution to energy savings.

Benchmarking and energy audits can encourage energy savings if they are accompanied by technical assistance and financial incentives, but so far small property owners are not mandated to share energy usage information and have had less access to energy audits. Rebate programs encourage the purchase of energy-efficient appliances mostly among higher-income households who, in some instances, may purchase them absent the rebate. Access to effective subsidies, credit, or both remains a persistent barrier among lower-income households. Therefore, despite the desire to create incentives that serve all households, limited attention to the needs of lower-income households has led to ineffective targeting and less adoption than is needed to expand decarbonization to levels needed to meet climate and other sustainability goals.

Community-based approaches are place-based initiatives that address the specific needs of households living in a particular geography and that share commonalities in climate exposure, energy prices, building types, or income. By engaging communities actively in the decarbonization process, state and regional governments seek to tailor strategies to the unique characteristics of places. Motivations for community-based approaches include supporting grassroots innovation, adapting policies to local needs, building local capacity, achieving multiple sustainability goals, and addressing social and economic inequalities.

Diverse implementation strategies include innovation grants to build local capacity, pilot projects targeting priority communities, and initiatives integrating health promotion with decarbonization. Examples from the UK and U.S. demonstrate the success of community-led initiatives in increasing participation and achieving sustainability goals. Approaches that specifically target priority communities and partner with local leadership and community-based organizations for program design, delivery, and evaluation can increase participation and contribute to social benefits such as improved housing quality and household health.

Deeper engagement with community leadership in priority communities can help overcome the compounding challenges of historical disinvestment, distrust in government and other institutions, worse housing and energy infrastructure conditions, limited resources and knowledge of decarbonization, and higher sensitivity to increases in energy bills. To address these intersectional challenges, research has highlighted the need for sustainable community-level institutions that can act as intermediaries between the state, energy utilities, implementers, and households.

Equity Implications for Program Evaluation

This section provides a framework for evaluating equity outcomes across comprehensive dimensions of program impacts, including greenhouse gas (GHG) emission reductions, climate resilience, housing security, energy security, population health, and health equity.

Greenhouse Gas Emissions and Sustainability: Housing decarbonization efforts can significantly reduce greenhouse gas emissions and indoor and outdoor air pollution, leading to improved population health outcomes. Strategies such as electrification, energy efficiency, and renewable energy integration are essential for achieving these reductions. Disadvantaged communities that are disproportionately exposed to air pollution will disproportionately benefit from clean air, contributing to reductions in health disparities. Furthermore, neighborhood-scale electrification can support decommissioning parts of the natural gas system, further contributing to reduced GHG emissions and the burden on individual households to maintain the natural gas system.

Climate Resilience: Housing plays a crucial role in protecting communities from climate hazards such as extreme heat, wildfire smoke, and flooding. Decarbonization measures that improve the thermal comfort and air quality of the home can enhance the resilience of residential buildings to extreme weather and mitigate health risks. Disadvantaged communities that face disproportionately higher exposure to climate risks will reap outsized benefits from protective retrofits.

Housing Security: Decarbonization programs have the potential to improve housing quality and stability, thus contributing to housing security. By addressing issues such as hazard remediation (e.g., mold, lead, asbestos), inadequate heating and cooling, and other health and safety hazards, these programs can reduce health risks and promote overall well-being among residents. To achieve contributions to housing security and avoid displacement, program designers must address the split incentives between landlords and tenants and enact enforceable renter protections.

Energy Security: Housing decarbonization can help alleviate energy insecurity by reducing energy costs, improving thermal comfort, safety, and enhancing energy efficiency–all with economic benefits to utilities and consumers. These efforts can benefit low-income households disproportionately affected by high energy bills and inadequate housing conditions. To reduce energy bills, there is a need to reduce consumption or to combine electrification with energy efficiency, solar photovoltaics (PV), and bill assistance programs.

Health Equity: Housing decarbonization strategies advance population health with outsized benefits to vulnerable populations. These initiatives have the potential to advance health equity by addressing structural determinants of health and prioritizing households facing social inequities. By targeting priority communities, these programs can mitigate health disparities among population groups.

2. Introduction

2.1. The Equitable Housing/Residential[5] Decarbonization Project

In June 2023, the California Air Resources Board (CARB) partnered with researchers from the University of California, Berkeley, to conduct a study on equitable implementation pathways for housing decarbonization. This project is being conducted in collaboration with community-based and environmental justice organizations via a participatory action research (PAR) model.

This project is designed to meet three objectives:

(1) Increase understanding of how different governance and program structures are implementing decarbonization across California, along with the strengths and limitations of existing approaches.
(2) Collect and analyze data on the financial and energy costs as well as health and financial impacts of implementation for low- and middle-income (LMI) households.
(3) Develop a framework to increase local capacity for equitable implementation of decarbonization efforts among priority communities.

This project uses mixed methods to achieve these objectives through the following tasks:

Task 1: Implement a participatory action research model and form an advisory committee to guide all aspects of the study, including data collection, analysis, interpretation, and knowledge dissemination.

Task 2: Develop a literature review of equity implications for the design, implementation, and outcomes of housing decarbonization programs.

Task 3: Run a statewide review of decarbonization programs in California to identify opportunities and barriers for implementation in priority communities.

Task 4: Conduct a household survey aimed at gathering insights on the process of engagement and on the energy, financial, and health impacts for participating households.

Task 5: Draft a critical review of policy cost analysis and the development and integration of equity indicators to evaluate decarbonization policies.

Task 6: Recommend policies to build community capacity for housing decarbonization. This project will deliver actionable recommendations on how to ensure equity in the design, implementation, and evaluation of housing decarbonization programs; develop recommendations to increase local capacity for implementation; and provide insights into

[5] We use the terms residential decarbonization and housing decarbonization interchangeably throughout the document.

the approaches that are most effective in increasing the participation of priority communities in housing decarbonization.

The following literature review completes Task 2 of this study.

2.2. Project Team

UC Berkeley Team

- Principal Investigator (PI) Carolina Reid, Associate Professor, Department of City and Regional Planning
- Principal Investigator (PI) Rachel Morello-Frosch, Professor, Department of Environmental Science, Policy and Management and the School of Public Health
- Co- Investigator (CI) Yael Nidam, Doctoral Candidate, Department of City and Regional Planning
- Ruby Zalduondo, Graduate Student, Department of City and Regional Planning
- Ethan Elkind, Director of the Climate Program, Center for Law, Energy & the Environment (CLEE)
- Ted Lamm, Associate Director, Center for Law, Energy & the Environment (CLEE)
- Zack Subin, Associate Research Director, Housing + Climate Research Initiative, Terner Center for Housing Innovation

PAR Advisory Committee

- Katie Valenzuela, Sacramento City Councilmember; Building Energy Equity & Power (BEEP) Coalition Member
- Edgar Barraza, Physicians for Social Responsibility Los Angeles (PSR-LA); Building Energy Equity & Power (BEEP) Coalition Member
- Jessica Tovar, Local Clean Energy Alliance (LCEA); Building Energy Equity & Power (BEEP) Coalition Members
- Hernando Sanchez, Local Clean Energy Alliance (LCEA); Building Energy Equity & Power (BEEP) Coalition Members
- Chris Selig, People Organizing to Demand Environmental and Economic Justice (PODER); Building Energy Equity & Power (BEEP) Coalition Member
- Armando Ortiz, Manager, Sustainable Energy Solutions Team, Self-Help Enterprises (SHE).
- Michelle Vigen Ralston, Principal and Founder, Common Spark
- Sooji Yang, Consultant, Common Spark
- Katie Wu, Managing Director, Common Spark
- Fatima Abdul-Khabir, Senior Associate, Association for Energy Affordability, Inc.
- Brendan Wade Brown, Director of Research, Green & Healthy Homes Initiative
- Diana Hernández, Associate Professor of Sociomedical Sciences, Columbia University

2.3. State Goals and Policy Alignment

Equitable housing decarbonization is key to meeting California's climate and environmental justice goals. In the past two decades, legislators have tasked the California Air Resources Board (CARB), the California Energy Commission (CEC), and the California Public Utilities Commission (CPUC) with the implementation of building decarbonization and equity goals. Table 1 in the Appendix reviews the most relevant laws and regulations enacted by the state of California to advance housing decarbonization and environmental justice.

The state's GHG reduction goals were set by Assembly Bill (AB) 32, and further developed through California Senate Bill (SB) 32 and AB 1279, which requires California to reduce greenhouse gases by at least 85 percent below the state's 1990 levels by 2045. CARB is tasked with meeting those targets, and its 2022 Scoping Plan outlines specific goals for the residential sector, including the installation of six million heat pumps by 2030 and seven million climate friendly homes by 2035.

The Scoping Plan also outlines equity strategies such as the prioritization of residents in low-income, disadvantaged, rural, and tribal communities in the state's Equitable Building Decarbonization Program, and "ensuring that incentive programs prioritize energy affordability and tenant protections, promote affordable and low-income household retrofits that improve habitability and reduce expenses, protect and empower small landlords and homeowners, address overlooked consumer groups, and pair decarbonization with other critically needed renovation efforts to ensure that buildings support human health and are climate and weather-resistant"(CARB, 2022).

2.4. Housing Decarbonization Measures

Housing decarbonization refers to a set of strategies and actions aimed at reducing the carbon emissions associated with residential buildings. The CEC identified seven strategies for building decarbonization, which apply both to commercial and residential buildings (Kenney et al., 2021). Below, we briefly describe all strategies related to building retrofits, management of the energy system, and the carbon emissions of appliances.

Strategies relating to building retrofits:

Energy efficiency includes measures that reduce the energy demand for heating and cooling of the home by upgrading appliances and lights to energy-efficient technologies, while improving indoor thermal comfort.

The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) (2020) defines thermal comfort as "that condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation." This is affected by individual preferences, activity, climate, and the built environment.

Measures to improve thermal comfort in homes include weatherization (insulation of walls, attics, and basements; draft sealing; installation of windows that can resist heat flow) and switching to more energy-efficient and space appropriate Heating, Ventilation, and Air Conditioning (HVAC) systems (Rupp et al., 2015). Together, these measures can reduce energy demand by half while improving indoor thermal comfort (Nadel and Ungar, 2019).

Electrification requires switching from combustible, fuel-based appliances to electricity-based appliances, including those used for space heating, water heating, clothes drying, and cooking. Space heating and water heating alone account for 70 percent of residential energy consumption in the United States (EIA, 2020a). Upgrading the electric panel capacity of homes can also support electric mobility choices such as electric scooters and vehicles. The goal of residential electrification is to reduce the use of combustible fuels (e.g., gas and propane) in homes and to pave the way toward the eventual decommissioning of the gas system.

Clean energy (distributed energy sources) can be achieved either by generating clean energy on-site (e.g. rooftop solar, wind, fuel cells) or by receiving clean energy from the grid. When residential photovoltaics are paired with on-site battery storage or via advanced vehicles, it can be designed to increase the energy resilience of homes by providing a period of emergency backup power during outages (Mango et al., 2021).

<u>Strategies relating to management of energy systems:</u>

Residential demand response technologies such as smart meters, communicating thermostats, and flexible devices are designed to shift or reduce electricity demand in response to economic or reliability signals. The purpose of demand response is to support grid reliability, lower overall consumption, enable customers to reduce energy bills, and provide sustainable energy resource management. This active management of electricity consumption reduces the need for utilities to use gas peaker plants to compensate for periods of high electricity demand. Gas peaker plants, while known for their quick response to sudden demand increases, introduce high-pollution and high-emitting fossil fuel generation into the energy mix. Price-based demand response can also give more control to consumers over when and how much electricity they use, lowering their electricity bills in the process (California Energy Commission, 2024; Dahlke and McFarlane, 2015; Siano, 2014).

Decarbonizing the electricity generation system complements building electrification by supplying electricity from renewable sources (Kenney et al., 2021)**.**

Decarbonizing the gas system entails replacing a portion of fossil gas with renewable gas such as biomethane or other zero carbon alternatives (Kenney et al., 2021)**.**

<u>Strategies relating to the greenhouse gas emissions of appliances:</u>

Refrigerant leakage reduction and low-Global Warming Potential (GWP) refrigerants. SB 1383 established economy-wide goals to reduce hydrofluorocarbon emissions by 40 percent from 2013 levels by 2030, which if successful, would eliminate 7.5 million metric tons of carbon dioxide equivalent (MMTCO2e) from residential and commercial buildings in 2030 (Kenney et al., 2021).

2.5. Public Health Implications of Housing Decarbonization

Housing decarbonization strategies can improve household members' health by reducing exposure to extreme weather, improving indoor air quality, reducing energy bills, improving energy security and resilience, and improving satisfaction with the home (Jessel et al., 2019; Wilkinson et al., 2009; Ryan and Campbell, 2012; Gillingham et al., 2021; Willand et al., 2015). This section reviews the evidence for the impact of energy efficiency, electrification, and clean energy projects on human health.

As energy efficiency programs are the longest-serving building decarbonization programs, there is a large body of literature demonstrating the health benefits of implementing these measures. In a review of 28 energy efficiency interventions in the U.S., western Europe, Australia, and New Zealand, Willand et al. (2015) show that residential energy efficiency improved winter warmth and lowered relative humidity with benefits for cardiovascular and respiratory health. Their review also revealed that improved mental and social health was associated with a greater satisfaction with the home along with financial considerations (Willand et al., 2015).

In an empirical review of the association of residential energy efficiency retrofits with indoor environmental quality, comfort, and health, Fisk et al. (2020) show that subjectively reported thermal comfort, thermal discomfort, non-asthma respiratory symptoms, general health, and mental health nearly always improved after retrofits (Fisk et al., 2020). The review included 36 studies conducted mostly in the cold climate regions of the U.S., UK, and New Zealand among mostly low-income populations. They note the challenges in assessing the general relationship between energy efficiency and health due to differences in which energy efficiency measures were implemented, limited measurements of objective health outcomes, limited data from retrofits in warm-humid climate, limited data on non-low-income populations, and limited data on retrofits implemented by private companies.

The study of the Weatherization Assistance Program (WAP) is of specific interest since it provides a package of energy efficiency measures at no cost to income-eligible households and has been operating since 1976. In a comprehensive assessment of the WAP program for FY 2008 and FY 2010 that included a pre-post survey, Tonn et al. (2018) found that weatherization improved the general mental and physical health of respondents. Specifically, the number of days in the previous month respondents reported "not good" mental or physical health were reduced by 48 percent. Weatherization also reduced asthma symptoms and accompanying visits to emergency departments by 11 percent and hospitalization by 3 percent. The authors attributed these findings to improved indoor air quality and thermal comfort. The author also conducted a cost-benefit assessment that incorporated non-energy benefits and estimated that the average total benefit per unit weatherized in 2008 was $22,000 versus an average total cost of $4,700. These results for 2010 were $20,000 and $6,800, respectively (Tonn et al., 2018). The WAP program and this study demonstrate that investment in energy efficiency for low-income households can provide substantial health and sustainability benefits.

At the same time, if energy efficiency measures are implemented without ensuring adequate ventilation, there is a risk of not improving indoor air quality by trapping indoor contaminants. For example, in an assessment of 514 homes participating in the WAP program in 2009 across different U.S. regions, Pigg et al. (2018) find that weatherization could result in small but statistically significant increases in some indoor contaminants such as radon and humidity (Pigg et al., 2018). In a smaller study of 81 households, Francisco et al. (2017) show that indoor air quality and health improve when weatherization is accompanied by an ASHRAE residential ventilation standard (Francisco et al., 2017). These studies demonstrate the importance of appropriate implementation of residential energy efficiency retrofits.

Research on the health benefits of electrification measures also demonstrates a wide range of health benefits associated with switching to all-electric space heating, water heating, and cooking. Gas stoves deteriorate indoor air quality by releasing methane and nitrogen oxides (Lebel et al., 2022). Replacing gas stoves with electric stoves eliminates this source of indoor air pollution and reduces the risk of respiratory illnesses (Jarvis et al., 1996; Paulin et al., 2013; Knibbs et al., 2018; Daouda et al., 2024). The technology for space heating electrification is new, and its health impacts are relatively understudied. Several studies have found that electrifying space heating can significantly reduce carbon emissions if it is powered by clean energy sources (Addo-Binney et al., 2022; Deetjen et al., 2021; Walker et al., 2022). Walker et al. (2022) emphasize that achieving carbon and energy cost savings is much easier when replacing older, low-efficiency equipment. In a recent study comparing the natural gas furnace to the cascade heat pumps[6], Addo-Binney et al. (2021) found that factors that can cause harm to human respiratory systems are decreased almost ten times when using the cascade heat pump as an alternative heating system (Addo-Binney et al., 2022). Evidence from these studies show that the key contribution of residential electrification is improving indoor air quality, and additional benefits in thermal comfort and energy savings are relative to the replaced technologies.

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[6] A cascade heat pump is a multi-stage system that connects two or more heat pump cycles so that the output of one stage serves as the input for the next, enabling higher temperature lifts than achievable with a single-stage unit. This cascading arrangement enhances overall efficiency and flexibility. Refrigerants used in cascade heat pump systems should have a very low or near-zero ozone depletion potential, low global warming potential, and a short atmospheric life (Addo-Binney et al., 2022).

There is abundant evidence in the literature that renewable energy sources improve population health via the reduction of air pollution associated with burning fuels for energy production (Buonocore et al., 2019, 2016; Owusu and Asumadu-Sarkodie, 2016). At a more granular level, Patel et al. (2021) and Galvan et al. (2020) use modeling simulations to show that shared rooftop solar systems in residential communities in California and Oregon can enhance community resilience to power outages in the aftermath of natural disasters (Galvan et al., 2020; Patel et al., 2021). Having power during days of extreme heat or cold, or in the aftermath of an earthquake, can protect people's health by maintaining thermal comfort, keeping essential medical equipment connected to the grid, and maintaining use of the refrigerator to protect food. For example, Tosado et al. (2021) interviewed 15 families that received solar-powered battery systems to power medical devices following Hurricane Maria in rural Puerto Rico. They found that almost all families were pleased with the systems, and a majority would recommend solar-powered battery systems to a neighbor. Evidence shows that residential renewable energy contributes to improved health by reducing exposure to air pollution. There is potential for using renewable energy to increase resilience to energy shutoffs.

To conclude, energy efficiency measures improve thermal comfort by improving insulation and upgrading the HVAC system. They can also improve indoor air quality by sealing drafts, requiring the remediation of lead or asbestos, and improving ventilation. However, these benefits are dependent on adherence to indoor air quality guidelines or best practices. Energy efficiency upgrades reduce household energy consumption and energy bills. Electrification improves indoor air quality by removing polluting cooking and heating sources and also improves thermal comfort by introducing a more efficient heating system. Electrification upgrades typically do not lead to bill savings unless they are combined with energy efficiency strategies or rooftop solar. Energy efficiency and electrification measures are both effective in improving protection against extreme heat or cold, both of which are expected to increase under a changing climate. Renewable energy reduces air pollution, and residential rooftop solar can provide protection against shutoffs when combined with battery storage.

These improvements translate into improvements for human health. The evidence shows that housing decarbonization measures can improve mental and physical health by reducing health risks associated with living in energy-inefficient homes such as cardiovascular disease, respiratory illnesses, and stress.

3. Equity Implications for Program Design

Housing decarbonization program designers are tasked with addressing diverse needs across building ages, building types, ownership types, and infrastructure readiness, as well as differing levels of participant knowledge, motivation, resources, and capacity to engage. In this section, we provide an overview of prevailing knowledge pertaining to decarbonization program participation challenges within high-priority populations.

We consider the following groups as high-priority communities for equitable housing decarbonization: LMI households, renter households, and disadvantaged communities (as defined by SB 535). These groups are priority communities for decarbonization programs for two reasons:

(1) Prior research identifies these groups as disproportionately situated within older and energy-inefficient housing (Davis, 2011; Goldstein et al., 2022a; Fournier et al., 2024), demonstrating greater need and potential for energy savings.
(2) Prior research identifies these groups as disproportionately underserved by decarbonization programs. Evidence shows that participation in housing decarbonization and electric vehicle programs is higher among households that are more affluent, have higher levels of education, live in single-family homes, or are homeowners (Federico et al., 2019; Frank and Nowak, 2016; Guo and Kontou, 2021; Ju et al., 2020; Pigman et al., 2021a; Sunter et al., 2019; Xu and Chen, 2019).

Therefore, including priority communities in housing decarbonization programs is imperative both for meeting equity goals and wide-scale adoption goals. Households often face several simultaneous barriers to participating in decarbonization programs, highlighting the importance of holistically addressing these challenges, discussed below, in the design of housing decarbonization programs.

3.1. Existing Conditions in the Home (Retrofit Needs)

Across California, there are a diversity of building ages, types, and qualities of construction. More than half of homes in California were built before 1980 (United States Census Bureau, 2020), in an era preceding the regulation of residential energy efficiency (Allcott and Greenstone, 2012). Building age serves as a reliable indicator for the potential existence of many conditions that can pose a barrier to implementation:

- Older homes are more likely to have irregular construction, structural issues related to the roof, roof orientation unsuitable for solar panel installation, and mold.
- Hazardous materials in home, including asbestos siding or insulation, vermiculite insulation, and lead paint (US EPA, 2013; U.S Government Publishing Office, 1978) are prevalent in housing built prior to 1980s.

- Unsuitable electrical systems such as “Knob and Tube” electrical wiring are prevalent in housing built prior to 1940. This is considered a safety hazard due to increased fire risk near insulation (Desai and Chovanec, 2023; Gromicko and Shepard, 2016).
- Units built prior to 1950-1980 often have panel capacity below 60-100 amps, which is insufficient for full electrification (Fournier et al., 2024).

If any of the above conditions exist, building code requires installers to address the health and safety risks posed by these conditions prior to installing new HVAC systems. These conditions are more prevalent in older housing stock, which often requires remediation of these pre-existing conditions to address health and safety hazards prior to the implementation of decarbonization measures (Scavo et al., 2016). An inability to implement “retrofit needs” can preclude residents from participating in decarbonization programs. Necessary structural repairs, remediation of hazardous materials, the need to reconfigure space and relocate equipment to a new location, and upgrades to electrical systems before the implementation of electrification and energy efficiency upgrades often increase upfront costs and construction time. Consequently, property owners face varying levels of upfront costs, which in turn impact their ability to effectively engage with housing decarbonization programs.

Low-income households and communities of color are more likely to live in older housing stock (Fournier et al., 2024; York et al., 2022) and are therefore more likely to encounter retrofit barriers. For example, a recent study on electric service panel capacities in California's residential buildings found that low-capacity panels are more common in older homes and rental properties. These types of buildings are more frequently located in areas designated as disadvantaged communities (Fournier et al., 2024). Even though only about 3 percent of single-family homes in California have electrical panels that are too small, these homes are four times more common in disadvantaged communities than in more affluent neighborhoods (Fournier et al., 2024). For these households, which already bear high energy cost burdens (Sherman, 2023), upfront costs of upgrading panel capacity and ineligibility due to significant retrofit needs contribute to lower participation in decarbonization programs (BEEP Coalition, 2023).

In addition to building age, building type is also an indicator for the potential presence of substantial retrofit needs. For the multi-family housing sector, which consists of several subsectors based on size, ownership type, and building configuration, retrofit needs are often a major barrier. This becomes more complicated by the size, complexity of the property (e.g., the presence of an elevator), and ownership structure. Older multi-family buildings typically have electrical infrastructure insufficient to support electrification and may also have physical space constraints to install new equipment. Additionally, multi-family buildings may require additional retrofit needs depending on HVAC and domestic hot water (DHW) system types and whether the focus of upgrades are in common areas, dwelling units, or both (Aitchison et al., 2021). Ownership structure may also pose a challenge if several owners need to agree on changing the energy equipment (e.g., electrical panel, HVAC system) of the property.

Manufactured homes, a type of prefabricated housing constructed in a factory and then transported to a site, accounted for 3.7 percent of total housing stock in California in 2019 (Leon et al., 2021). More than half of manufactured homes in California were built before 1980 and are relatively energy inefficient (Leon et al., 2021). They are more likely to have low electrical panel capacity, limited space availability for decarbonization measures, and high remediation needs (Maneta, 2023). These high needs include addressing manufactured homes' high prevalence of poor insulation, hard-to-access ductwork, old electrical wiring, small closet sizes, and rooftops that are unsuitable for solar panel installation (Leon et al., 2021; McGrath and Dugger, 2024).

Another barrier to decarbonization implementation for residents in manufactured homes is the presence of master metering, common in mobile home parks. Master meters prevent many functions that are essential to decarbonization retrofits, such as tracking granular electricity use, identifying energy inefficient equipment, and incentivizing the fair distribution of energy costs among mobile home park occupants (CPUC, 2020). The CPUC's Mobilehome Park Utility Conversion Program aims to address these issues by funding the conversion of master metering to direct metering (CPUC, 2020).

Addressing these retrofit challenges is important to increasing equitable access to decarbonization for residents of manufactured homes who are also disproportionately low-income (Leon et al., 2021). These low-income households, like their counterparts living in non-manufactured housing, face challenges affording the upfront costs of addressing readiness upgrades.

3.2. Electricity Infrastructure and Rates

Building and transportation decarbonization requires preparing electricity infrastructure for increased demand and the integration of clean energy (Elmallah et al., 2022a). Researchers distinguish between three aspects relating to changes in electricity infrastructure: (1) generation of electricity from clean energy sources, (2) transmission of clean electricity to local substations, and (3) distribution of electricity from local substations to distribution feeders that provide electricity to homes and businesses for end-use consumption. Each of these aspects represents a wide area for research and practice and has distinct equity implications. In this section, we focus specifically on the equity aspects relevant to housing decarbonization.

First, adequate energy infrastructure at the local level impacts the ability of households to adopt rooftop solar. A study of California's two largest investor-owned utilities (IOUs), Pacific Gas and Electric (PG&E) and Southern California Edison (SCE), reveals that over half of residential households served by these utilities lack adequate grid capacity for solar photovoltaics (PV). The study also found that households in census block groups with large proportions of Black residents or that were identified as disadvantaged communities have disproportionately less access to new solar PV capacity based on circuit hosting capacity (Brockway et al., 2021). The lack of access to adequate energy infrastructure is therefore an important, yet understudied, barrier to equitable solar adoption.

Second, households' ability to electrify end uses depends on the capacity of the distribution grid to service increased demand. A study of PG&E's distribution infrastructure reveals that the additional capacity needed to service new electrical loads based on state goals would exceed PG&E's planned upgrades and historical rate of upgrade projects (Elmallah et al., 2022a). Across the U.S., efforts to upgrade electricity infrastructure are challenged by the availability of both equipment and skilled workers (Elmallah et al., 2022a; Loeff, 2022). Hence, there is a need for more research to understand grid capacity and workforce constraints to ensure equity in service provision in communities across the state.

Third, electricity rates impact households' motivation and ability to electrify. Residential electricity rates for California's three largest investor-owned utilities are significantly higher than the national average. Two-thirds to three-fourths of these costs are attributable to the fixed costs of operation, which do not change when a customer increases or decreases consumption (Borenstein et al., 2021). In California, the fixed costs of operation are particularly high because, in addition to infrastructure maintenance, they include a range of services such as wildfire mitigation, energy efficiency programs, subsidies for income-eligible customers, and rooftop solar.

California's higher electricity costs place a significant burden on poor households. In 2022, 12.2 percent of California households were classified as living in poverty (American Community Survey, 2022), although the federal definition of poverty doesn't account for California's high cost of living. A study that calculates poverty based on the cost of living in California estimated that in early 2023, 31.1 percent of residents were poor or near poor, with resources up to one and a half times the California poverty line (Sarah Bohn et al., 2023). Many of these households are eligible for subsidies. For example, households earning 200 percent of the federal poverty level or less and who are customers of IOUs can enroll in the California Alternate Rates for Energy (CARE) program to receive a 30 to 35 percent discount on their electricity bill and a 20 percent discount on their natural gas bill. Families whose household income disqualifies them from CARE but whose total earnings don't exceed 250 percent of the federal poverty level qualify for the Family Electric Rate Assistance (FERA) Program, which applies an 18 percent discount to their electricity bill. Still, there are concerns that these subsidies are insufficient to prevent energy cost burdens, especially as electricity rates increase.

Energy rate policy is also important. Borenstein and colleagues (Borenstein et al., 2021) argue that the recovery of fixed costs through higher volumetric electricity prices is (1) economically inefficient because it contributes to higher electricity costs, which reduces the cost-effectiveness of electrification; (2) regressive, because lower-income households spend a relatively large share of their income on electricity; and (3) inequitable because lower- and moderate-income households "are increasingly having to cover high fixed costs from a shrinking base as wealthier customers leave for rooftop solar." Observing these trends, the CPUC, guided by AB 205, developed an income-graduated fixed charge in residential rates that aims to reduce bills for low-income ratepayers and improve the cost-effectiveness of electrification. This evidence and ongoing policy efforts highlight the importance of electricity rates to housing decarbonization. More research is needed to understand the impacts of energy rates and income-eligibility definitions on households' energy burden, motivation, and ability to implement decarbonization measures.

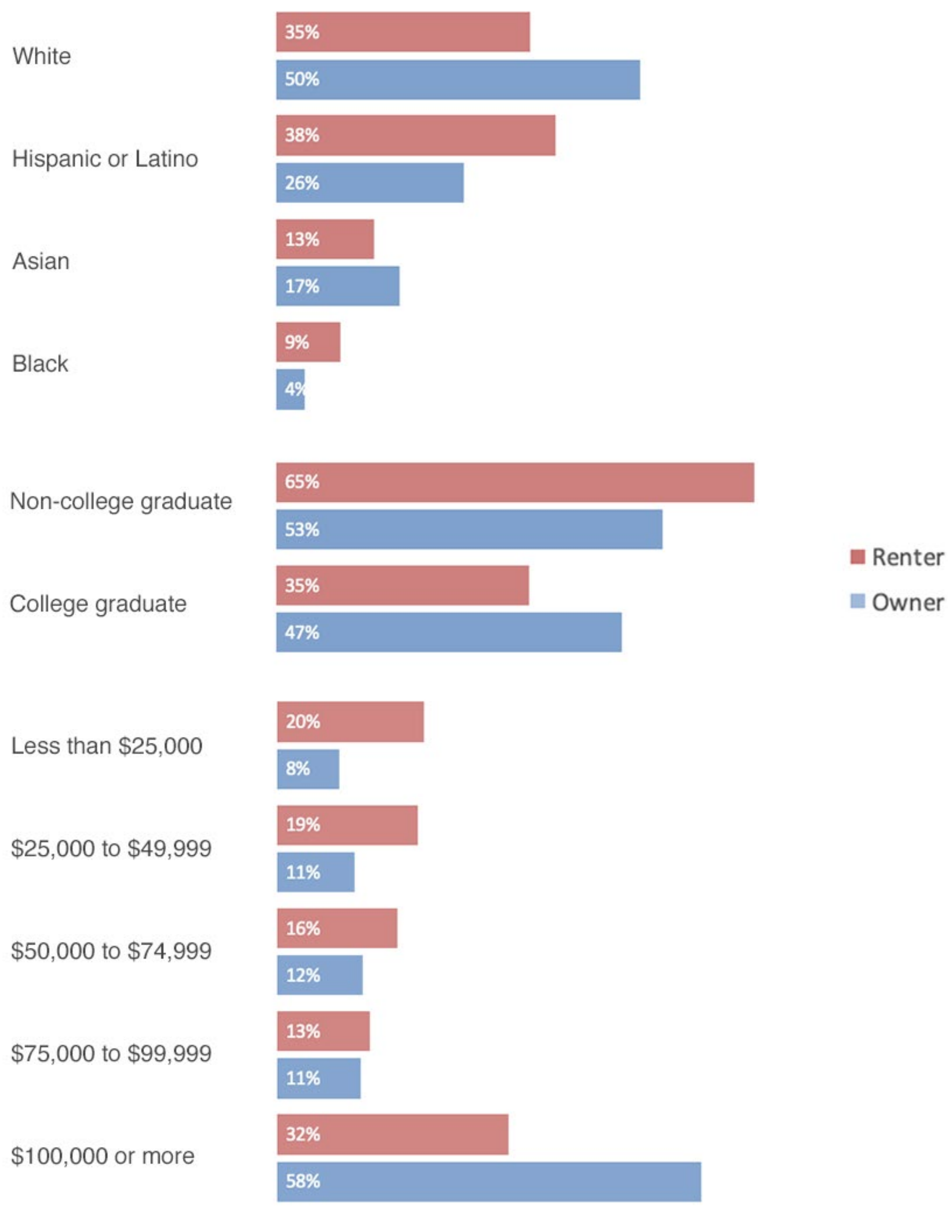
Lastly, there is a need to improve the understanding of the relationship between electrification and natural gas system decommissioning. A recent report commissioned by the CEC highlights the equity implications of electrification for the remaining natural gas costumers: "If customers depart the gas system in large numbers, remaining customers could face significant increases in their gas rates to pay for the largely fixed costs of maintaining the gas system. Without mitigating policies, these impacts would be disproportionately borne by low-income homeowners and renters. A planned transition of the gas system, supported by multiple cost mitigation strategies, will be needed to manage long-term customer cost impacts" (E3, 2022, 2020).

3.3. Landlord/Tenant Split Incentives

Renters face unique barriers in comparison to owners. They often do not have legal authority to make changes to their home, and many do not know if they will reside in the property long enough to recover the cost of investment in building decarbonization upgrades. Hence, renters have less capacity and financial incentive to invest in housing decarbonization measures (Bird and Hernández, 2012). More than 45 percent of households in California are renters, who on average have lower levels of educational attainment, are lower-income, and are more likely to be people of color compared to homeowners (Figure 1).

Landlords' decisions on whether to invest in rental properties are subject to the principal-agent problem (often referred to as the "split-incentive" problem), whereby landlords make decisions relating to energy equipment, but renters pay for or benefit from that decision. For example, if the renter pays for the energy bills, the landlord has no financial incentive to make changes in the home to reduce energy bills via energy efficiency or other upgrades. Vice versa, if the landlord pays for energy bills and chooses to invest in energy efficiency improvements, the renter does not have a financial incentive to conserve energy post-implementation. These split incentives between landlords and renters are a well-known barrier to housing decarbonization (Gillingham et al., 2012; Gillingham and Palmer, 2014).

Figure 1: Percent distribution of California's renter and owner populations by race/ethnicity, education, and income



Source: American Community Survey 2022 1-year estimates, Tables B25118 and S2502
Notes: White, Asian, Black, and Asian race categories are non-Hispanic.
Total estimated renters and owners in California are 5,985,084 and 7,565,502 respectively.
The differences between renters and owners are statistically significant.

The split incentives between owners and renters contribute to energy inefficiency in rental properties (Best et al., 2021; Souza, 2018a). A study using 2015 Residential Energy

Conservation Survey (RECS) data found that renters use approximately 9 percent more electricity than non-renters even when controlling for location, socioeconomic, and many appliance-quantity controls. Multiple factors explain this additional electricity use, including inferior energy efficiency of appliances, behavioral factors, differences in bill payment responsibilities, and reliance on electric space and water heaters (Best et al., 2021). Similarly, in an analysis of American Housing Survey data, Souza (2018) finds that rental properties across the U.S. are less likely to have energy-efficient appliances. Of the rental properties that did include energy-efficient appliances, they were more likely to be either long-term rentals or properties where the landlord pays the energy bill. These findings further substantiate the impact of split incentives between renters and owners on the energy efficiency of rental properties.

These split incentives impact renters in different ways depending on the type of ownership of the rental housing. In this literature review, we are primarily concerned about impacts on low-income renters. The impacts on these households depend on whether they live in subsidized housing, and even then, there can be differences in split incentives depending on the subsidy type. Properties funded by the Department of Housing and Urban Development (HUD) programs (e.g. public housing or project- and tenant-based Section 8 housing) base rent on a household's income (generally 30 percent) and apply utility allowances set by the local Public Housing Authority (PHA). Properties not funded by HUD, but subsidized by Low-Income Housing Tax Credits, may rely on PHA set utility allowances, but they may also have different approaches to calculating utility allowances that can affect the split incentive calculus. For example, if utility allowances are capped for each fuel separately, then increasing electricity demand and reducing natural gas demand may result in underfunding electricity bills and under-utilized natural gas allowances.

Because rents and utility allowances on subsidized units are set by regulatory policy and not actual energy use, the savings-to-investment ratio may not be enough to justify making energy-efficient upgrades, as the costs of decarbonization investments cannot be recouped through higher rents (Copiello, 2015). The lower rents on these properties also mean that it is difficult to take on additional debt to finance the retrofits. Affordable housing providers need both technical assistance to maximize the energy savings potential of their projects and financial assistance to ensure the recovery of costs through solar energy and battery storage, low-interest loans, or grants. Without adequate support, there is a risk that affordable housing providers will not be able to decarbonize their properties.

The majority of low-income renters live in "unsubsidized" affordable housing, which are lower-cost rental properties that do not receive government subsidies, though they may be subject to local rent controls. Among unsubsidized affordable housing, equity concerns arise if participation in decarbonization programs leads to higher rents. One way for landlords to align their financial incentives for housing decarbonization is to sell the property at a higher price post-implementation or pass the cost of implementation to the renters in the form of increased rent. In these scenarios, investment can be financially worthwhile for the landlord due to expected higher home value post-implementation (Cajias and Piazolo, 2013; Fuerst et al., 2015; Bruegge et al., 2016; Kholodilin et al., 2017; Walls et al., 2017; Hopkins et al., 2020). As a result of a change in ownership, increased rent, or both, tenants might be displaced out of higher quality and energy-efficient homes (Bouzarovski et al., 2018; Chelsea Kirk, 2021).

Inequitable access to high-quality and energy-efficient homes has many negative implications for renters:

(1) Energy-efficient homes could have higher rent due to the landlords' desire to recover the cost of the retrofit. While the housing affordability crisis is a result of many compounding and concomitant pressures, any factor that increases rent burden may increase displacement risk.
(2) Energy-inefficient homes often incur higher energy costs because they require more energy for heating/cooling and operation of appliances. For low- and moderate-income renters, these mechanisms might exacerbate energy insecurity, leading to detrimental health outcomes (Hernández and Bird, 2010; Bird and Hernández, 2012; Hernández, 2013).

Several California nonprofit organizations have written about these risks as a result of decarbonization (BEEP Coalition, 2023; Chelsea Kirk, 2021; Kirk, 2023; Solis et al., 2022; Strategic Actions for a Just Economy, 2022). More research is needed to fully understand the impacts of decarbonization policy on housing stability and displacement risk, as well as studies that can inform how utility allowances in subsidized housing should be calculated to encourage decarbonization without increasing cost burdens upon renters.

3.4. Access to Technology, Capital, and Financing

Most market-based incentive programs rely on the assumption that investment in home energy efficiency pays for itself over time. However, for low- to moderate-income households, there is often no means to finance the investment, even for discounted appliances. Forrester and Reames (2020) found that for households with incomes between 80 and 120 percent of area median income (AMI), access to upfront capital is a primary barrier for participation in residential energy efficiency programs. These households, which made up 11 percent of households in California in 2019, often do not qualify for programs targeting lower-income households. Yet, at the same time, they struggle to get traditional financing due to cut-offs based on FICO, debt-to-income, and other traditional underwriting criteria alone (Forrester and Reames, 2020; Schafran et al., 2024).

Exacerbating access to credit for decarbonization, broader financial trends related to risk assessment in the face of climate change may further limit the ability of households to decarbonize their homes. In a 2023 report by The Greenlining Institute, researchers found that financial institutions are beginning to increase prices or withdraw services in areas they perceive as climate and environmental risks, a process they term “bluelining.” This emergent financial exclusion appears to disproportionately impact low-income and communities of color, mimicking processes caused by redlining, such as residential segregation, divestment, and discrimination (Montgomery and Palmeira, 2023).

Households living in lower-income areas might also have less geographical access to energy-efficient technologies or providers. For example, Reames et al. (2018) found that energy-efficient bulbs were less available and more expensive in high-poverty areas and smaller stores, highlighting spatial variation in access to housing decarbonization measures. Brown et al. (2023) find that across all technologies, high upfront costs decrease adoption. Financial incentives are most effective among lower-income households.

In summary, both the lack of access to affordable, energy-efficient appliances in the same geographic area and the inability to access financing limit the ability of LMI households to participate in housing decarbonization programs. In the next chapter, the section about regulatory and incentive-based approaches discusses several strategies to provide financing opportunities for low- to moderate-income households (e.g., inclusive utility investment, on-bill financing), go-green financing).

3.5. Capacity to Engage

There are many factors that impede the improvement of existing affordable and market-rate housing, such as rising construction, land, and labor costs, state and local zoning and growth management regulations, building and rehabilitation codes, and environmental regulations and restrictions (HUD, 2021). For all property owners, having the capacity to overcome these challenges and undertake a decarbonization project depends on a variety of factors. These include having knowledge about the program, an understanding of the benefits and risks of participation, the ability to conduct a cost-benefit analysis, access to financing, and the time and ability to manage a construction project (Nidam, 2019). Property owners with limited capacity who are unable to manage these factors are less likely to undertake complex decarbonization programs. For example, Fournier et al. (2021)'s analysis of the implementation of TECH Clean California found that program participants were biased towards households already possessing the necessary financial resources and motivation required to pursue electrification measures.

The characteristics of the property owner often determine their capacity to engage. Among homeowners and small-scale landlords who own single-family homes, participation rates are higher for those with higher levels of education and higher incomes (Frank and Nowak, 2016; Pigman et al., 2021). These households are better equipped to engage with complex and multi-step programs, are better able to handle high administrative burdens, and have the legal authority to make changes to their property (Nidam, 2019). In contrast, those with lower incomes and without higher levels of education are more likely to struggle with engaging in a program that has complex eligibility criteria and requires a lot of paperwork and follow-up (York et al., 2022).

The more complex a property's ownership structure, the higher the administrative burden. Individuals who own a unit in a multi-family building (e.g. condo) will face higher barriers to participation in housing decarbonization programs because changes to the building, such as replacing the HVAC system or changing the façade, require agreements among all the unit owners (Energy Programs Consortium, 2013).

Large-scale property owners of multi-family buildings often have higher capacities to engage in the complex and multi-step process required for the implementation of housing decarbonization measures. These landlords may have a property manager with the time and expertise to oversee a renovation project, including aspects such as conducting research into the different housing decarbonization options, running a financial cost analysis, applying for multiple sources of funding, managing contractors, and checking the quality of implementation (Nidam, 2019). Smaller-scale or nonprofit owners may face more barriers. While there are many factors and incentives that contribute to both large-scale landlords and small-scale "individual" landlords' likeliness to decarbonize their rental holdings, large-scale landlords report making more capital improvements to their rental properties than individual landlords. However, small-scale landlords spend more per unit on upgrades compared to large-scale landlords because they typically own single-family rentals which are generally larger and cost more to maintain than multi-family units (Joint Center for Housing Studies of Harvard University, 2020).

As noted above, for providers of subsidized affordable housing, the use of traditional HUD utility allowances may disincentivize them from electrifying their multi-family buildings. Traditional HUD utility allowances, which apply to various types of subsidized affordable housing, are designed to make housing more affordable by estimating the reasonable cost of utilities and subtracting this amount from the tenant's rent calculation. While this ensures that tenants in affordable housing do not pay an excessive portion of their income on utilities, the calculated allowances have been historically unlinked to actual consumption, assume that an increase in electric equipment results in higher energy bills, and do not accurately reflect the lower utility costs associated with energy-efficient, electrified buildings (Armstrong et al., 2022; HUD, 1998). As utility allowances rise and affordable housing providers are able to charge lower rents, providers that use traditional HUD utility allowances may be disincentivized from electrification and energy efficiency upgrades (York et al., 2022).

In 2005, the California Energy Commission (CEC) developed the California Utility Allowance Calculator (CUAC) to provide an alternative method for calculating utility allowances for affordable housing projects in the state. The CUAC allows affordable housing providers to calculate utility allowances based on actual energy consumption, accounting for several factors including the energy efficiency of properties. The CUAC calculation is more precise than traditional HUD utility allowances, results in potentially lower utility allowances and costs for tenants, and encourages the development of energy-efficient affordable housing (California Energy Commission, 2022). However, not all buildings are qualified to use the CUAC, as it is only intended for new affordable housing construction and some substantial rehabilitation projects. The CEC notes that the CUAC is not appropriate for existing buildings built to energy efficiency standards before 2005 or for projects that do not include energy efficiency or PV upgrades (California Energy Commission, 2022). According to the California Tax Credit Allocation Committee (CTCAC), which administers the federal and state Low-Income Housing Tax Credit (LIHTC) programs, only 15 to 25 percent of their developments have used the CUAC each year since 2011 (Armstrong et al., 2022). This means that a significant portion of California's existing subsidized affordable housing stock still uses traditional HUD utility allowances and may be disincentivized from electrifying their buildings.

Another concern for affordable housing providers is their ability to meet the California Building Standards Code (which applies to new and existing buildings), local building energy codes with requirements beyond state minimums, and building performance standards that aim to reduce GHG emissions (Kumar and California Housing Partnership, 2021). Many providers struggle to navigate costly and constantly changing standards and believe that federal, state, and local governments should provide additional support to the affordable housing sector to comply (Jarrah et al., 2024). Researchers suggest that regulations could be designed to maximize flexibility, like allowing for extended compliance timelines, creating alternative compliance pathways, and offering financial assistance. Providers also note that some local building codes prevent or make cost-prohibitive electrification and clean energy installations (Kumar and California Housing Partnership, 2021). For retrofits of manufactured homes, owners must comply with the National Manufactured Home Construction and Safety Standards as well as state and local building codes[7].

Electrifying can add significantly to a building's existing electrical load, with implications for the electricity panel. This presents another cost barrier, especially for multi-family buildings. Costs can range from $13,500 to $122,000 per building depending on the number of units and depth of upgrade (Aitchison et al., 2021; York et al., 2022). The lower limit represents a typical multi-family building that has 20 or fewer units and does not have major upgrade hurdles. The upper limit represents more complicated upgrades typically

[7] The Manufactured Housing regulations can be found in California Code of Regulations, Title 25, Division I, Chapter 3, Subchapter 2, commencing with section 4000. Federal regulations governing manufactured housing are located in Title 24, Code of Federal Regulations, beginning with Section 3282.1. Construction standards for manufactured homes are found in Title 24, Code of Federal Regulations, Chapter XX, Part 3280 .

associated with commercial or large multi-family properties (Aitchison et al., 2021). Physical space limitations may also pose problems as some heat pump water heaters and space heaters require more space for ventilation. Appliance size issues are especially challenging for multi-family, manufactured, and affordable housing units where space tends to be more limited (York et al., 2022).

Collective forms of tenure, such as cooperatives and shared equity and community land trusts, have aligned incentives to implement housing decarbonization measures. There are approximately 224 housing cooperatives in California which include 17,247 households and 2,164 student residents (Abell et al., 2021). Common to these tenure types is community-centered management that engages residents in decision-making about housing changes and works to maintain housing affordability and quality for residents. The literature cites many examples in which cooperative and community land trusts have equitably implemented housing decarbonization measures as well as other climate resilience measures (Grannis, 2020; Lamb et al., 2022; York et al., 2022). Even so, cooperative and community land trusts would benefit from additional technical assistance to bridge information gaps, data on the costs and benefits of the proposed project, and financial strategies to recover collective costs and maintain housing affordability.

Lastly, homeowner associations (HOAs) are a prominent form of residential governance which use codes, covenants, and restrictions to govern the ways that their members engage in alterations to their homes. Carr and Kramer (2022) found that HOA clauses can create more barriers to sustainable residential development than opportunities. The researchers found that HOA restrictions can include “no energy production” clauses, prohibiting the installation of solar panels. Although these restrictions can generally be contested within the HOA, these restrictions have implications for scaling decarbonization efforts, as 65 percent of owner-occupied homes in California live within an HOA (Foundation for Community Association Research, 2023). The researchers noted that HOAs have an untapped potential to encourage electrification through their policies (Carr and Boyd Kramer, 2022).

3.6. Perceptions, Knowledge, and Concerns about Decarbonization

The knowledge of and desire for decarbonization varies across diverse communities.

First, households are concerned about increasing utility bills. As long as the price of electricity is higher than the price of natural gas, there is a risk that decarbonization upgrades will increase total utility bills (Borenstein et al., 2021). Therefore, decarbonization program designs must consider the household’s energy bill after implementation to ensure equity in outcomes.

Second, households are concerned that electricity service is unreliable. In recent years, California residents have experienced an increasing frequency and duration of public safety power shutoffs (PSPS) due to extreme weather conditions and as a strategy to avoid wildfires (Bedsworth et al., 2018). These events affect household decision-making with regards to decarbonization. Some residents hesitate to switch to all-electric cooking and heating because they fear those appliances will not be usable during an outage. Other households that have had more experience with outages are more likely to adopt solar and batteries as a way to protect themselves from the impact of future outages (Zanocco et al., 2021).

Third, households might not understand how to use new appliances or how to operate them for maximum efficiency (Scavo et al., 2016). Lessons learned from the San Joaquin Valley (SJV) pilot show that even among those households that received no-cost installation of electric stoves and thermostats, there was a challenge in maintaining use of these new appliances due to lack of knowledge on how to operate them. Induction stoves also require a new set of pots and pans that work with induction cooktops, and those are often not provided with installation (DePew et al., 2022; Evergreen Economics, 2022).

Knowledge and motivation are also critical to household adoption of decarbonization measures. In an analysis of the literature on households' willingness to electrify their homes, Brown et al. (2023) find that knowledge about the technology, such as how it works as well as its costs and benefits, is a key driver of adoption. They also find that pro-environmental attitudes are key for the adoption of solar panels and electric vehicles, yet they do not appear to influence heat pump adoption. Other studies have found that environmental messaging is less effective among self-reported conservative households (Gromet et al., 2013).

The role of peer influence on customer attitudes, demand, and adoption of energy efficiency and clean energy technology is an area of emergent study (Axsen and Kurani, 2012; Bollinger et al., 2022; Graf-Vlachy et al., 2018; Sintov and Schultz, 2015; Wolske et al., 2020). Through an analysis of rooftop PV installation records in the United States, O'Shaughnessy and colleagues (2023) found that customer demand for rooftop PV can be influenced by peers within their income group. However, the researchers found that peer influence is weaker for LMI households compared to non-LMI households. These results suggest that low-income peer influence is stymied by barriers to low-income adoption, exacerbating inequitable adoption of emerging technologies. In a study in the UK, Hamilton et al. (2019) found that attitudes and practices around energy are influenced by peer stigma. Interviewees in the study noted that stigma around concern for the environment, social justice, money, "preaching," or energy being an off-putting subject are barriers to talking about energy conservation among peers. The researchers, however, noted that respondents were most likely to have a conversation about energy with family members, neighbors, and those with whom they have strong social ties. In sum, these studies signal the importance of considering the psychosocial, cultural, and community dimensions of program targeting, engagement, and adoption. Customer buy-in is influenced by the quality, quantity, visibility, and spread of social connections and virtuous behavior, not only economic policies and incentives (Bollinger et al., 2022; Caferra et al., 2023).

3.7. Workforce

In 2022, California's energy efficiency[8] and solar energy sectors employed 294,396 and 115,251 workers, respectively, the most of any state in the U.S. (Department of Energy, 2023). Employment opportunities in these sectors are expected to grow by up to 80,600 new jobs by 2045 in the existing building retrofit industry alone. This industry holds the largest job growth potential in California's energy sector. For residential retrofits specifically, researchers found that 26,000 to 39,300 new jobs could be created by 2045 (Jones et al., 2019). Despite the sector's optimistic outlook and anticipated growth, California energy employers are challenged by workforce development and availability issues, limiting their ability to meet residential decarbonization demand (Department of Energy, 2023, 2017; Foster et al., 2020; Stange, 2019; Thomason et al., 2024). The lack of a qualified and diverse energy workforce has created a bottleneck in the wide deployment of energy efficiency and electrification technologies at the household scale, posing a barrier to meeting statewide GHG emissions reduction targets.

Factors explaining the shortage of skilled workforce, described in more detail below, include lock-in to familiar energy-inefficient technologies, lack of training on new technologies that further exacerbates the skills gap, uncertainty about work stability and lower wages in the construction sector, and insufficient recruitment of employees from underserved communities. While these factors affect the broad deployment of energy efficiency programs, low-income households will be more severely affected by factors that increase costs, and communities of color will be more affected by factors that limit diversity (Dunn et al., 2005; E2 et al., 2021; Reames, 2016).

Lock-in refers to two related situations:

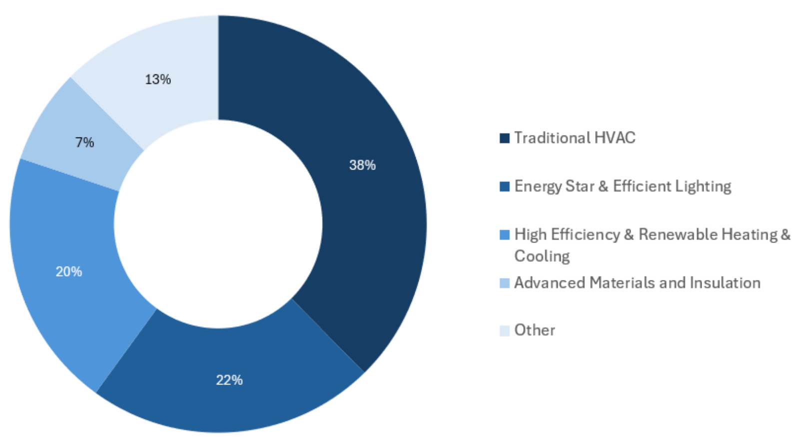
(1) Contractors are "locked in" to older, less efficient technologies due to familiarity, perceived reliability, longstanding industry practices, or ease of installation.
(2) Failing to retrofit buildings to contemporary decarbonization standards "locks in" decades of inefficient, high-energy consumption patterns.

In 2022, 38% of employment in the energy efficiency sector was for firms that manufacture, sell, install, or otherwise work with traditional HVAC products and services (Figure 2). Contractors are risk-averse when it comes to their businesses and typically promote and install systems that they know and trust. Additionally, some contractors are frustrated by continuously having to incorporate new technologies into their business

[8] The U.S. Department of Energy defines energy efficiency employment as work that "includes both the production of energy-saving products and the provision of services that reduce end-use energy consumption" (DOE Chapter 5).

models and are more interested in providing an uncomplicated service than promoting equipment that can be difficult to explain and install (Foley, 2022). The fear of customer dissatisfaction, which can be mitigated by customer education, has compelled some contractors to add risk premiums to the installation of new technologies and equipment to offset risk (Foley, 2022). This "lock-in" to traditional HVAC systems and resistance to new technologies, despite their benefits for customers, results in the second type of "lock-in" for residents, committing them to decades of energy inefficiency. Both types of lock-in also impede new technology's market penetration.

Figure 2: Energy Efficiency Employment by Detailed Technology Application in California



Source: 2023 US Energy and Employment Report by State
https://www.energy.gov/sites/default/files/2023-06/2023%20USEER%20States%20Complete.pdf

Workforce skill gaps and insufficient training are significant barriers to energy sector growth and ability to meet demand. In 2022, 95 percent of construction firms working in energy efficiency reported difficulty hiring qualified workers, especially those skilled in low-carbon technologies (Foster et al., 2020). They reported high competition, small applicant pools, and lack of candidate experience, training, and technical skills as major impediments to their businesses growth (Department of Energy, 2017; Foster et al., 2020; Thomason et al., 2024). The research literature primarily attributes the lack of a large enough qualified workforce to two explanatory factors.

First, decades of decline in vocational electricity industry training programs contributes to the workforce sufficiency gap (Center for Energy Workforce Development, 2023; Department of Energy, 2017; E2 et al., 2021; Stange, 2019). Beginning in the 1980s, economic and cultural shifts towards a four-year college education coincided with the decline of trade or vocational schools. This undervaluing of vocational education and lower than expected growth in the electricity industry resulted in lower enrollment, reduced public funding, and subsequently led to the closure of many technical high schools

(Department of Energy, 2017; Jacob, 2017; Stange, 2019). Currently, the electricity workforce is primarily trained in community colleges, apprenticeship programs, and certificate programs, which has led to a lack of uniformity of standards and curricula. Furthermore, as a high share of the existing workforce retires, they also take with them industry experience, impeding knowledge transfer to new employees (Department of Energy, 2017).

Second, current skill gaps can be partially attributed to the constant evolution and emergence of new technologies and the fact that it takes a significant amount of time and money to train workers on these technologies (Department of Energy, 2017). Aligning the workforce's skill sets and training with the most updated technologies is crucial to market penetration and resultant reductions in GHG emissions. However, uncertainty over whether a new technology will be widely adopted influences contractors' willingness to spend time and money for their employees to be trained on that technology. Additionally, the construction sector's highly cyclical nature means that employers hire employees when work is available but let go of workers when a project is completed, the season comes to an end, or the economy slows. As a result, there are few incentives for contractors to incur the expense of employee training without a guarantee of employee retention (Duncan and Ormiston, 2019).

Paired with "lock-in" discussed earlier, these factors reinforce the cycle of limited adoption and insufficient skilled labor of electrification technologies. For example, the heat pump market share is relatively low, and in most regions of the U.S., contractors are largely unaware of their applicability (Foley, 2022). When inexperienced contractors install heat pumps improperly or incorrectly size the system to the home, customers can experience lower-than-anticipated energy savings. This can result in contractors getting call-backs from unsatisfied customers and contractors being less likely to promote heat pumps in the future, further limiting adoption (Foley, 2022). These self-reinforcing issues have resulted in the shrinking of some energy-efficiency construction firms' workforce despite predictions of sector expansion. In 2023, contractors working in "high efficiency and renewable heating and cooling" and "advanced materials and insulation" only accounted for 27 percent of the energy efficiency workforce (Department of Energy, 2023). These issues also negatively impact firm performance, the deployment of energy efficiency technologies, and downstream reductions in GHG emissions (Foster et al., 2020; Truitt et al., 2022).

Low wages and uncertainty about the stability of demand create barriers to the expansion of the workforce for decarbonization projects. In California, most public programs that fund residential decarbonization projects do not include labor standards (Thomason et al., 2024), and the workforce sector for residential decarbonization is generally not unionized (E2 et al., 2020). As a result, new employees entering the sector face high uncertainty about wages and benefits. For example, a recent study of the Bay Area residential decarbonization industry and workforce reveals that the median hourly wage of Bay Area residential decarbonization workers is $32.87 per hour, lower than the median wage for all residential and commercial construction workers ($34) and workers across all industries ($36) in the Bay Area (Thomason et al., 2024). These wage gaps, coupled by uncertainty about the continuity of public funding to support demand for residential decarbonization, contributes to challenges in training construction workers in residential decarbonization.

A recent study found that establishing requirements for prevailing wage or a wage standard on decarbonization projects would have broad societal benefits, including improving earnings and benefits for workers, increasing racial equity in worker earnings, and increasing economic activity (Thomason et al., 2024). However, the report also found a modest increase in consumer costs, which may pose barriers to decarbonization projects especially for lower-income households. Prevailing wages can also impose administrative burdens, especially for smaller contractors. Overcoming these challenges will be critical for long-term equitable decarbonization efforts.

Racial and gender diversity in the workforce will be crucial as the energy efficiency sector expands to avoid the risk of leaving communities of color behind (E2 et al., 2021; Truitt et al., 2022). Research on barriers to energy efficiency program participation in low-income neighborhoods shows that a workforce that reflects the community it works in can positively impact residents' perception and willingness to participate (Reames, 2016). A case study in Kansas City, Missouri, showed that hiring all-Black staff members to promote the Weatherization Assistance Program in a majority Black neighborhood fostered more credibility for and trustworthiness in the program (Reames, 2016). Moreover, numerous studies underscore the tangible benefits of a diverse workforce, including enhanced financial performance, stronger customer orientation, increased employee satisfaction, and heightened innovation (Truitt et al., 2022, 2022).

Race and gender gaps in the construction workforce are shaped by a number of factors, including racial discrimination in access to education and gender bias in the industry. The lack of access to STEM educational opportunities for Black, Indigenous, People of Color, and women contributes significantly to underrepresentation in the energy sector (Department of Energy, 2017). Additionally, the construction industry has a historically poor record of gender and racial/ethnic parity in the workforce. Professions involving manual labor are typically male-dominated, driven by the unfair perception of women's capabilities and both explicit and implicit gender bias (Azhar and Griffin, 2014). These issues are compounded by outdated industry practices that fail to address the diverse economic backgrounds, cultural values, and prior experiences of underrepresented groups, further hindering recruitment and retention (Truitt et al., 2022).

As a result, race and gender disparities are common in the industry. Sixty-one percent of clean energy workers across the United States are non-Hispanic white individuals, while women constitute only 25 percent of the energy efficiency sector and a mere 4 percent of solar industry installers. Additionally, Black, Hispanic, Latine, and multiracial workers remain underrepresented across both industries (E2 et al., 2021). This lack of racial diversity in the clean energy and energy efficiency sectors has the potential to negatively affect program success in communities of color, especially those which experience intersecting barriers related to distrust of government and others (Reames, 2016). Therefore, racial and gender diversity in the workforce is viewed as a critical component of equitable decarbonization (E2 et al., 2021).

The energy efficiency sector reaches every community in California. Its growth is a consequential bridge for reaching a low-carbon society while creating significant economic opportunity (Energy Futures Initiative, 2019). Addressing workforce development challenges is crucial to realizing the multiple benefits of statewide decarbonization, including improving the economic health of California communities, supporting new technology adoption, ensuring a robust electricity system, and achieving GHG emissions reduction goals.

3.8. Social Factors

Social factors affect both the existing conditions people live in and their ability to improve those conditions. Prior research has identified bias based on race, age, disability, language, and immigration status as factors that are associated with both living in energy inefficient homes and disproportionately lower participation rates in decarbonization programs (Adua et al., 2022; Goldstein et al., 2022; Pigman et al., 2021).

Race

Structural racism refers to “the totality of ways in which societies foster racial discrimination through mutually reinforcing systems of housing, education, employment, earnings, benefits, credit, media, health care, and criminal justice” (Bailey et al., 2017). As such, structural racism is a recognized cause of housing inequalities in the United States (Bailey et al., 2017; Swope and Hernández, 2019), which in turn affects the ability of non-White households to participate in housing decarbonization programs through several mechanisms. First, due to a history of residential segregation and contemporary reinforcing practices, communities of color disproportionately inhabit homes of lower quality and lower energy efficiency (Goldstein et al., 2022; Swope and Hernández, 2019). As a result of the difference in the quality of homes, communities of color face higher barriers related to the condition of the home such as the need to remediate lead or asbestos, fix structural issues, or upgrade the electrical panels.

Second, residential segregation also leads to neighborhood-level differences relating to thermal comfort and air quality. Jesdale et al. (2013) found that residential segregation is associated with higher exposure to extreme heat among communities of color, which is attributed to a lack of trees and vegetation in urban environments along with higher building density (Jesdale et al., 2013). Morello Frosch et al. (2018) found that extreme heat waves disproportionately impact low-income people and people of color, who have higher exposure to extreme heat and limited access to coping tools such as air conditioning (Frosch et al., 2018). In California specifically, communities across the state are projected to experience higher average temperatures and more frequent and severe heat waves (California Natural Resources Agency, 2022). Histories of redlining and urban renewal have also resulted in contemporary disparities in access to green space (Hoffman et al., 2020; Nardone et al., 2021) and proximity to pollutant-creating infrastructure, such as freeways and industrial centers, which are disproportionately located near low-income communities of color. A recent analysis of CalEnviroScreen 4.0 revealed that Latine and Black Californians disproportionately reside in areas impacted by environmental pollution (OEHHA, 2021). Along with public health and other environmental justice issues, proximity to high-polluting industries and infrastructure can also contribute to higher energy consumption in exposed areas. For instance, He et al. (2020) found that higher energy usage associated with HVAC systems is a “human defensive behavior on the demand side” to cope with exposure to high concentrations of particulate matter. Consequently, households living in neighborhoods with higher exposures to extreme weather and pollution have both higher exposure to environmental and climate hazards and higher energy demands.

Third and relatedly, residential segregation leads to geographic differences in energy infrastructure and costs. Communities of color affected by historical redlining continue to experience infrastructure divestment, which can include being serviced by lower-quality energy facilities and systems. Infrastructure divestment can result in higher energy costs and worse health outcomes for residents in these areas. Cranmer et al (2023) found that power plants are more frequently located in low-income communities of color in states with the highest racial, ethnic, and economic diversity. These power plants create air pollution that leads to detrimental health outcomes, and their retirement is associated with improved health outcomes such as a reduction in asthma rates and pre-term birth (Casey et al., 2018, 2020; Daouda et al., 2021; Cushing et al., 2023). In addition, reduced access to renewable energy and lower grid capacity reduces the ability of these households to engage in decarbonization measures, as discussed in more detail in the section on electricity infrastructure and rates (Brockway et al., 2021; He et al., 2020).

Fourth, difficulties with affording the upfront costs of decarbonization measures are exacerbated by historical and contemporary racial disparities in access to financing and homeownership. Communities of color have historically faced significant barriers to homeownership because of redlining, racially restrictive housing covenants, and discriminatory mortgage lending practices. Lower rates of homeownership among non-White households, especially Black and Hispanic households, limits generational wealth-building and precludes them from the benefits that homeownership affords (Reid, 2021). Additionally, racial discrimination in housing has contributed to the suppression of housing values in non-White communities, further undermining wealth accumulation. These factors have many downstream effects, as housing and neighborhood conditions are linked to health equity, access to credit, and a household's ability make long-term investments in the conditions of their home (Bocian et al., 2011; Center for Sustainable Energy, 2016; Reid, 2005; Reid, 2021; Swope and Hernández, 2019). These disparities in homeownership, access to credit, and eligibility for financing affect a household's ability to secure financing for energy efficiency and electrification upgrades (Davis et al., 2023), especially for households that are not wealthy enough to qualify for credit or low-income enough to qualify for public assistance (Hummel and Lachman, 2018).

Fifth, it is critical to recognize the social dynamics tied to race that may impede decarbonization. Distrust in government, utilities, and other institutions is a significant barrier that affects some households' participation in programs (Reames, 2016; Sovacool, 2009). Overcoming community distrust related to decades of divestment, duplicitous promises of socially beneficial development, and lackluster implementation requires tactful and longitudinal commitment from decarbonization program designers (Reames, 2016). Distrust can impact all phases of program implementation, from initial outreach to reducing propensity to engage in audits and follow-ups (Kleeman et al., 2023; Tozer et al., 2023). Failing to build relationships and trust between program implementers and communities can result in programs that do not adequately meet the needs of high-priority households (BEEP Coalition, 2023; Evergreen Economics, 2022; Reames, 2016).

While decision-makers in California are prohibited from using race as a direct factor in the allocation of resources in policy and program design due to Proposition 209, they are still bound by legal standards for compliance with federal civil rights. As such, agencies responsible for decarbonization programs still have an obligation to structure and evaluate their regulations, policies, and practices to ensure that they do not undermine equal protections and opportunities based on race or other protected classes.

Age and Disability

There are unique barriers to engaging in decarbonization associated with age, disability, and retirement status. Research across three decades of Residential Energy Consumption Survey (RECS) data shows that there is a strong relationship between age and increased residential energy consumption (Estiri and Zagheni, 2019), even after accounting for income, housing type, and climate. The researchers attributed this to the general increase in home size over the life course. They found that energy usage was lowest among young adults, increasing through adulthood to reach a peak around the age of 55, and then a decrease in consumption between the ages of 60 and 80, and then another increase in energy usage for people older than 80. Given increasing energy costs, vulnerability to extreme temperatures, and reliance on critical electric medical devices, decarbonization could have an outsized positive impact on older and disabled residents (Ahrentzen et al., 2016).

For older or disabled residents who collect social security, Social Security Disability Insurance, or who otherwise have low- or fixed incomes, their ability to make large upfront investments in home renovations and upgrades is limited. Costs can be prohibitive for these households, which may already experience energy insecurity, fuel rationing, and fuel poverty (Tonn and Eisenberg, 2007). Even if upfront cost is not an issue, depending on the retrofit package chosen, energy savings payback periods range from five to 30 years (Brecha et al., 2011; Leinartas and Stephens, 2015; Liang et al., 2018), which may impact an older homeowner's decision to invest. Research has also shown that difficulties and expenses associated with modifying the home may prompt larger doubts about whether remaining in the home is the best choice or not (Herbert and Molinsky, 2019).

For older or disabled individuals who depend on electronic medical devices, such as CPAP machines, ventilators, or electric wheelchairs, there are additional barriers and risks related to decarbonization access. First, these devices may necessitate higher energy use in the home (Schipper, 1996). Second, power outages can disrupt and render essential medical devices non-functional, possibly leading to severe health complications (Do et al., 2023). Lastly, medical devices may limit residents' ability to have extensive home renovations completed. Working with and around installed assistive and mobility devices in the home can make retrofits challenging and costly (Herbert and Molinsky, 2019).

Lastly, negative perceptions and concerns about decarbonization measures may be more prevalent among older adults. Knowledge and technological skill gaps reduce their propensity to adopt new smart-meter and smart-home technologies (Courtney et al., 2008). Additionally, skepticism and fear of smart technologies present social barriers to adoption (Lee and Kim, 2020). In combination, all of these factors impact the propensity of older adults to engage with decarbonization.

Immigration Status and Language

From program design to implementation, equitable deployment of decarbonization initiatives can be limited by barriers related to immigration status and language. Immigrant communities make up a significant portion of low-income and energy-burdened households (BEEP Coalition, 2023). Moreover, immigrant communities are more likely to live in disinvested areas and bear the disproportionate impacts of climate change (Morales and Nadel, 2022; PODER and Emerald Cities, 2020).

Some government programs, such as the Low-Income Home Energy Assistance Program (LIHEAP) and WAP, are designed with citizenship and lawful permanent resident requirements, excluding many immigrant communities from benefits and services. Additionally, policies that prioritize citizens, by design or inadvertently, can contribute to disparities in access based on immigration status. Undocumented immigrants are less likely to engage in government programs, even if they are eligible, due to concerns about legal consequences, immigration enforcement, or being vulnerable to exploitation or misinformation (Healthy Neighborhoods Study, 2020; Marin Clean Energy, 2021; Piser, 2021; Stutz et al., 2019). Research also indicates that these households are less likely to complain about, and therefore more likely to accept, substandard housing conditions (Kirk, 2023; Swope and Hernández, 2019). The significant overlap between high-priority communities and immigrant communities makes reducing barriers to their participation paramount to the design of equitable decarbonization programs.

Over 52 percent of immigrant residents in California have limited English proficiency. Among non-citizen immigrants, this figure is over 61 percent (American Community Survey, 2021). In a study of 66 program evaluations in California, researchers found that language gaps have significant impacts on low-income customer participation as whole-home retrofit program participants are disproportionately White, English-language speakers, homeowners, and have incomes over $100,000 (Frank and Nowak, 2016). There are also significant gaps in awareness of decarbonization programs between households that do and do not speak English as their primary language. Moreover, these gaps are exacerbated by the complexity and challenge of navigating programmatic language and requirements (Scavo et al., 2016). Scavo and colleagues (2016) cite one 2013 survey that found that 32 percent of eligible low-income customers were unaware of the Energy Savings Assistance (ESA) Program. Among households for whom English was not the primary language, the awareness gap was 16 percent greater compared to households whose primary language was English. As a result, the researchers note that specialized and culturally-relevant marketing, outreach, and education in multiple languages in program design can greatly increase program access.

Individuals facing multiple intersecting barriers, such as being undocumented with limited English language proficiency, may experience cumulative disadvantages navigating decarbonization programs and, in some cases, effectively bar them from accessing benefits.

4. Equity Implications for Program Implementation

The United States and other nation members of the Organization for Economic Cooperation and Development (OECD) have over 50 years of experience in the implementation of housing decarbonization programs. In response to the energy crisis in the late 1970s, the United States and OECD members introduced new policies and programs to reduce energy demand in buildings and protect lower-income households from volatile energy prices (Allcott and Greenstone, 2012; Economidou et al., 2020). Decades of energy efficiency program implementation have yielded significant insights into the barriers and opportunities for housing decarbonization, as well as changes in implementation approaches.

In the U.S., residential electricity use per capita increased by an average of 3 percent per year from 1960 to 2010 (EIA, 2021), due in part to larger home sizes that offset energy efficiency gains. During the same time period, residential electricity use per capita in California has remained flat from 1975 to 2005, a trend explained by a combination of factors including higher electricity prices, higher dependence on natural gas for space and water heating, lower energy needs due to a more temperate climate, and energy efficiency regulations such as building codes, appliances codes, and utility-scale energy efficiency programs (Rosenfeld and McAuliffe, 2008).

Nationally, following the large-scale investment in energy efficiency spurred by the American Recovery and Reinvestment Act (ARRA) of 2009 and warmer weather, residential electricity use per capita has fallen by 5 percent between 2010 and 2020 (EIA, 2021). While this progress is encouraging, it is also much slower than expected and needed to meet climate mitigation goals. There are also significant inequities in access to housing decarbonization measures among priority communities (Reinhart et al., 2021; Goldstein et al., 2022). The 2021 Infrastructure Investment and Jobs Act and the 2022 Inflation Reduction Act offer new streams of expanded public investment in housing decarbonization (DeFazio, 2021; Yarmuth, 2022). There is a need to improve the understanding of the equity implications of these implementation pathways, so that public funds can be directed to programs that can have higher participation rates and avoid unintended negative impacts on priority communities. Gains in knowledge of effective norms and approaches can also support the practitioner and program design community.

In this section, we distinguish between three types of approaches to implementation: welfare approaches, market-based incentive and regulatory approaches, and community-based approaches. **Welfare approaches** target individual households and are designed to shield extremely low-income households from the negative impacts associated with the inability to afford energy services. Their primary objective is to ensure the provision of housing-related energy solutions to vulnerable populations. **Market-based incentive and regulatory approaches** endeavor to create financial incentives to drive the implementation of housing decarbonization initiatives at scale. These target both individual households and the supply chain of energy efficiency and decarbonization equipment manufacturers and installers. By introducing economic motivations, governments aim to spur market-driven solutions that accelerate the transition to low-carbon housing. **Community-based approaches** are place-based initiatives that center on addressing the specific needs of households living in a particular geography and that often share commonalities in climate exposure, energy prices, building types, income, and attitudes towards decarbonization. By engaging communities actively in the decarbonization process, state and local governments seek to tailor strategies to the unique characteristics of particular places.

This approach to classifying decarbonization programs seeks to highlight distinct trends in problem-framing and response strategy, advancing our understanding of implementation approaches in new ways. Each of these implementation approaches carries distinct equity implications. The ensuing discussion outlines these approaches, cites exemplar programs, and explores the structural dimensions of these efforts, specifically in terms of power dynamics, inclusivity of voice, and allocation of resources.

4.1. Welfare approaches

Welfare approaches to housing decarbonization refer to government policies and programs that provide direct install energy retrofits to households experiencing poverty. In contrast to programs that provide immediate assistance to households that cannot afford energy bills (e.g., bill assistance), welfare decarbonization programs provide funding to reduce the energy demand in the home, leading to decreased energy bills (Brown et al., 2020; Drehobl and Ross, 2016). The rationale for this approach is that the energy cost burdens and their contribution to poverty can be alleviated through the improvement of housing conditions (Tonn et al., 2021).

Policymakers designing welfare approaches must answer two important questions:

(1) **Program targeting**: Which segment of the population should be eligible for government assistance (i.e., how to define the energy dimensions of poverty)?
(2) **Program design and implementation**: What type of assistance should be provided to eligible households?

The answers to these questions determine the amount of funding needed, and the scale and scope of the decarbonization program (Moore, 2012). Furthermore, program designers may seek strategies to ensure that eligible households, such as low-income homeowners and renters, are able both to participate in these programs and be protected from displacement (Chelsea Kirk, 2021).

Welfare approaches to housing decarbonization have a long history. In the past 50 years, eligibility requirements and program designs have significantly changed and evolved. Currently, the two prominent models for the delivery of welfare approaches in the U.S. include government weatherization programs and energy utility low-income programs. Below, we first discuss the evolution of eligibility criteria for energy assistance programs, and then lessons learned from two prominent long-lasting and large-scale government housing decarbonization programs targeting priority communities in the U.S. and the UK, and lastly, lessons learned from utility-operated, low-income programs.

Program Targeting: Development of Definitions and Metrics for Eligibility for Energy Assistance Programs

How should program designers define the energy dimensions of poverty? This subsection reviews the development of eligibility definitions and metrics for energy assistance programs. The earliest concept is referred to as **energy burden**, calculated as the share of household annual income spent on residential energy expenditures, which is then compared to an established “too high” threshold (Tonn et al., 2021). UK scholar Brenda Boardman, in her seminal book *Fuel Poverty*, was the first to articulate this concept. She defined fuel poor households—or energy burdened—as those that spent more than 10 percent of their income on fuel (Ambrose and Marchand, 2017; Boardman, 1991). Boardman’s metric was based on the 1988 Family Expenditure Survey for UK households, which showed that 30 percent of households with the lowest incomes were spending an average of 10 percent of their income on fuel (Liddell et al., 2012).

In the U.S., there has been a scholarly debate on the threshold for energy burden, with several studies suggesting a 6 percent cut off, based on the notion that housing costs should not exceed 30 percent of income, with no more than 20 percent of housing costs allocated for energy (Brown et al., 2020; Heleno et al., 2022; Scheier and Kittner, 2022). Despite a lack of consensus on the threshold that defines energy burden, studies in the U.S. have consistently shown that low-income households have double to triple the energy burden of non-low-income households (Drehobl and Ross, 2016; Hernández and Bird, 2010).

In the past two decades, there has been a growing critique of using energy burden as the sole indicator of eligibility for energy assistance programs. In an evaluation of the use of the 10 percent energy burden metric to evaluate changes in fuel poverty in the UK, Hills (2011) found that when energy burden is calculated as energy costs divided by household income, a rise in the price of fuel can increase energy burden and mask the contributions of home energy retrofit programs. Other scholars have shown that this metric fails to account for residents' demographics and is insensitive to regional differences in income, cost of living, weather, energy consumption, and cost of energy services (Liddell et al., 2012; Agbim et al., 2020). Further, the energy burden indicator is not able to capture households that limit their energy consumption due to affordability concerns (Hernández, 2013).

Following decades of research and experience with the implementation of housing decarbonization programs, the UK government adopted the Low-Income Low Energy Efficiency (LILEE) indicator to measure **fuel poverty** in 2020. Under the **LILEE indicator**, a household is considered to be fuel poor if “*they are living in a property with a fuel poverty* *energy efficiency rating of band D or below*[9]*, and when they spend the required amount to heat their home, they are left with a residual income below the official poverty line*" (Department for Business, Energy & Industrial Strategy, 2022). The LILEE indicator depends on the interaction of three key drivers: (1) household income as a marker of financial stability; (2) household energy requirement as a marker of the energy efficiency of the housing unit; and (3) fuel prices, which reflect sensitivity to changing market conditions at the year of measurement. The new UK fuel poverty definition improves upon the previous income-based definition by distinguishing between low-income households that live in energy-efficient homes and those that do not, while also accounting for volatility in energy prices.

Further expanding the understanding of the interaction between energy services, housing quality, and poverty, U.S. scholars have proposed several definitions that seek to be more comprehensive. Hernández (2016) defines the term **energy insecurity** as "an inability to adequately meet basic household energy needs." She argues that energy insecurity is a *"multi-dimensional construct that describes the interplay between physical conditions of housing, household energy expenditures and energy-related coping strategies"* (Hernández, 2016). Similarly, Bednar and Reames (2020) propose to define U.S. **energy poverty** as *"a state where households are challenged by everyday situations in meeting basic energy needs because of an assemblage of socio-economic, technical and environmental-political factors. Factors known to be associated with energy poverty include gender, age, housing age, tenure type, energy inefficiency, education, employment, geography, socioeconomic status and race/ethnicity."* Both definitions integrate social and behavioral factors into the understanding of the interaction of energy and poverty.

While the U.S. does not have a formal definition for household-level energy poverty, the federal government started measuring household-level energy insecurity in 2015 through the Residential Energy Consumption Survey (RECS). The survey classifies a household as energy insecure if they report one of the following five experiences: (1) reducing or forgoing food or medicine to pay energy costs, (2) leaving the home at an unhealthy temperature, (3) receiving an energy service disconnect or delivery stop notice, (4) being unable to use heating equipment, or (5) being unable to use air conditioning equipment (RECS Survey, 2020). The markers of energy insecurity measured in the RECS survey represent a shift in the understanding of the interaction between energy and poverty and an effort to track the lived experiences of individuals at risk. Data from the 2020 RECS implies that 27 percent of U.S. households experience at least one type of energy insecurity. A previous report that only used being behind on utility bills, disconnections, and utility shutoffs as indicators of energy insecurity found that 25 percent of California households are energy-insecure (Sandova and Toney, 2018). Despite the differences in approaches, both studies find or

[9] Band D or below on the Energy Performance Certificate (EPC) scale identifies properties with low energy efficiency, leading to higher energy costs for heating and lighting.

imply that about 25 percent or more of California residents cannot meet their energy needs.

More recently, the U.S. government formalized energy assistance program guidelines for eligible communities. As of 2021, a Biden Administration initiative called Justice40 directed that 40 percent of benefits from federal climate related programs[10] flow to "disadvantaged communities" (Young et al., 2021). To identify disadvantaged communities, the White House developed a Climate and Economic Justice Screening Tool (CEJST), which uses multiple indictors to identify approximately 27,251 census tracts across the U.S. as disadvantaged. Census tracts are considered disadvantaged if their population is at or above the 65th percentile for being low-income[11] and if they meet the thresholds for at least one of the tool's categories of burden: climate change, energy, health, housing, legacy pollution, transportation, water and wastewater, or workforce development. Census tracts on land within the boundaries of Federally Recognized Tribes are also recognized as disadvantaged communities (Council on Environmental Quality, 2022). The establishment of a geographic neighborhood-based definition for energy assistance programs signified an important recognition of the multi-dimensional, social determinants of energy insecurity to inform implementation of government assistance programs.

In California, the CPUC utilizes several metrics to define vulnerable communities relative to energy services and environmental justice:

(1) **The Affordability Ratio (AR)** is a PUMA[12]-level energy burden metric that quantifies the percent of a household's income used to pay for an essential utility service after non-discretionary expenses, such as housing and other essential utility services, are removed from the household's income (CPUC, 2023). This metric aims to be more sensitive to local variation in income and housing costs by calculating energy burden after housing expenses are deducted.
(2) **The Hours at Minimum Wage (HM)** metric describes the number of hours needed to work at minimum wage to pay for essential levels of utility service. This metric accounts for the lowest legal wage in a given location, and as a result implicitly considers the impact of utility bills on lower-income customers regardless of the affluence of the community as a whole (CPUC, 2023).
(3) The CPUC uses three metrics to account for social factors:

[10] Justice40-covered programs are federal programs that make covered investments in any one of the following seven categories: climate change, clean energy and energy efficiency, clean transit, affordable and sustainable housing, training and workforce development, remediation and reduction of legacy pollution, and the development of critical clean water and wastewater infrastructure (Young et al., 2021).
[11] Percent of a census tract's population in households where household income is at or below 200% of the Federal poverty level.
[12] PUMA (Public Usa Microdata Area) is a geographic area used in the American Community Survey.

a. **The Socioeconomic Vulnerability Index (SEVI)** describes the relative socioeconomic characteristics of census tracts, referred to as communities, in terms of poverty, unemployment, educational attainment, linguistic isolation, and percentage of income spent on housing. The goal of the SEVI metric is to highlight those communities where uniform changes in rates may have a disproportionate impact on affordability.
b. **Areas of Affordability Concern (AAC)** identifies specific areas in California where lower-income households have difficulty affording each essential service in the AR compared to the rest of the state.
c. **Disadvantaged Communities (DAC)** identifies vulnerable communities as developed by CalEPA and is primarily based on CalEnviroScreen (CES) scores (CPUC, 2023).

The CPUC report for 2021/2022 found that the AR, HM, and SEVI metrics consistently identified many of the same communities as being the most vulnerable. This suggests that poverty, pollution burdens, and high nondiscretionary expenses share a common footprint. The most vulnerable areas in California include census tracts in the Central Valley, the Los Angeles area, and the Bay Area (CPUC, 2023).

Program Design and Implementation: Lessons Learned from Government Programs in the UK and the U.S.

Both the UK and the U.S. have implemented nationwide housing decarbonization programs that are similar in targeting, design, and implementation. The UK implemented a program called “Warm Front” between 2000 and 2013, and the U.S. has implemented the Weatherization Assistance Program (WAP) since 1976. Both programs are designed to deliver insulation and heating equipment upgrades to low-income households. These programs provide important lessons for housing decarbonization programs.

First, the income-based eligibility criterion used by both programs was ineffective in reaching the target population. The UK government drew on Broadman’s scholarship to define fuel poor households as those that “*spend more than 10 percent of their income on all fuel use and to heat their home to an adequate standard of warmth”* (Liddell et al., 2012). The U.S.– which doesn’t formally recognize energy poverty–utilized a general poverty definition to determine eligibility for energy assistance. To participate in WAP, households must meet the 200 percent federal poverty line criteria or be eligible to receive other forms of aid[13] (Bednar and Reames, 2020). In both cases, the use of income-based criteria has

[13] WAP eligibility criteria: households at or below 200% of the poverty income guidelines or households that receive Supplemental Security Income or Aid to Families with Dependent Children. In addition, each state or territory may elect to use the U.S. Department of Health & Human Services (HHS) Low-Income Home Energy Assistance Program (LIHEAP) criteria of 60% of state-median income.

been criticized for not accurately capturing energy-poor households (Bednar and Reames, 2020; Hills, 2011).

In the UK, difficulty in targeting poor homes led to some of the funds being disbursed to low-income households whose homes were already energy efficient. In addition, between 42 and 57 percent of fuel-poor households did not participate, with one study suggesting that they either did not consider themselves fuel-poor or did not want to admit it (Sovacool, 2015). In the U.S., the WAP program has been criticized for measuring outcomes by the total homes weatherized, and not by alleviating energy poverty (Bednar and Reames, 2020). A study of the demographics served by WAP and other income-eligible programs in the U.S. found the need for assistance among individuals experiencing poverty varies significantly. Approximately 20 to 30 percent of households report significant material deprivation and poor health, whereas 50 to 75 percent of households do not. Based on these findings, the research team recommended that WAP improve targeting by including financial hardship, material deprivation, and health problems in the eligibility criteria, and that WAP collaborates with the health care and public health sectors to identify and refer households in most need of their services (Tonn et al., 2021).

Second, program evaluation metrics that focus on the number of households served or the number of households no longer spending more than 10 percent of their income on energy bills proved problematic as indicators of success. In the case of the UK, it was difficult to track the impact of the program because the definition of fuel poverty was too sensitive to changes in fuel prices. During program implementation, the data showed an increase in the number of people experiencing fuel poverty (i.e., spending more than 10 percent of their income on energy bills), which could be attributed to rising fuel prices and not necessarily to program effectiveness. Nevertheless, these findings lead to the eventual discontinuation of the program in 2013 (Sovacool, 2015). In the U.S., fluctuations in program funding significantly limited the number of households that could participate, leading to long wait times and the exclusion of eligible households (Bednar and Reames, 2020; Raissi and Reames, 2020).

Third, both the UK and U.S. programs faced technical challenges in administering insulation and heating equipment measures due to retrofit needs in the home (e.g., the need to remediate lead or asbestos; removal of mold prior to installation; and insulation, low panel capacity, and structural issues). In both cases, program funding included aspects relating to the installation of new equipment, but not to the remediation of existing conditions. In some cases, when houses had pre-existing habitability issues (e.g. mold, pests), they would be automatically disqualified. In other cases, habitability retrofits brought retrofit costs above the maximum grant level. As a result, those who could not afford to cover the difference could not participate, leaving the most vulnerable households behind (Bednar and Reames, 2020; Raissi and Reames, 2020; Sovacool, 2015).

Fourth, a significant number of households in the UK did not consume less energy post-intervention due to latent demand that could finally be addressed, inaccurate modeling, or inadequate implementation (Sovacool, 2015). These assessments illuminate the need for both improving the technical design of interventions and for evaluating the non-energy benefits of interventions.

Fifth, in both programs, cumbersome paperwork burdened both households and program staff, especially during intake and eligibility evaluation process (Raissi and Reames, 2020; Sovacool, 2015). In both programs, households request to participate via an online form and provide documentation of their eligibility. For households that meet the eligibility criteria, program staff conduct an energy audit and recommend energy efficiency measures. In the UK, private contractors would compete for the bid to perform the recommended energy efficiency measures, and the program staff did quality checks post-installation (Sovacool, 2015). In the U.S., WAP staff and pre-approved private contractors implemented the recommended measures (Bednar and Reames, 2020). In both programs, implementation could be slowed down by the administrative burden of collecting documents to prove eligibility. Households would commonly struggle to find documents, and administrators struggle to record massive amounts of private data.

Sixth, in both programs, racial and ethnic minorities were the least likely to participate and benefit from the assistance, highlighting the importance of considering social factors in program design and outreach (Bednar and Reames, 2020; Hamilton et al., 2015).

Despite the challenges these programs faced, both were found to be cost-effective and delivered substantial benefits to low-income households. In an evaluation of Warm Front, Sovacool (2015) reports that it “successfully reduced the extent of fuel poverty among 2.36 million English homes from 2000 to 2013,” as well as improved thermal comfort and public health, reduced mortality, reduced GHG emissions, concluding that benefits outweighed the costs of the program (Gilbertson et al., 2006; Sovacool, 2015). Similarly, in the U.S., several evaluations have found that the total benefits attributable to WAP are greater than the total program costs when taking non-energy benefits (e.g., health and safety benefits, support for job creation) into consideration (Bednar and Reames, 2020; Tonn et al., 2018).

We note that an important, under-studied aspect of these programs is ensuring that renters are not displaced from retrofitted properties. The U.S. Weatherization Assistance Program established renter protection agreements to ensure that low-income tenants can benefit from energy upgrades and are not displaced out of renovated housing units. The Department of Energy (DOE) regulation (10 CFR440.22(b)(3)) provides guidelines on how to structure landlord-tenant agreements for potential grantees, and those are detailed by the administrative department in each state. In California, the Department of Community Services and Developments (CDS) that administers the WAP program includes language on all energy service agreement forms that prohibits property owners from raising rents within two years as a result of building improvements from weatherization work, discloses tenant complaint procedures and property resale restrictions, and stipulates permission to enter the property for purposes of this program. The agreements are signed by the owner, occupants, tenants, and rental property (Newsom et al., 2022). There is a need for research to evaluate the effectiveness of these displacement protections in protecting low-income renters from eviction out of retrofitted homes.

Program Design and Implementation: Lessons Learned from Energy Utility Programs in the U.S.

The 2009 American Recovery and Reinvestment Act (ARRA) mandated state governments to develop agreements with utility companies to create energy efficiency incentive programs in their service territories, including those that specifically target low-income customers. By 2013, rate-payer funded, utility-operated, low-income energy efficiency programs became available to most U.S. households (Seth Nowak et al., 2013). A recent review of these low-income programs across the U.S. revealed similar challenges to those experienced by the WAP program discussed above, including funding shortages, inattention to readiness upgrades, complex enrollment processes, and a focus on shallow upgrades instead of deep retrofits. Underinvestment in low-income programs lead to both limited reach and focus on low-cost installations such as LED lighting, which have less impact on the households' overall energy use (Morales and Nadel, 2022).

Summary

The lessons learned from the implementation of welfare-based approaches to decarbonization demonstrate the complexity of providing energy assistance to priority households. First, eligibility criteria and measurement strategy shape which households are eligible and how the program will be designed and operated. There is a need to improve the understanding of the target population by using multiple indicators and not relying solely on income as the metric of disadvantage. Second, evaluation criteria impact the funding estimates as well as the quantity and quality of services offered. A narrow focus on energy savings in cost-benefit analysis disregards the many non-energy benefits of these programs, leading to an incomplete understanding of benefits and limited funding. Third, low-income households face additional barriers in engaging with decarbonization programs, even if they are provided at no cost. There is a need for program design that takes into consideration the barriers discussed in the previous section, otherwise implementation challenges will persist.

4.2. Market-Based Incentive and Regulatory Approaches

Market-based incentives refer to government interventions that incentivize the transition to low-carbon homes through regulation (e.g., appliance standards, building codes, benchmarking, utility regulation), financial incentives (e.g., rebates, tax credits), and workforce development programs. The underlying theory is that market barriers and behavioral anomalies cause an “energy efficiency gap” between the socially optimal level of decarbonization and individuals’ choice to implement retrofits (Allcott and Greenstone, 2012; Gillingham and Palmer, 2014). Therefore, if market barriers and behavioral anomalies are correctly identified and addressed, then utility-maximizing market actors (i.e. manufacturers, sellers, installers, households) will participate to derive financial benefits. If enough market actors participate, economies of scale will drive costs down, leading to widespread adoption of housing decarbonization measures (Geller et al., 2006; Doris et al., 2009; Gillingham and Palmer, 2014).

In the past 50 years, market-based incentive approaches have been the dominant strategy to advance housing decarbonization in the U.S. and other nation members of the OECD (Allcott and Greenstone, 2017, 2012; Bergman and Foxon, 2020). Below, we review the market failures that need to be overcome, strategies to address them, and the equity implications of these approaches.

Key Market Failures

- **Unpriced externalities** refer to the social cost of air pollution and carbon emissions not reflected in the price of energy consumption and production. As a result, there are inadequate financial incentives to conserve energy (Allcott and Greenstone, 2024). In the context of housing decarbonization, this can include the social cost of air pollution not being adequately reflected in the price of electricity and natural gas or in the price of energy efficiency appliances and upgrades.
- **Imperfect information** describes the challenge of decision-making in the context of insufficient knowledge or in cases where the buyer has less information than the seller. In the context of housing decarbonization, this can include failing to undertake a retrofit because one does not understand the value of the investment, or lack of energy-conserving behavior because one does not understand its value (Gillingham and Palmer, 2014; Singhal et al., 2022).
- **Principal-agent problems** arise “when one party makes a decision relating to energy use, but another party pays or benefits from that decision”(Gillingham and Palmer, 2014). In the context of housing decarbonization, this market failure is used to describe the split incentives between landlords and tenants.
- **Credit constraints** hinder the ability to finance housing decarbonization among groups with limited access to credit. While energy efficiency investments are estimated to be cost effective, the return on investment may take five to 30 years

(Nidam, 2019). Therefore, households that cannot afford the upfront cost and do not qualify or have access to a direct install program will need to borrow money. Lenders may limit access to credit either because they lack information about the payoff from energy efficiency (imperfect information) or because of poor credit history (Gillingham and Palmer, 2014; Singhal et al., 2022).

- Economists also use the terms **behavioral anomalies and failures** to refer to consumer behavior that doesn't follow the standard assumptions of economic theory (e.g., rational decision making). The behavioral economics principle of time-inconsistent preferences, for example, can manifest in consumers underestimating the long-term cost savings of decarbonization in the face of shorter-term higher costs. These and other common household behaviors—e.g., making decisions based on community rather than individual benefits, or being influenced by the way decarbonization programs are framed—can prevent households from pursuing energy-efficient options (Gillingham and Palmer, 2014).

It is unclear to what extent these factors impact decarbonization efforts and how these different types of failures shape consumer decisions. One clear need to convince "economically-driven" households is for better data on the cost savings from decarbonization measures (Gillingham and Palmer, 2014). Some researchers argue that housing decarbonization measures make smaller contributions to energy savings than models estimate. Hence, low adoption rates are rational responses to low energy savings (Allcott and Greenstone, 2012). Data that can improve program targeting to reach those households that will see the biggest benefits from decarbonization (i.e. those with energy-inefficient homes or that exhibit high levels of energy demand) could increase adoption rates (Singhal et al., 2022). Acknowledging this data gap, California agencies have developed retrofit programs that include data collection efforts: the TECH program and the Equitable Building Decarbonization (EBD) program. Data collected through these efforts will assist California agencies in identifying homes with the best potential for GHG emissions reductions as well as energy and bill savings.

Key Strategies

Overcoming market failures include policies that focus on regulations and financial incentives that motivate market actors to develop and implement residential decarbonization measures. While regulatory and incentive-based approaches share common tenets, there is great variation in how these approaches are implemented (Nowak et al., 2013; Li and Yi, 2014). Below, we discuss common approaches to regulatory and incentive-based interventions, provide a brief review of the literature on their effects, and highlight their equity implications.

Regulatory energy-efficient building standards are designed to ensure a baseline level of energy efficiency in the production of new buildings. The strategy responds to market failures related to unpriced externalities, particularly the undervaluation of "green" buildings. The U.S. first passed legislation in 1978 requiring states to initiate energy efficiency standards for new buildings (Allcott and Greenstone, 2012), and those have been updated at the federal and state level since.

There is robust evidence that energy-efficient residential building codes lead to significant energy savings. For example, a study of 158,112 homes in Sacramento revealed that the average house built just after the adoption of building codes for thermal comfort in 1978 used 8 to 13 percent less electricity for cooling than a similar house built just before 1978 (Novan et al., 2022). Similarly, a study of residential buildings in northern Florida found that residences constructed just after an increase in the stringency of Florida's energy code in 2002 consumed 4 percent less electricity and 6 percent less natural gas in comparison with residences constructed just before the code change (Jacobsen and Kotchen, 2013). An assessment of compliance with voluntary energy efficiency standards in Florida also demonstrated significant energy savings among houses built to meet more stringent requirements (Li and Carrión-Flores, 2017).

Although building codes can have a positive impact on energy efficiency, equity considerations arise if the associated costs (e.g., labor, materials, and appliances) of new building energy standards significantly impact the cost of housing construction. For example, a study of 350,000 residential buildings in California found that stricter energy codes (corresponding with different climate regions) create a reduction in homes' square footage and the number of bedrooms at the lower end of the income distribution, but not the higher end (Bruegge et al., 2019). This finding demonstrates that smaller homes may be one pathway to develop energy-efficient homes for LMI households. For the same homes, and controlling for construction costs, land scarcity, and other local factors that could affect the value of an existing home, the authors found that the home values of lower-income households fell (partially attributed to the reduction in home size and the number of rooms) compared to home values of lower-income households living in bigger, energy-inefficient homes. Meanwhile, home values of high-income households rose compared to similar-sized homes that were not energy efficient (Bruegge et al., 2019). Several studies found that home values are higher for newly-constructed, energy-efficient homes (Bruegge et al., 2016; Chegut et al., 2016). These findings illuminate the need to examine the relationship between building energy codes and housing construction costs.

Similarly, **standards for the energy efficiency of appliances** are designed to ensure a baseline level of energy efficiency in the manufacturing of new appliances. This strategy addresses the market failure of unpriced externalities, as well as the market failure of imperfect information by providing the buyer with information about differences in the energy use of different products. The U.S. first established mandatory federal minimum energy efficiency requirements in 1987 and voluntary energy efficiency standards for appliances, the Energy Star program, in 1992 (Brucal and Roberts, 2019). Both have been continually updated at the federal and state level. Energy Star products must meet the energy efficiency standards set by the Environmental Protection Agency (EPA), identified by a blue label, and include appliances, windows, insulation, electronics, lighting, computer equipment, and heating and cooling products (Ohler et al., 2020).

Energy efficiency standards for appliances spur market transformation, leading to innovation in the design of appliances to become more energy efficient over time. Several studies find that the combination of federal minimum energy requirements and the Energy Star program contributed to an improved quality and energy performance of appliances with little impact on the price (Brucal and Roberts, 2019; Houde and Spurlock, 2015; Spurlock and Fujita, 2022). These findings are aligned with previous studies that showed that mandatory energy performance requirements and labels were a highly cost-effective policy tool for encouraging the reduction of average energy consumption in equipment without reducing consumer choice or triggering sustained increases in prices (Jollands et al., 2010).

However, there is mixed evidence on the contribution of Energy Star labeling to residential energy savings. Ohler et al. (2020) found that the Energy Star refrigerator was the only appliance to provide strong evidence of a 2.6 percent decrease in electricity usage and an estimated $50.93 in annual energy cost savings. Sekar et al.'s (2019) evaluation of Energy Star televisions, clothes washers, and dryers in the U.S. found large variability in the energy, economic, and carbon savings between households, showing the largest savings were among heavy users of those appliances. These studies reveal that the ability of eco-labeling to induce energy savings depends on a range of market and place-based conditions (e.g., energy price, climate, compliance of the manufacturer with the regulation) and demographic conditions (e.g., household income, being a renter).

Research has identified several areas where energy efficiency and the Energy Star program have had inequitable outcomes. First, a study of Energy Star appliances in multi-family rental units in the U.S. revealed that there was a 1.6 percent average rent premium per Energy Star product included in a rental unit (Hopkins et al., 2020). Another study conducted in ten U.S. cities found that energy-efficient features increased the units’ rent from 6 to 14 percent (Im et al., 2017). These studies have not examined whether the higher rents were accompanied by a reduction in energy bills, however. Second, lower-income households, renters, and racial minorities are less likely to buy Energy Star products, either because they are not aware of the benefits associated with the products (Murray and Mills, 2011), because of limited availability of these products in their neighborhoods (Reames et al., 2018), or because they live in properties where the renter pays the utility bills and hence the owner has no financial incentive to invest in appliances that would reduce that bill (i.e. owner-renter split incentives) (Souza, 2018).

Benchmarking, disclosure ordinances, energy audits, and green building certifications are policy tools that are designed to overcome information asymmetry and improve consumer decision-making by mandating owners to assess the energy demand of their properties and evaluate measures to minimize consumption. For example, property owners that meet the inclusion criteria for mandatory benchmarking (usually large properties of multifamily units) must measure and disclose their energy use information through the EPA's free online benchmarking tool called Energy Star Portfolio Manager. In turn, EPA provides eligible properties with an Energy Star score scaled from 1 to 100 (Meng et al., 2017). In some localities, benchmarking ordinances require that owners implement energy saving measures within defined timeframes (Mims et al., 2017). In California, starting in June 2019, owners of commercial and multi-family residential buildings, both public and private, with more than 50,000 square feet and 17 or more utility accounts are mandated to annually report energy use to the CEC. In contrast, owners of smaller properties are generally not mandated to disclose their energy use but are encouraged to conduct voluntary energy audits through programs that offer them at no cost or that offer a green building certification (Fowlie et al., 2015; Houde, 2018).

There is limited evidence on the impact of mandatory benchmarking of large properties on energy savings (Mims et al., 2017; Seyrfar et al., 2020). An evaluation of building energy benchmarking and transparency programs in 24 state and local jurisdictions in the U.S. found that most of the reviewed programs indicated 3 to 8 percent reductions in gross energy consumption or energy use intensity over a two- to four-year period of policy implementation (Mims et al., 2017). In New York City, one study found that the combined effect of benchmarking and disclosure ordinances led to a 14 percent reduction in energy use intensity over the first four years of program implementation (Meng et al., 2017), although a separate study of the program found energy use reductions of only 2.5 percent for multi-family residential buildings (Kontokosta et al., 2020b). Across all studies, researchers highlight that benchmarking and transparency policies alone are insufficient in inducing large-scale energy savings if not accompanied by other measures (e.g., technical assistance, financial incentives) that play a key role in encouraging investment in energy efficiency (Kontokosta et al., 2020b; Mims et al., 2017; Seyrfar et al., 2020)

Green building certifications can also incentivize energy efficiency measures, particularly in new construction, and can provide a return to developers and property owners by increasing demand and property values. A study of 876,000 single-family homes in the Netherlands demonstrated that energy-rated homes were sold faster than non-energy-rated homes (Aydin et al., 2019). Several U.S. studies find that disclosure of a building's energy efficiency information or the receipt of the Energy Star certification (score above 75) is associated with increased property value at sale (Bruegge et al., 2016; Myers et al., 2022; Walls et al., 2017). In California, "green" homes sell for a 5 percent price premium (Kahn and Kok, 2014). While it is encouraging that consumers value residential energy efficiency, this correlation between higher property values, faster sales, and energy-efficient homes suggests that green certification programs do not address the challenges low-income households still face in securing low-carbon housing.

Market-based policies are also least likely to reach small- to medium-scale property owners, with evidence showing that these owners are less likely to participate in energy audits, even when those are offered at no cost. There are high non-monetary costs associated with conducting energy audits (e.g., time availability, capacity to engage, awareness, trust in the auditor), which decrease the ability of homeowners to engage with these programs (Fowlie et al., 2015; Nidam, 2019). Furthermore, even for those who participate in energy audits, the effectiveness of energy audits in encouraging investment in energy efficiency measures depends on several factors, including the quality of the energy audit, expected savings, existence of financial incentives, and the motivation of the property owner (Kontokosta et al., 2020b). Therefore, there is mixed evidence about the effectiveness of energy audits in the residential sector (Ramos et al., 2015), and it is reasonable to assume that information barriers persist for the majority of homeowners and small-scale property owners.

Financial incentives for energy-efficient appliances and home retrofits targeting the general population are designed to address financial constraints by subsidizing the difference in cost between polluting and green investments. The intention is to increase the market for green investments and ultimately lead to a price reduction of green investments due to economies of scale. In the context of housing decarbonization, financial incentives include a wide range of measures such as tax incentives, rebates, and low- to zero-interest loans. In the U.S., the adoption of the American Recovery and Reinvestment Act (ARRA) in 2009 spurred widespread investment in financial incentives for residential energy efficiency measures (Allcott and Greenstone, 2012; Seth Nowak et al., 2013). The recent passage of the Infrastructure Investment and Jobs Act and Inflation Reduction Act further expands financial incentives for housing decarbonization measures (DeFazio, 2021; Yarmuth, 2022).

There is abundant evidence that tax credits for decarbonization measures disproportionately benefit higher-income households (Borenstein and Davis, 2016; Jacobsen, 2019; Guo and Kontou, 2021). A study of the distributional effect of residential energy tax credits in the U.S. utilized IRS data between 2006 and 2012 to find disproportional adoption among higher-income households. For example, while households earning more than $200,000 annually are 3 percent of the population, 14 percent of those households claimed residential energy credits. Similarly, while households earning between $75,000 and $200,000 annually are 18 percent of the population, this demographic claimed 48 percent of residential energy credits. In contrast, households earning less than $20,000 annually are 35 percent of the population and claimed only 1 percent of residential energy credits (Borenstein and Davis, 2016). Further, higher income households are also significantly more likely to adopt solar panels and electric vehicles (Borenstein and Davis, 2016; Guo and Kontou, 2021; Ju et al., 2020; Sunter et al., 2019). This finding is not surprising considering that tax incentives are only effective among those who have a “tax appetite” (i.e. those who are required to pay taxes at a larger amount than granted in the tax incentives). Many low-income households are not included in that category (Hvelplund et al., 2009; Brown et al., 2020).

The evidence for the distributional effect of rebates for energy-efficient appliances is more mixed and depends significantly on contextual factors (Jacobsen, 2019). Some suggest that consumers would have purchased the energy-efficient appliance without the rebate. A study of 1.8 million rebates issued between 2008 and 2012 in the U.S. estimated that about 70 percent of the consumers claiming a rebate would have bought an Energy Star-rated appliance without it (Houde and Aldy, 2017). In contrast, a recent study that utilized RECS 2020 data to study the distribution of heat pumps found that adoption of this technology is even across income in the United States. Its adoption is more strongly correlated with geography, climate, and electricity prices (Davis, 2023). Variations between these studies, which represent different eras of incentive structure and targeting, call attention to the importance of evaluating the distributional effect of rebate programs.

Past experiences show that financial incentives are often inadequate in resolving barriers to decarbonization due to persistent non-financial barriers in reaching LMI households (Berzolla et al., 2023; Jacobsena, 2019; Olsthoorn et al., 2017). Explanations of the mechanisms that lead to limited adoption of financial incentives among LMI households include: lower rates of homeownership (Jacobsen, 2019), limited access to credit to pay in advance for rebate programs (Forrester and Reames, 2020; Nidam, 2019), willingness to purchase Energy Star models, and limited “tax appetite”(Jacobsen, 2019). In addition, as discussed in section 2.1, retrofit needs barriers, which require additional cost for remediation, can prevent households from benefiting from a rebate that covers only part of the cost for the equipment. Overall, rebate programs are better suited for reaching LMI households than tax incentives, especially if the rebates avoid targeting appliances that tend to be disproportionately owned by higher-income households (Jacobsen, 2019). However, there is a need for more research to improve the understanding of who benefits from financial incentives for decarbonization.

Green financing mechanisms are designed to address the credit constraints that hinder the ability to cover the upfront costs of housing retrofits. They are particularly beneficial for households that do not qualify for no-cost programs due to their income level, but also have insufficient credit scores to secure traditional financing (Campbell et al., 2023; Forrester and Reames, 2020). Below, we discuss two primary green financing mechanisms in California: (1) GoGreen Financing programs, a state-administered and utility ratepayer-funded, low-interest loan initiative, and (2) Inclusive Utility Investment (IUI) programs, also known as tariffed on-bill (TOB) financing, funded by the California EPA and regulated by the California Public Utilities Commission (CPUC). Both strategies aim to lower credit barriers for low- to moderate-income households in accessing energy efficiency and clean energy upgrades.

A collaboration between the state treasurer's office, the CPUC, and California's investor-owned utilities (IOUs), GoGreen Home Financing is a low-interest loan program that serves single-family homes, duplexes, triplexes, and fourplexes. GoGreen Financing offers partnering banks and credit unions a credit enhancement in the form of a utility ratepayer-funded loan loss reserve (LLR), which safeguards lenders against losses and enables them to offer more attractive terms to borrowers. These improved terms include lower interest rates, larger loan amounts, and longer repayment periods (ACEEE, 2017; CHEEF, 2021). For example, while lenders typically require borrowers to have a credit score of at least 640, through GoGreen Home, lenders can approve loans for borrowers with credit scores as low as 580. Additionally, lenders can extend repayment terms from five years to 15 years, which significantly lowers monthly payments for borrowers. Lastly, while lenders typically limit unsecured loans to about $25,000, most lenders are able to offer up to $50,000 for all borrowers (CHEEF, 2021). Therefore, through the GoGreen program, finance companies can approve loans for a broader range of borrowers who would otherwise be unable to access financing.

An early evaluation of the GoGreen Home program showed that it provided financing for 592 projects in 2023 (CAEATFA, 2024). While this number demonstrates the demand for this initiative, it also hints that demand far exceeds the availability of service. The same evaluation also showed that 60 percent of loans and 59 percent of the amount financed went to households in low- to moderate-income census tracts, and 10 percent of property upgrades occurred in disadvantaged communities (CAEATFA, 2024), demonstrating potential successful reach to the target audience. That said, it is hard to know if participating households were in the lower or higher income distribution of the low- and moderate-income census tracts. A study at the household level is needed to determine which income groups participated and at what level of financing to improve our understanding of LMI households' ability to access these programs. In examining how low-income households used the GoGreen program, Campbell et al. (2023) observe that micro-loans, used to buy one appliance as opposed to finance a whole home retrofit, were popular among households with low credit scores and renters, demonstrating the success of this approach in reaching the target audience.

As of 2023, the multifamily component of the GoGreen program has seen no participation from property owners, suggesting that barriers beyond financing continue to impede decarbonization efforts (CAEATFA, 2024; Campbell et al., 2023). The California Alternative Energy and Advanced Transportation Financing Authority (CAEATFA) attributes this to several challenges in the affordable multi-family housing sector, including the extensive time and capacity required to develop multi-family energy projects, limited ability to recoup savings from in-unit upgrades, and strict cash-flow requirements (California Alternative Energy and Advanced Transportation Financing Authority, 2024). This lack of engagement from multi-family property owners, a significant portion of California's housing stock, has led to program designers rolling the GoGreen Multifamily Financing program into the GoGreen Business program starting in 2024.

GoGreen Home Financing's ratepayer-funding model raises equity concerns, as utility rates are regressive compared to income taxes. Cost recovery through this model can be problematic because utilities must balance the need to recover the costs of financing the program with the need to keep rates affordable. If funding for GoGreen Financing comes from ratepayers, it could result in higher utility bills, disproportionately affecting lower-income customers who have less disposable income. In a recent evaluation of California's consumer energy finance programs, Campbell et al. (2023) argue that a taxpayer or state-funded model could reach more customers across all utility service areas, reduce limits on which customers can receive funds, and make revenue generation more equitable by relying on more progressive tax sources rather than regressive utility charges.

The second type of green financing mechanism in California is Inclusive Utility Investment (IUI) programs. These programs involve the utility providing the upfront capital for customers' energy efficiency and electrification upgrades, recovering the costs through a fixed charge on the customer's utility bill. IUI programs are designed to overcome credit constraint barriers in four key ways:

1) They spread the costs of upgrades over time, eliminating the barrier of high upfront customer investment.
2) Unlike on-bill loan programs or third-party financing, they do not require credit checks, making financing available to those without traditional credit.
3) Cost recovery is not debt-based and is tied to the residence's utility meter rather than the customer.
4) Repayment plans can be designed to align with the energy savings generated by the upgrades, where the savings from reduced energy consumption offset the upgrade costs, minimizing financial burden on households (Campbell et al., 2023; US EPA, 2023).

California has several active and completed IUI programs, including the Water Upgrades Save program sponsored by the Bay Area Regional Energy Network (BayREN), the TECH Public Reporting Inclusive Utility Investment Pilot sponsored by the TECH Initiative, and two municipal utility Pay As You Save (PAYS®) programs in Windsor and Hayward. A nationwide evaluation of the PAYS® programs found that over two-thirds of customers accepted their utility's offer of upgrades, with utilities reporting an average loss rate of just 0.1 percent (Ferguson et al., 2022; LibertyHomes and Energy Efficiency Institute, Inc., 2022). Utilities attributed the high participation rates to broad eligibility criteria and minimal barriers to participation (Ferguson et al., 2022). Overall, Ferguson et al. (2022) found that the PAYS® system is beneficial for many households, particularly for those in homes with high-energy demand, high-energy burden, and frequent bill complaints.

At the same time, it is important to note that the PAYS system included mostly low-cost measures such as insulation, air sealing, duct sealing, water heater load control switches, advanced power strips, water heater wraps and pipe insulation, low flow fixtures, air conditioning coil cleaning, solar water heaters, Energy Star-certified smart thermostats, LED lighting, and heat pump water heaters (Ferguson et al., 2022). Therefore, there is a need for additional analysis to examine which retrofit needs can be addressed by the PAYS program and which cannot. Customers whose homes require retrofits or repairs to install new equipment may not be able to participate in the PAYS® system until repairs and remediation are completed. This is problematic as those with the highest energy burden often live in older homes that require the most repair. Additionally, Ferguson et al. (2022) note that the PAYS® system may not be suitable for customers who already have low energy usage due to latent demand, and who may not achieve sufficient net energy or bill savings from the upgrades to justify the investment. Thus, while the PAYS® system offers advantages for customers for whom loan-based programs are not suitable, it may not be appropriate for a key segment of low-income customers who either have retrofit needs (e.g., remediation of lead or asbestos, electric panel upgrades) or who already limit energy usage due to energy insecurity.

To address readiness upgrade challenges and other funding gaps, IUI programs can be braided with other programs to better serve low-to-moderate income households. In a case study by Midwest Energy, a customer-owned electric and natural gas cooperative in Kansas, the utility braided their IUI program with the Kansas Weatherization Assistance Program (WAP) to fund upgrades for an energy-insecure customer. Midwest Energy found a natural synergy between the programs by using WAP to obtain air sealing, insulation, and duct sealing, while the IUI program funded the installation of new heating and cooling equipment. This approach resulted in more comprehensive energy efficiency upgrades that WAP alone could not cover, ultimately saving the customer over $53 per month on utility bills (U.S. EPA, 2022).

Summary

The regulatory and incentive-based strategies described above have significant implications for efforts to decarbonize housing. While building standards have improved the overall quality of buildings, in some cases, they have also increased the costs of development and raised the price premium for homes with energy-efficient features. Appliance standards and eco-labels have improved the energy efficiency of appliances, but lower adoption among renters and LMI households due to information barriers, credit barriers, and split incentives limit their contribution to energy savings. Benchmarking and energy audits can encourage energy savings if they are accompanied by technical assistance and financial incentives, but so far small property owners are not mandated to share energy usage information and have had less access to energy audits. Rebate programs encourage the purchase of energy-efficient appliances mostly among higher-income households who in some instances may purchase them absent the policy. Access to effective subsidies or credit also remains a persistent barrier among lower-income households. Limited attention to the needs of LMI households within these strategies has led to ineffective targeting and less adoption than is needed to expand decarbonization to levels needed to meet climate and other sustainability goals.

4.3. Community-Based Approaches

Community-based approaches refer to place-based programs that are tailored to the local context. We adopt a broad interpretation of the term 'community' to include a wide range of organizations that serve a local geography such as community-based organizations, local governments, local health care providers, local energy providers, and Native American Tribes. The theory underlying these approaches recognizes that household energy consumption is influenced by various social, economic, cultural, and political factors, which cannot be fully captured by either welfare programs, regulations, or financial incentives. Addressing the drivers of inequalities in housing decarbonization requires systemic change, with community-level organizations emerging as the most promising leaders of such change (Karvonen, 2013; Goldthau, 2014; Reames, 2016; Karvonen, 2017; Brummer, 2018; Putnam and Brown, 2021; Cha and Pastor, 2022; Sovacool, 2022; Sovacool et al., 2023). Community-based approaches often overlap with existing welfare approaches and financial incentive programs, often serving as an important intermediary to ensure lower-income and priority communities benefit from them.

Motivation for Community-Based Approaches

In the past two decades, there has been rising interest in community-based approaches for the transition to low-carbon buildings and cities, with the majority of studies conducted in the past decade (Y. Zhu et al., 2022). Common motivations for community-based approaches include:

- **Support grassroots innovation** to improve policy design and implementation by aggregating learning from diverse contextual strategies and generations of best practices (Seyfang et al., 2014).
- **Adapt policy goals to local priorities, needs, and contextual factors** with the purpose of increasing participation among households whose needs were unaddressed by the more rigid design of other programs. Working with local community members to identify the specific barriers in their neighborhoods enables both the discovery of local challenges and the design of contextual solutions to address them (Gupta et al., 2014; Karvonen, 2013).
- **Build local capacity for implementation** by creating community-level institutions that can facilitate the transition to low-carbon homes, build the local workforce and

supply chain, and increase awareness and motivation among homeowners and contractors. Several studies show that community-level institutions fill a critical gap in a multi-level energy governance system[14] by building wider networks, providing feedback and long-term support to state agencies, local implementers, and residents, and facilitating the transition to low-carbon homes even when government funding fluctuates (Karvonen, 2013; Putnam and Brown, 2021). Community-level institutions are also critical in developing local training programs to address workforce shortages and support the local economy. Through collective bargaining, community initiatives can create economies of scale for the delivery of services at a lower cost, and collective organizing can also help in securing attractive financing opportunities (Putnam and Brown, 2021). Finally, community organizers are best positioned to socialize knowledge of energy services, build awareness and readiness for participation, and establish trust and accountability (Gupta et al., 2014; Putnam and Brown, 2021). Through all these efforts, effective community-based approaches can shift the burden of implementation from the individual to the collective.

- **Achieve multiple sustainability goals.** Community-based programs often include additional dimensions to increase uptake within the local context. Examples include health promotion strategies, training for well-paying jobs, or knowledge exchange on energy-saving behaviors (GIZ, 2024; Gupta et al., 2014; Norton and Brown, 2014; Research Into Action, Inc., 2015). Consequently, community-based approaches generate more co-benefits and increase the likelihood of adoption.
- **Recognize social inequalities and address existing disparities in access to low carbon homes.** Priority communities face unaddressed barriers to participation including financial, social, regulatory, and market barriers (Reames, 2016). Partnering with community leadership in priority communities is essential in addressing these structural problems and key to advancing an equitable energy transition (Elmallah et al., 2022b; Reames, 2016).
- **Advance a vision for a just energy transition.** In response to the service gap in government programs, community-based organizations and nonprofits across the U.S. have begun leading initiatives for a just energy transition (Carley et al., 2021). A recent survey of visioning documents authored by nonprofits and priority community members in the United States identified six recurring principles for a just energy future: (1) being place-based, (2) addressing the root causes and legacies of inequality, (3) shifting the balance of power in existing forms of energy governance, (4) creating new, cooperative, and participatory systems of energy governance and ownership, (5) adopting a rights-based approach, and (6) rejecting

[14] Multi-level energy governance system refers to energy policies, regulations, programs, and services provided by multiple levels of government (e.g., federal, state, county, municipality).

false solutions (i.e solutions that ignore the needs of priority communities) (Elmallah et al., 2022b).

Community-based approaches require deep engagement that goes beyond consultation about outreach and education, including creating community institutions that can adequately represent priority communities in decision-making to facilitate an equitable transition.

Diversity in Implementation Strategies and Target Population

Community-based approaches often involve experimentation, and there is great variation in how these approaches are implemented. We review three different types of implementation strategies: (1) innovation grants to create community-based programs, (2) pilot projects to increase participation among priority communities, and (3) pilot projects to integrate health promotion and decarbonization strategies.

1) Innovation Grants to Create Community-based Programs

Both the U.S. and UK governments have allocated funding to local organizations with the purpose of designing and implementing community-based programs for housing decarbonization across a broad range of places. From 2010 to 2012, the UK implemented the Low Carbon Communities Challenge (LCCC) that allocated £10 million (an average of £450,000 per grantee) to 22 local authorities and councils, local strategic partnerships, or legally constituted third sector organizations (DECC, 2012; Gupta et al., 2014; Seyfang et al., 2014; Hobson et al., 2016b, 2016a; Lucas et al., 2017; Y. Zhu et al., 2022). The UK government required grantees to include both technical and behavioral interventions in their program design. Technical interventions included physical upgrades to the home such as insulation, energy-efficient heating systems, and solar panels. Behavioral interventions included energy feedback measures (energy monitors), education programs, and regular community meetings and events (DECC, 2012).

From 2010 to 2013, the Better Buildings Neighborhood Program (BBNP) in the United States allocated $508 million to 41 state and local programs, ranging from $1.4 million to $40 million per grantee (Gillich et al., 2018; Research into Action et al., 2015; Research Into Action, Inc., 2015).

In both countries, local organizations applied for the government grants in partnership with community-based organizations. Those that were selected to participate received funding and technical assistance to design and implement local housing decarbonization programs. Several studies highlighted the success of these community-led initiatives in reaching households (Gupta et al., 2014; Lucas et al., 2017), although, as we note at the end of this section, more robust evaluations are needed to fully understand their impact.

The success of community-led initiatives in increasing the motivation, ability, and intention to participate in housing decarbonization programs is attributed to multiple factors. First, community organizers were able to utilize existing networks, familiarity with the attitudes and needs of the local community, and established trust to create more effective outreach. For example, Lucas et al. (2017) found that among participants that attended community events about housing decarbonization, most indicated that they "came to the research events for personal reasons (e.g., to meet neighbors, see what was going on, see their children perform, curiosity, entertainment, day out, fun, learn about money savings) rather than to learn about energy or climate change per se." This finding highlights the strength of community organizers in integrating energy activities into the social fabric of a community by creating informal and interactive events, providing space for questions and dialogue, and cultivating a culture of acceptance and interest (Lucas et al., 2017).

Second, through open dialogue with local households, community organizers were able to identify the specific barriers to participation affecting their community and design measures to address them (Gupta et al., 2014). For example, Gupta et al. (2014) highlighted the important role of community groups as a source of trusted information, and in providing advice and support on how to overcome practical, social, and economic constraints. Together, the ability to improve communication; provide valuable knowledge and peer support; and address community concerns as well as practical, social and economic constraints, catalyzed interest and motivation to engage with decarbonization projects (DECC, 2012; Gupta et al., 2014; Lucas et al., 2017).

In addition to the development of energy efficiency upgrade programs, the U.S. Department of Energy (DOE) required grantees to meet multiple goals including job creation, economic development, and financial accountability. They also required the collection of tangible metrics for the number of buildings retrofitted, the amount of energy and bill savings, and leveraging of additional resources (Research Into Action, Inc., 2015). Following a competitive bidding process, state and local governments that received the grants worked with nonprofits, building energy efficiency experts, contractor trade associations, financial institutions, utilities, and other organizations to develop community-based decarbonization programs for the residential as well as commercial, industrial, and public sectors. A comprehensive evaluation estimated that BBNP created more than 10,000 jobs and generated $1.3 billion in net economic activity as well as $129 million in net taxes. The Better Buildings Neighborhoods Program (BBNP) also delivered over 100,000 energy upgrades, over $40 million in annual energy bills savings and an estimated $700 million lifetime energy bill savings. More than 84 percent of grantees reported that their programs or elements thereof would continue after the three-year evaluation period, with the most common source of post-grant support being ratepayer funding received by integrating with utility or energy agency home upgrade programs. The final report concluded that the BBNP was successful in meeting the initiative's goals and objectives (Research into Action et al., 2015).

Evaluation studies of the BBNP programs found that successful features included engagement with community-based organizations and workforce development. Similar to the UK experience, community-based organizations with long-standing relationships with the target communities and mission alignment with decarbonization efforts provided effective outreach by tailoring messages and engagement strategies to overcome their constituents' particular barriers and meet their specific needs. For example, "energy-impact house parties," organized by community partners and contractors in Illinois, sought to overcome reluctance by community members who did not want to sign up for the program online. The house party hosts were provided with a free home energy assessment. Attendees could have their homes assessed for $99 or host their own party and receive the assessment for free. This strategy led to 1,440 one-on-one meetings, over 1,000 community meetings, and 2,399 assessments, ultimately leading to 1,277 completed retrofits (Gillich et al., 2018; Research Into Action, Inc., 2015).

Engagement with the local workforce has also been shown to be essential for scaling up adoption of deep retrofits. BBNP grantees incentivized contractors by including suitable contractors in referral pools and by providing technical training (how to install new technologies) and non-technical training (sales and business). The inclusion of contractors on a pre-approved list also fostered participant trust in contractors and allowed participants to contract directly with the service provider of their choice. Programs that included quality assurance and quality control mechanisms further improved trust in the program. In some programs, the use of an independent energy advisor, which served as an intermediary between the contractor and the homeowner, helped bridge information gaps and build trust. Lastly, knowledgeable contractors who possessed strong communication skills to explain costs and benefits were able to motivate homeowners to achieve greater energy savings by taking a holistic approach to home energy upgrades (Gillich et al., 2018; Research Into Action, Inc., 2015). Therefore, attention to the knowledge and cost-effectiveness of contractors and building trust in implementers proved essential to the success of programs.

One drawback and lesson learned from these programs was that there was insufficient attention to data collection. Government-sponsored evaluations of these programs did not include an equity analysis, meaning that there are no data on the demographic or socioeconomic characteristics of households that participated in these programs. In addition, a lack of consistent monitoring and evaluation made it difficult to assess contributions towards carbon emission reductions across all programs (DECC, 2012; Hobson et al., 2016a, 2016b). Investing in research focused on community-based approaches could build the field's knowledge of equitable decarbonization implementation.

2) <u>Pilot Projects to Increase Participation Among Priority Communities</u>

Community-based approaches to increase the participation of priority communities in housing decarbonization interventions have distinct goals and design features. Specifically, even when decarbonization programs are offered at no cost, programs in priority communities must recognize that barriers to participation (e.g., trust, motivation, information, and required readiness upgrades) are likely to be more prevalent and harder to overcome (Reames, 2016; Nidam, 2019). In the U.S., community-based approaches are starting to be used within the two primary models for housing retrofits in priority communities: the Weatherization Assistance Program (WAP) and low-income retrofit programs offered by energy utilities. Below, we review two examples of a community-based approach to implementing these programs. The Green Impact Zone (GIZ) initiative in Kansas City, Missouri, is an example of a community-based approach to implementing the federal Weatherization Assistance Program (WAP) (Reames, 2016). The San Joaquin Valley Disadvantaged Communities Pilot is an example of a community-based approach to implementing a utility direct install program.

Kansas City Green Impact Zone (GIZ)

The GIZ initiative targeted residents in five neighborhoods that had high rates of poverty and a history of discrimination and disinvestment. In a comprehensive evaluation of the GIZ initiative, Reames (2016b) outlines how the regional government created a community-level institution to lead the GIZ initiative; built local capacity for implementation; and overcame social, market, and regulatory barriers. To overcome trust barriers, the regional government recruited dedicated staff to oversee the program. Those staff members worked with the five neighborhood associations to develop a system of block captains who would lead outreach. This strategy ensured that information about the program came from trusted members in this community. To overcome social barriers associated with environmental issues being a low priority for residents, the GIZ staff worked with neighborhood association leaders to frame marketing materials highlighting the program features that mattered most to the community: bill savings and improved housing quality and health. Environmental motivations were introduced last as they were the least salient motivation in this community. GIZ staff also addressed knowledge barriers by providing training on energy efficiency and advocacy to neighborhood association leaders and block captains, followed by an outreach campaign that included door-to-door visits, community events, and social media.

To overcome the landlord/tenant split incentives—especially given that half of the residents in the community were renters—the GIZ program included outreach to landlords and offered significant financial incentives. Landlords were required to only pay for 5 percent of the retrofit costs for buildings with less than five units. GIZ staff also found additional sources of funding to implement measures in houses that did not meet the WAP eligibility criteria, either because the buildings were too old and included uncovered readiness upgrades, or because the household had already received WAP assistance sometime after 1994.

At the end of the five-year initiative, 329 out of the target 659 houses were weatherized (Reames, 2016). While the initiative reached only 50 percent of its target audience over a five-year period, this rate is much higher than the 2 percent annual adoption rate observed for WAP programs. Further, building the capacity of the neighborhood associations had significant co-benefits. These include improving local workforce development efforts through sponsored trainings and certifications and securing more than $178 million in additional funding to support neighborhood priorities such as deep retrofits and affordable housing (GIZ, 2024). The challenges and opportunities of this initiative provide a model for the effectiveness of deep community engagement in program design and delivery in priority communities.

San Joaquin Valley (SJV) Disadvantaged Communities Pilot

The San Joaquin Valley (SJV) Disadvantaged Communities Pilot in California relied on a complex coordination effort between government agencies, energy utilities, implementers, and community-based organizations. The California Public Utilities Commission (CPUC) initiated the pilot project in 2018 to test out approaches for making energy more affordable for communities in the SJV that lacked access to natural gas. The pilot tested a community-based approach to implement deep retrofits and electrification in low-income communities that are dependent on propane and wood and live in housing structures that require significant readiness upgrades or significant investment in energy infrastructure to enable electrification (CPUC, 2018). Following project authorization by the CPUC, each of the investor-owned utilities (IOUs) serving the Central Valley (PG&E, SCE, and SoCalGas) developed unique program offerings to target the selected SJV communities within their service territories.

Once program design was complete, local community-based organization Self-Help Enterprises (SHE), with their expertise in housing and energy renovations, led outreach and assisted residents with filling out applications to participate in the pilot. After receiving applications from SHE, the project implementers hired by the IOUs conducted energy audits and recommended a retrofit plan for the IOU serving the community. After the IOU staff approved the retrofit plan, the project implementer installed the recommended measures (Evergreen Economics, 2022). Implementation concluded in January 2024. This initiative is notable for its efforts to expand access to retrofits in priority communities in California.

Preliminary analysis of this project offers valuable lessons. The pilot found that there is a need for significant investment in energy infrastructure to support electrification in rural disadvantaged communities. A South California Edison progress report from March 2023 revealed that 78 percent of 114 completed homes had an electric panel with less than 200 amps, triggering an electrical panel upgrade averaging the cost of $4,300, along with new circuit runs to the upgraded electric equipment (SCE, 2023). Readiness upgrades also required that the pilot braid funding across government agencies with different eligibility criteria, complicating implementation. For example, SCE utilized funding from the following additional sources: Technology and Equipment for Clean Heating (TECH) initiative funding and the Self-Help Enterprises Grant.

The pilot also invested in education and trust-building. A presentation by Self-Help Enterprises from April 2022 highlighted the important role of community outreach to households and advocated for enhancing the role of community partners to include sustained relationships, education programs, and demonstration projects that build awareness, knowledge, and trust (Abigail Solis, 2022). Program designers also tried to address barriers to participation associated with the fear of bill increases by providing discounts and recommending retrofits that would not increase energy costs. This strategy had marginal success as some households struggled to trust that these promises would be kept (Evergreen Economics, 2022).

The SJV pilot also considered how to address split-incentives between landlords and renters as well as concerns about tenant protections (Abigail Solis, 2022). In this pilot, renter protections against significant rent increase or unfair eviction were protected through an agreement between participating renters and their landlords. In an evaluation from October 2022, a survey of participating renters revealed that only 11 percent experienced rent increases, and that none attributed the rent increase to the retrofit project. Participating landlords valued improving the quality of the property and reducing safety hazards. At the same time, there was evidence that some landlords did not agree to participate because they did not want to sign the rental agreement. Landlords concerns included wanting to sell the house within the next five years and fear that the tenants would take the appliances with them when they leave (Evergreen Economics, 2022).

While the evaluation of the SJV pilot is ongoing, these preliminary findings highlight the need for further research on the role of community organizers in supporting these initiatives and the need to identify funding sources for remediation issues and for the alignment of eligibility criteria across decarbonization programs.

3) Pilot Projects to Integrate Health promotion and Decarbonization Strategies

In the past decade, several factors have contributed to the development of community-based programs that integrate health and energy strategies. First, improved understanding of the contribution of home energy interventions to health and safety, including reducing respiratory illness (e.g., asthma, COPD) in children, highlights the importance of decarbonization for health and health equity. Second, increased government funding and availability of low-cost and no-cost programs to support retrofits in LMI households (De Souza et al., 2019; Norton and Brown, 2014; RAMP, 2018) have provided much needed resources to expand programs. Local communities in Washington (Weatherization Plus Health), Maryland (The Green & Healthy Homes Initiative Healthy Homes Demonstration Project 2010-2013), Pennsylvania (Built to Last), and California (Contra-Costa County Pilot Program & Bay Area Healthy Homes Initiative) exemplify the implementation of these strategies.

These approaches share a similar implementation strategy: health care providers receive training on the relationship between energy retrofits and health as well as local decarbonization programs. When engaging with patients that can benefit from an energy intervention, health care providers refer them to a local housing decarbonization program, and in many cases, also help them fill out the application. In some cases, the local housing decarbonization program includes a person that can conduct an energy audit with a focus on health. The program staff then braid resources from several sources to ensure health strategies can be implemented. (For example, lead abatement and mold remediation may not be covered by energy programs but could be covered by home repair programs). In summary, these approaches fill a gap in coordination between public health and energy agencies by consolidating resources for interventions that meet the goals of both agencies (De Souza et al., 2019; Norton and Brown, 2014; RAMP, 2018).

Preliminary findings from Baltimore strengthen the evidence of decarbonization's contribution to public health, child educational outcomes, and work productivity. Among 139 children that participated in an assessment of the Green & Healthy Homes Initiative (GHHI), 95 percent reported their asthma as controlled six-months post intervention, which represented a 74 percent reduction in the experience of acute symptoms. Project participants also reported reductions in the number of hospitalizations (65.5 percent) and emergency room visits (27.7 percent), as well as an overall mean reduction of 37 percent for missed work days and 27 percent for missed school or day care (Norton and Brown, 2014). These findings demonstrate the significance of integrating health strategies into decarbonization programs to advance public health and work productivity.

Not all decarbonization programs will lead to improved health outcomes. Many programs are unable to perform a retrofit project if health hazards such as lead or mold are found in the home. These limitations further highlight the importance of coordinating efforts across agencies to streamline funding, align eligibility criteria, and ensure that the target population can easily learn about these initiatives and access them. Best practices include (1) referral by health providers and community partners as trusted sources of information; (2) home visits by an expert practitioner who can identify both ways to reduce energy demand and improve health outcomes; and (3) presence of an administrator who can serve as the primary contact with the household, assist with filling applications, and secure funding from multiple sources. Alternatively, improved program design at the agency level (e.g., the alignment of eligibility criteria between agencies with housing programs, making it easier for households to enroll) can reduce administrative burdens for households. Lastly, households that live in older and substandard housing will benefit the most from interventions to simultaneously improve indoor air quality and reduce energy bills (De Souza et al., 2019; Norton and Brown, 2014; RAMP, 2018).

Summary

Evidence shows that community-based approaches are effective in increasing participation in housing decarbonization programs by adapting program design and delivery to the local context and building local capacity for implementation. Community-based approaches that specifically target priority communities and partner with local leadership (elected officials or leaders in community organizations) for program design, delivery, and evaluation can significantly increase participation and contribute to social benefits such as improved housing quality and household health. The need for deeper engagement with community leadership in priority communities stems from the compounding challenges of historical disinvestment, distrust in government and others, worse housing and energy infrastructure conditions, limited resources and knowledge of decarbonization, and higher sensitivity to energy bills.

5. Equity Implications of Program Outcomes

Housing decarbonization is crucial to meet California's climate and environmental justice goals. To achieve housing decarbonization, there is a need to transform the way electricity is produced and transmitted, the physical characteristics of homes, and the appliances used at home. To better understand this transformation, it is important to review the ways decarbonization progress is measured. This section presents a comprehensive framework for evaluating decarbonization efforts that consider their multi-dimensional impacts and equity implications.

In this section, we review the contributions of equitable housing decarbonization programs towards meeting GHG emissions reduction goals, as well as enhancing climate resilience, energy security, and housing stability. The table summarizes the key interventions, outcomes, and contributions to population health and health equity. The ability to achieve wide and equitable benefits depends on the incorporation of these dimensions into program design, implementation, and evaluation.

Table 5.1 Housing decarbonization outcomes and their implications for population health and equity

	GHG Emissions & Electric Grid Stability	**Climate Resilience**	**Housing Security**	**Energy Security**
Level	Community level	Household level	Household level	Household level
Key Interventions	Energy infrastructure: Electrical panel capacity & circuit capacity upgrades; Electrification: Heat pumps, electric stoves, solar and batteries, electric vehicles; and Energy efficiency: insulation, demand-response, etc.	Multi-hazard approach to weatherization: insulation, draft sealing, energy-efficient heating/cooling, and flood proofing	Pollutant hazard remediation, financial support for LMI households, renter protections, policies to address split incentives between owners and renters	Comprehensive retrofits to reduce energy bills, improve thermal comfort, and indoor air quality

Key Outcomes	Reduce GHG emissions, air pollution, and improve grid reliability	Protect against extreme heat and cold, indoor wildfire smoke, and flooding	Improve housing quality and stability	Improve financial security and reduce energy burden
Population Health	Reduce disease and mortality associated with air pollution (e.g. cancer, cardiovascular disease, and respiratory disease)	Reduce disease and mortality associated with extreme heat, cold, and mold (e.g. heat stroke, kidney disease, asthma, hypothermia). Reduce negative mental health effects	Reduce adverse physical and mental health outcomes associated with housing insecurity	Reduce adverse physical and mental health outcomes associated with energy insecurity
Health Equity	Prioritizing high-risk populations will have outsized benefits for those groups, contributing to reduction in health disparities			

In this section, we review the literature in each of these four outcomes and highlight implications for health equity, indicating the scope of decarbonization interventions, the existing knowledge of the linkages between decarbonization and population health outcomes, and their equity considerations.

5.1. Greenhouse Gas (GHG) Emissions and Electric Grid Stability

Housing decarbonization has significant direct and indirect impacts on statewide GHG emissions and electric grid stability. Residential buildings account for 8 percent of the state's GHG emissions, predominately from the onsite use of electricity, gas space and water heating, and gas appliances. A smaller amount comes from the combustion of propane, kerosene, diesel, and wood, as well as leaking hydrofluorocarbons from refrigeration and air conditioning appliances (CARB, 2023; Kenney et al., 2021). These emissions can be significantly reduced by implementing measures to transition away from the use of combustible fuels in homes, replacing natural gas appliances with electric ones, reducing household energy demand, and reducing hydrofluorocarbon emissions (CARB, 2022; Kenney et al., 2021).

As noted in Section 1.3, California has established economy-wide goals to reduce hydrofluorocarbon emissions through SB 1383 and CARB has adopted appliance standards to limit global warming potential (Kenney et al., 2021). At scale, residential decarbonization programs can also catalyze decarbonization in other sectors. For example, electricity infrastructure upgrades to support higher residential electricity demand can enable the adoption of electric cars, contributing to the decarbonization of the transportation sector, which accounts for 27 percent of the state's GHG emissions (CARB, 2023). Therefore, housing decarbonization can lead to direct GHG reduction via changes to residential housing consumption, and to indirect GHG reduction via changes to energy infrastructure to facilitate both residential and transportation decarbonization.

Combining electrification, energy efficiency, and clean energy strategies is critical to achieving GHG reduction in the housing sector. As discussed in Section 1.4, wide-scale residential electrification without the simultaneous implementation of energy efficiency can result in higher electricity demand and grid instability. A recent study in Southern California found that aggressive electrification of residential end-use appliances has the potential to exacerbate daily peak electricity demand, increase total household expenditures on energy, and, in the absence of a fully-decarbonized electrical grid, likely result in only limited GHG emissions abatement benefits (Fournier et al., 2020). In contrast, a study of electrification scenarios in Pierre, South Dakota, found that combining deep energy efficiency with electrification can reduce peak demand by about half relative to low-efficiency electrification (Maxim and Grubert, 2023). Therefore, a combination of strategies to avoid GHG emissions from end-use appliances and electricity production is critical for both the stability of the electric grid and GHG emission reductions.

Further GHG emission reductions can be achieved by synchronizing in-home decarbonization strategies (e.g., building end-use electrification, refrigerant leakage reduction, energy efficiency, solar plus storage, and demand response) with upgrades to the natural gas and electricity infrastructure (Brockway et al., 2021; CARB, 2022; Fournier et al., 2020; Kenney et al., 2021; Maxim and Grubert, 2023; Relf et al., 2018). There are the critical interdependencies between the natural gas and electricity systems. Ideally, reducing household use of natural gas could allow for reduced investment in, and the eventual decommissioning of, California's natural gas distribution infrastructure (Jones et al., 2022). At the same time, California may need to retain its gas infrastructure to meet industrial hard-to-electrify uses (Jones et al., 2022; Kenney et al., 2021). Therefore, by synchronizing building decarbonization strategies with avoiding gas system investments, programs can achieve significant savings for utility ratepayers.

GHG emissions and associated air pollution constitute the largest environmental impact on human health (Gallagher and Holloway, 2020; S. Zhu et al., 2022). Long-term exposure to outdoor air pollution is associated with asthma, chronic obstructive pulmonary disease, cardiovascular disease, low birth weight, cerebrovascular disease, chronic kidney disease, dementia, type 2 diabetes, hypertension, lung cancer, and pneumonia (Bevan et al., 2021; Bowe et al., 2019; Dedoussi et al., 2020; Jiang et al., 2016; Manisalidis et al., 2020; Wang et al., 2022). Additionally, the use of natural gas and other combustible fuels within households is known to produce substantial indoor air pollution, such as nitrogen dioxide, particulate matter, and carbon monoxide which are associated with negative health outcomes such as respiratory disease, allergies, and skin disease (CARB, 2005; Francisco et al., 2017; Paulin et al., 2013). Moreover, research has shown that the physical layout and size of homes impact indoor air pollution concentration, with smaller homes accumulating pollutants at a faster rate than larger homes in the absence of ventilation (Ferguson et al., 2021). Separate, but relatedly, the accumulation of natural gas in residential homes can result in accidental fires and explosions, causing loss of property and injuries (Song et al., 2021).

Housing decarbonization measures can reduce indoor and outdoor air pollution. Strategies to improve indoor air quality include removing combustion-based heat sources, sealing drafts, encouraging lead and asbestos abatement, and improving ventilation to avoid trapping indoor contaminants (Fisk et al., 2020; Francisco et al., 2017; Goforth and Nock, 2022; Willand et al., 2015; S. Zhu et al., 2022). Additionally, strategies focused on residential electrification and curbing fossil fuel-based energy generation could decrease fine particulate matter in the atmosphere by 18 to 37 percent in major metropolitan areas of California compared to business-as-usual levels (Zhao et al., 2019). Decarbonization measures that prioritize reductions in indoor and outdoor air pollution have the potential to dramatically improve population-level health. Several studies of decarbonization pathways in California show that focusing on housing decarbonization will maximize health benefits associated with cleaner air and avoid 12,200 premature deaths per year (Wang et al., 2020; Zhao et al., 2019).

There are several implications to consider in evaluating equity in air pollution exposure, electric grid capacity, and the maintenance of natural gas infrastructure. First, air pollutants are disproportionately concentrated in disadvantaged communities across California, meaning that the health co-benefits of decarbonization will be disproportionately higher in disadvantaged communities (Wang et al., 2020). This could lead to reduced state spending on health care costs and outsized benefits for the most vulnerable social groups (Zhao et al., 2019; S. Zhu et al., 2022). Second, disadvantaged communities are disproportionately served by lower-capacity energy infrastructure that poses barriers to solar panel installation (Brockway et al., 2021). Third, as discussed in Section 2, as more customers leave the gas system, there is concern that low-income households that are not able to electrify will have to pay higher gas rates to maintain legacy infrastructure and stranded natural gas assets (Borenstein et al., 2023, 2021). Meeting California's GHG emission reduction goals through equitable decarbonization requires engaging all households in California with a special emphasis on households that have faced unaddressed barriers to participation (CARB, 2022).

5.2. Climate Resilience

Climate resilience, as defined in California's Fourth Climate Change Assessment, refers to the "capacity of any entity–an individual, a community, an organization, or a natural system–to prepare for disruptions, to recover from shocks and stresses, and to adapt and grow from a disruptive experience" (Rodin, 2014, as quoted in Bedsworth et al., 2018).

California residents are already exposed to severe climate hazards which are expected to increase in frequency and severity in the coming decades. The summer of 2023 broke 241 temperature records across the state of California, with temperatures predicted to continue rising each year (Bedsworth et al., 2018). Increasing air temperatures and extreme heat also coincides with an increase in wildfires, a hazard that impacts millions of residents directly and indirectly through the spread of smoke (Baars et al., 2021). Finally, California's already high variability of year-to-year precipitation is projected to become more volatile, with an intensification of seasonal dryness and more extreme precipitation and flooding (Bedsworth et al., 2018).

Exposure to these weather extremes poses direct and indirect risks to public health. Extreme heat exposure increases the risk of heat-related illness or death and can exacerbate underlying cardiovascular and respiratory illnesses (CDPH, 2022; Morello-Frosch et al., 2009). As longer, more frequent, and more severe heatwaves are projected to increase, researchers estimate that heat-related mortality could rise between 6,700 to 11,300 deaths per year by 2050 (CDPH, 2022). Wildfires present significant health risks for the entire state, with over 2.7 million Californians currently living in high-risk areas and many more residents being exposed to resultant wildfire smoke. Smoke exposure is linked to increased rates of respiratory illness, exacerbated asthma, and chronic obstructive pulmonary disease (COPD) (Reid et al., 2016). Extreme precipitation and resultant flooding present risks of direct injury, exposure to waterborne bacteria, debris, and mold, increasing the likelihood of the development of lung disease (American Lung Association, 2024).

The built environment plays a critical role in mitigating and protecting communities from climate hazards (Cohen et al., 2024; Morello-Frosch et al., 2009). The climate resilience of residential buildings depends on building quality, materials, and methods of construction. While not all decarbonization approaches will protect against all environmental hazards, approaches that include weatherization can improve the condition of the home and increase climate resilience against extreme temperatures, precipitation and flooding, and wildfire smoke exposure. Improved insulation, tightened building envelopes, and energy-efficient heating and cooling systems can minimize thermal loss and prevent water, drafts, and smoke from penetrating the home (Cohen et al., 2024; HUD, 2022a). A study on the impacts of energy-efficiency retrofits on indoor air quality showed that loose building envelopes allowed more wildfire smoke infiltration, raising particulate matter levels indoors which can persist for eight to ten hours (Shrestha, 2018). In all, housing decarbonization measures have been shown to substantially reduce human mortality due to climate hazards (Bedsworth et al., 2018).

The equity implications of housing decarbonization outcomes on increasing climate *resilience* relates to their ability to decrease climate *vulnerability*, which is tied to social and economic differences across communities. There are three widely accepted and interrelated facets to climate vulnerability: physical exposure to hazard, sensitivity to hazard, and capacity to adapt to hazard (Kauffman and Hill, 2021; McCarthy et al., 2001; Smit and Wandel, 2006).

- **Physical exposure to climate hazards** in California varies based on geographic location and the conditions of the built environment, with the state's diverse geography leading to differing impacts across regions. Projections indicate an overall temperature increase of 5.6°F by 2100, with the most significant rises expected in Southern California and the Central Valley (Cal-Heat, 2024). In cities, the urban heat island effect will exacerbate heat-related challenges, leading to differences of five to ten degrees Fahrenheit between grey and green urban environments (Aram et al., 2019), resulting in higher indoor temperatures and higher energy demand for cooling (Berry et al., 2013). Disadvantaged communities in California are disproportionately exposed to extreme heat because they are disproportionately located in hotter climate regions, in neighborhoods that lack trees, and in housing that lack insulation and cooling devices (Chakraborty et al., 2019; Cushing et al., 2022; Frosch et al., 2018; Goldstein et al., 2022; Hoffman et al., 2020; Newsome, 2023). Moreover, residents in subsidized housing are disproportionately located in the hottest tracts in California and simultaneously have the most sensitive populations and barriers to adaptation (Gabbe and Pierce, 2020).
- **Sensitivity to hazard** refers to the degree to which an individual could be harmed by exposure due to pre-existing health conditions. There is consensus among scholars that social inequalities impact individuals' opportunities to be healthy, leading to worse health outcomes among those experiencing social disadvantage (Arcaya et al., 2015; Bailey et al., 2021; P. Braveman et al., 2011; Marmot, 2005; Marmot et al., 2008; Wilkinson and Marmot, 2003). For example, asthma, a condition highly associated with air pollution and substandard housing, is more prevalent among disadvantaged communities in California (Alcala et al., 2019). On days of extreme heat, people with pre-existing health conditions like asthma face elevated health risks, resulting in disproportionate negative health outcomes (Morello-Frosch et al., 2009; Schwarz et al., 2021).
- Finally, **adaptive capacity** refers to a household or community's ability to cope with and recover from climate events. Factors that affect a household's adaptive capacity include tenure, housing type, education, race, language and income (Gabbe and Pierce, 2020). One study found that a disproportionate share of California's subsidized units are located in tracts that have simultaneously the highest exposure to extreme heat, highest sensitivity, and highest barriers to adaptation (Gabbe and Pierce, 2020). The same study notes that site-based public housing has much lower prevalence of air conditioning and adequate insulation than the general housing stock and compared to low-income households in non-subsidized housing.

The ability to increase adaptive capacity involves access to social, financial, and political resources. Renters, who comprise 44 percent of California households (United States Census Bureau, 2022) have limited ability to engage with decarbonization programs (as discussed in Chapter 2). There are many pathways towards increasing adaptive capacity among priority households. One study that evaluated a community-based approach to scaling WAP-funded energy efficiency retrofits showed that deep community engagement led to 50 percent participation rates among low-income and minority households, significantly higher than the 2 percent engagement rate observed in other approaches (Reames, 2016). Evaluations of the SJV pilot also attributed deep community engagement to higher participation rates (Evergreen Economics, 2022; Opinion dynamics, 2021).

The equity implications of housing decarbonization outcomes on climate resilience relate to their ability to address uneven climate vulnerability due to social and economic differences across communities. Social inequities lower households' abilities to cope with, recover from, and adapt to climate hazards via improving their living conditions. Additionally, climate change can cause myriad effects on mental and social health, including anxiety, depression, exhaustion, and stress (Clayton et al., 2021). As a result, housing decarbonization measures that decrease climate vulnerability and increase resilience can have outsized benefits for priority communities who face disproportionate exposure to climate hazards and health disparities (Cushing et al., 2022; Morello-Frosch et al., 2009).

5.3. Housing Security

Housing security is a term that refers to hardship in affording, accessing, acquiring, and retaining quality housing that meets residents' needs (DeLuca and Rosen, 2022). The U.S. Department of Housing and Urban Development (HUD) identifies the following dimensions of housing insecurity: (1) housing stability; (2) housing affordability; (3) housing quality; (4) housing safety; (5) neighborhood safety; (6) neighborhood quality; and (7) homelessness (Cox et al., 2019). HUD's housing insecurity research module measures housing insecurity based on "lack of [housing] affordability; lack of stable occupancy, and lack of safety and decency" (HUD, 2022b). Housing quality and stability are thus recognized as critical dimensions of housing security, each of which can be affected by housing decarbonization efforts.

Housing decarbonization programs can significantly contribute to housing security by improving the **quality of the home**. HUD clearly identifies poor housing quality related to electricity, heating, structural, and other deficiencies as contributing to housing insecurity (HUD, 2022). A study on the state of U.S. rental housing found that almost 15 percent of rental units in 2017 had substantial quality issues and low-income households disproportionately occupied these units (GAO, 2020). Of these units, almost 80 percent lacked proper heating and water. Another study by the California Department of Public Health found that from 2006 to 2010, 45.3 percent of properties inspected tested positive for some kind of lead hazard (Lutzker and Tobacman, 2013).

Another equity dimension of housing security is **residential stability**. On one hand, improved housing quality among low-income households can contribute to an increase in housing value and generational wealth. Research indicates that investments in energy efficiency upgrades are capitalized in the residential resale market compared to non-upgraded buildings (Bruegge et al., 2016; Kholodilin et al., 2017). Given the suppression of home values for low-income and communities of color (An et al., 2019; Appel and Nickerson, 2016; Reid, 2021), resale value poses a potential opportunity for these households. On the other hand, there are risks associated with increased housing value: (1) an increase in property taxes, which can make homeownership unaffordable, and (2) an increase in renter financial burden and the risk of renter displacement due landlords' desire to profit from their investment through rent increases. Research has found that landlords are more likely to invest in energy efficiency upgrades if those upgrades will translate to income generated either from energy cost savings or higher rent (Bird and Hernández, 2012; Kholodilin et al., 2017).

Housing insecurity and its contributing factors are associated with a myriad of negative physical and mental health outcomes. Disproportionate exposure to housing-related pollutants (e.g., lead, allergens, and mold) are linked to increased rates of asthma, lead poisoning, neurodevelopmental disability, and other chronic health problems, especially among priority communities (Rauh et al., 2008). Inadequate housing conditions have also been linked to depression, anxiety, and psychological stress (Coley et al., 2013; Hernández, 2016; Shenassa et al., 2007). Chronic stress and coping mechanisms to deal with stress are widely known to cause deleterious health effects. Financial insecurity related to housing costs is also linked to increased stress levels, especially for low-income residents faced with neighborhood changes associated with gentrification (Binet et al., 2021). Relatedly, voluntary and involuntary displacement has been shown to catalyze myriad impacts on individual and population health, including increased psychological stress due to financial strain, loss of neighborhood resources, disruption to social networks, social marginalization, and many other burdens (Schnake-Mahl et al., 2020).

Given the factors that contribute to housing insecurity and associated risks, residential building decarbonization has the potential to address housing deficiencies and residential stability, thus increasing housing security. Retrofitting homes to high quality standards, such as ensuring functional hot and cold running water, can contribute to safer and more secure housing conditions (Rauh et al., 2008). Along with these physical benefits, housing quality has also been shown to promote positive outcomes in mental health, educational attainment, and employment (HUD, 2022b). Therefore, ensuring housing decarbonization programs target substandard housing can have a positive impact on housing security in California.

Addressing residential stability requires policy strategies to protect low-income households and renters from displacement and address split incentives between landlords and renters. Without sufficient renter protections, landlords may try to capitalize on their investments by raising rents or energy bills and contribute to the financial burden or displacement of their tenants. This would negate any health, economic, and environmental benefits for priority communities, as residents displaced via green gentrification, ironically, tend to move to even more peripheral, contaminated, and vulnerable areas (Anguelovski et al., 2018). These dynamics present a double hazard for low-income renters who face both the risk of being displaced out of retrofitted homes, and at the same time, are priced out of low-carbon homes.

Lastly, for large-scale decarbonization to reach renters and LMI households, financial incentives must be designed to meet the economic needs of these residents. These incentives can include subsidies and grants, on-bill financing which allows property owners to make monthly repayments through their existing utility bill, and incentives that accrue savings for both landlords and renters (Bird and Hernández, 2012). Therefore, to ensure that housing decarbonization interventions enhance housing security, implementation pathways must ensure housing quality and stability (BEEP Coalition, 2023; Chelsea Kirk, 2021; Singla et al., 2022).

5.4. Energy Security

Energy insecurity is defined as “an inability to adequately meet basic household energy needs” (Hernández, 2016). Hernández (2016, 2023) characterizes energy insecurity through three dimensions: economic, physical, and behavioral:

1) **Economic:** Excessively high energy bills lead to increased financial strain for low-income households whose resources are already limited (Hernández, 2023). Exacerbated by high energy inefficiency, dedicating an inordinate fraction of monthly income on high-cost energy can perpetuate poverty cycles (Bohr and McCreery, 2020). Kontokosta et al. (2020) found that household energy cost burdens (ECBs) were on average 7 percent for low-income households, whereas higher income counterparts had an average burden of 2 percent (Kontokosta et al., 2020a). Burdens relate to higher costs in combination with lower incomes.

   Data from the 2020 Residential Energy Consumption Survey (RECS) showed that energy-insecure households were on average billed $0.26 more per square foot for energy than non-energy insecure households (EIA, 2023). The same dataset showed that energy costs are also $0.17 per square foot higher for Black residents, $0.24 per square foot higher for renters, and $0.19 per square foot higher for poorly insulated homes than the national average. The U.S. Energy Information Administration (EIA) explains this discrepancy in household energy expenditures as a function of "many factors including weather, the types of energy sources used, household behavior, and the energy-consuming space (or square footage) of the home."

In California specifically, electricity services are relatively expensive for low-income households in areas across the state, with the highest burdens in the Central Valley and select areas of Los Angeles, the Inland Empire, the Bay Area, San Diego, and Northern California. Moreover, according to the CPUC's 2021/22 Annual Affordability Report, utility bills are expected to become less affordable through 2026, largely driven by forecasted increases in electricity rates that are expected to outpace inflation, particularly in hotter climate regions served by IOUs (CPUC, 2023).

2) **Physical:** According to EIA, energy-insecure households are more likely to report physical housing deficiencies than households that do not experience energy insecurity. These physical housing deficiencies include lack of functional heating and cooling appliances, poor insulation, drafts, and reliance on older, less energy-efficient lighting and appliances. These factors affect a home's energy performance, necessitating more energy use to reach thermal comfort, and thereby raising monthly utility bills (Hernández, 2016). About 4 percent and 5 percent of households in the Pacific region report being unable to use heating equipment or air conditioning in their homes because it was broken, respectively (EIA, 2020). Energy-insecure households are also more likely to report living in drafty and poorly or non-insulated homes than households that are not energy insecure (EIA, 2020b).
3) **Behavioral:** This dimension refers to adaptive strategies households use to cope with inadequate housing conditions and economic hardship. Energy-insecure households may limit their energy consumption to a level that is uncomfortable or risky to their health or forego other basic needs entirely (Hernández, 2016). Households may use potentially hazardous sources of heat, such as stoves, ovens, and electric space heaters, when a primary source is inadequate or inefficient (Hernández, 2023). Data from RECS 2020 showed that almost 20% of households in the U.S. reduce or forego food or medicine to pay for energy costs. Additionally, almost 10 percent of U.S. households report leaving their home at unhealthy temperatures (EIA, 2020b).

These dimensions of energy insecurity capture the compounding stressors of climate exposure, housing insecurity, and high energy costs on low-income households. This cycle of disproportionate exposure to extreme weather, insufficient housing conditions to cope with weather, and incurring insurmountable debt to utilities is not uncommon and can cause low-income households to eventually become disconnected due to non-payment, thus exacerbating the cycle (Barreca et al., 2022; Hernández, 2016). The cumulative burden that arises triggers behavioral coping strategies that are detrimental to mental and physical health (Best et al., 2021; Hernández, 2016; Huang et al., 2023; Boateng et al., 2021; Cook et al., 2008; Hernández, 2023, 2016; Hernández and Siegel, 2019).

Housing decarbonization measures can increase the energy security of households through the following pathways:

- **Economic:** Relatively small improvements in energy efficiency and thermal comfort can reduce energy costs by as much as $1,500 per year for low-income households, reducing overall financial hardship and psychological stress (Binet et al., 2022; Giandomenico et al., 2022; Kontokosta et al., 2020b). Additionally, load management and demand response technologies, which modulate residential energy usage to optimize supply and demand levels, can also offer financial benefits, reduce utility bills, and reduce overall financial hardship (Albadi and El-Saadany, 2007; Hurley et al., 2013; Palensky and Dietrich, 2011). These savings free up income for households to spend on other needs or purposes, which can be especially impactful for low-income households.
- **Physical:** Installing more energy-efficient appliances, improving insulation, and other weatherization upgrades to a building's envelope can result in reduced energy consumption and increased thermal comfort (Gallagher and Holloway, 2020; Hernández, 2016; Lutzker and Tobacman, 2013). Energy efficiency and weatherization retrofits will have outsized benefits for households that are most energy insecure. A recent review of 23 residential retrofit programs found that low-income households saved over four times as much energy as middle- and high-income households (Giandomenico et al., 2022). Additionally, residential rooftop solar with battery storage can safeguard against utility shutoffs (Galvan et al., 2020; Patel et al., 2021; Tosado et al., 2021), protecting those who rely on electricity for life-saving medical devices or medicine (Hernández, 2016).
- **Behavioral:** Reductions in the physical and economic dimensions of energy insecurity mean that households are less likely to engage in unhealthy coping strategies. Improving a household's material conditions results in residents being less likely to (1) sacrifice thermal comfort and safety to avoid high energy costs, (2) fear utility shutoffs, and (3) move homes to avoid faulty heating systems. These material, and thus behavioral, changes lead to direct and indirect improvements in physical and mental health (Hernández, 2016).

Given that an estimated 31 percent of California households are energy insecure (EIA, 2020b), a combination of measures that focus on improving thermal comfort and maximizing bill savings could have a significant positive impact on California's public health and health equity. Without comprehensive electrification and energy efficiency improvements, intervention risks increasing energy bills and exacerbating energy insecurity especially for low-income residents (Yim and Subramanian, 2023). In summary, to increase energy security for priority households, housing decarbonization programs must be designed with energy efficiency, thermal comfort, and bill savings as top priorities.

5.5. Health Equity

Health equity advances equal opportunities for well-being and health as a human right that is protected by nondiscrimination (Braveman, 2006; P. A. Braveman et al., 2011). There is consensus among scholars that social inequalities impact individuals' opportunities to be healthy, leading to worse health outcomes among those experiencing social disadvantage, discrimination, and marginalization (Wilkinson and Marmot, 2003; Marmot, 2005; Marmot et al., 2008; P. Braveman et al., 2011; Arcaya et al., 2015; Bailey et al., 2021). Therefore, achieving health equity requires improving opportunities to be healthy among those who were worse off to start, within an overall strategy to improve everyone's health (Braveman, 2006; P. A. Braveman et al., 2011).

Housing decarbonization programs can enhance health equity by addressing critical and intersecting structural determinants of health. We previously discussed the public health implications of housing decarbonization programs in section 2.5 of the introduction. Further, the sub-sections above delineated the pivotal role of housing decarbonization initiatives in mitigating air pollution, bolstering climate resilience, and ensuring housing and energy security for residents, all of which significantly influence health outcomes (Frosch et al., 2018; Jessel et al., 2019). Adopting a health equity lens necessitates prioritizing households that experience social inequities for housing decarbonization. Collectively, decarbonization strategies can be leveraged to effectively support households facing the greatest challenges and advance both health equity and overall population health.

6. References

Abell, H., Coontz, K., Nunez, R., 2021. California Cooperatives: Today's Landscape of Worker, Housing and Childcare Cooperatives. California Center for Cooperative Development. Retrieved from: https://cccd.coop/sites/default/files/Landscape%20of%20CA%20Coops_FNL.pdf.

Addo-Binney, B., Agelin-Chaab, M., Bamfo, E., Koohi-Fayegh, S., 2022. A Comparative Life Cycle Assessment of a Cascade Heat Pump and a Natural Gas Furnace for Residential Heating Purposes. *Integrated Environmental Assessment and Management* 18, 572–580. https://doi.org/10.1002/ieam.4494

Adua, L., De Lange, R., Aboyom, A.I., 2022. Differentiated Disadvantage: Class, Race, Gender, and Residential Energy Efficiency Inequality in the United States. *Energy Efficiency* 15, 49. https://doi.org/10.1007/s12053-022-10056-7

Agbim, C., Araya, F., Faust, K.M., Harmon, D., 2020. Subjective Versus Objective Energy Burden: A Look at Drivers of Different Metrics and Regional Variation of Energy Poor Populations. *Energy Policy* 144, 111616. https://doi.org/10.1016/j.enpol.2020.111616

Ahrentzen, S., Erickson, J., Fonseca, E., 2016. Thermal and Health Outcomes of Energy Efficiency Retrofits of Homes of Older Adults. *Indoor Air* 26, 582–593. https://doi.org/10.1111/ina.12239

Aitchison, J., Dirr, N., Dority, A., Cooper, B., 2021. Accelerating Electrification of California's Multifamily Buildings: Policy Considerations and Technical Guidelines. Retrieved from: https://www.stopwaste.org/sites/default/files/MF%20Electrification%20Readiness%20Report_FINAL.pdf.

Albadi, M.H., El-Saadany, E.F., 2007. Demand Response in Electricity Markets: An Overview, in: 2007 IEEE Power Engineering Society General Meeting. Presented at the 2007 IEEE Power Engineering Society General Meeting, pp. 1–5. https://doi.org/10.1109/PES.2007.385728

Alcala, E., Brown, P., Capitman, J.A., Gonzalez, M., Cisneros, R., 2019. Cumulative Impact of Environmental Pollution and Population Vulnerability on Pediatric Asthma Hospitalizations: A Multilevel Analysis of CalEnviroScreen. *International Journal of Environmental Research and Public Health* 16, 2683. https://doi.org/10.3390/ijerph16152683

Allcott, H., Greenstone, M., 2024. Measuring the Welfare Effects of Residential Energy Efficiency Programs (No. w23386). NBER Working Paper Working Paper 23386. https://doi.org/10.3386/w23386

Allcott, H., Greenstone, M., 2017. Measuring the Welfare Effects of Residential Energy Efficiency Programs. NBER Working Paper 23386. https://doi.org/10.3386/w23386

Allcott, H., Greenstone, M., 2012. Is There an Energy Efficiency Gap? *Journal of Economic Perspectives* 26, 3–28. https://doi.org/10.1257/jep.26.1.3

Ambrose, A., Marchand, R., 2017. The Contemporary Landscape of Fuel Poverty Research. *Indoor and Built Environment* 26, 875–878. https://doi.org/10.1177/1420326X17724914

American Community Survey, 2022. S1701: Poverty Status in the Past 12 Months.

American Lung Association, 2024. Floods and Water Damage. Retrieved from: https://www.lung.org/clean-air/emergencies-and-natural-disasters/floods-and-water-damage

American Society of Heating and Air-Conditioning Engineers (ASHAE), 2020. Standard 55 – Thermal Environmental Conditions for Human Occupancy. Retrieved from: https://www.ashrae.org/technical-resources/bookstore/standard-55-thermal-environmental-conditions-for-human-occupancy

An, B., Orlando, A.W., Rodnyansky, S., 2019. The Physical Legacy of Racism: How Redlining Cemented the Modern Built Environment. SSRN Working Paper. Retrieved from: https://doi.org/10.2139/ssrn.3500612

Anguelovski, I., Connolly, J.J., Garcia-Lamarca, M., Cole, H., Pearsall, H., 2018. New Scholarly Pathways on Green Gentrification: What Does the Urban 'Green Turn' Mean and Where is it Going? *Progress in Human Geography* 43, 1064–1086. https://doi.org/10.1177/0309132518803799

Appel, I., Nickerson, J., 2016. Pockets of Poverty: The Long-Term Effects of Redlining. SSRN Working Paper. Retrieved from https://doi.org/10.2139/ssrn.2852856

Aram, F., Higueras García, E., Solgi, E., Mansournia, S., 2019. Urban Green Space Cooling Effect in Cities. *Heliyon* 5, e01339. https://doi.org/10.1016/j.heliyon.2019.e01339

Arcaya, M.C., Arcaya, A.L., Subramanian, S.V., 2015. Inequalities in Health: Definitions, Concepts, and Theories. *Global Health Action* 8, 27106. https://doi.org/10.3402/gha.v8.27106

Armstrong, S., Stone, N., Dryden, A., 2022. The Impact of the California Utility Allowance Calculator and the Benefits of Standardization within California Title 24 Software. 2050 Partners and Southern California Edison. Retrieved from: https://www.redwoodenergy.net/research/the-impact-of-the-california-utility-allowance-calculator-and-the-benefits-of-standardization-within-california-title-24-software

Axsen, J., Kurani, K.S., 2012. Social Influence, Consumer Behavior, and Low-Carbon Energy Transitions. *Annual Review of Environment and Resources* 37, 311–340. https://doi.org/10.1146/annurev-environ-062111-145049

Aydin, E., Correa, S.B., Brounen, D., 2019. Energy Performance Certification and Time on the Market. *Journal of Environmental Economics and Management* 98, 102270. https://doi.org/10.1016/j.jeem.2019.102270

Azhar, S., Griffin, M.K.A., 2014. Women in Construction: Successes, Challenges and Opportunities – A USACE Case Study. Retrieved from: http://ascpro0.ascweb.org/archives/cd/2014/paper/CPRT249002014.pdf

Baars, H., Radenz, M., Floutsi, A.A., Engelmann, R., Althausen, D., Heese, B., Ansmann, A., Flament, T., Dabas, A., Trapon, D., Reitebuch, O., Bley, S., Wandinger, U., 2021. Californian Wildfire Smoke Over Europe: A First Example of the Aerosol Observing Capabilities of Aeolus Compared to Ground-Based Lidar. *Geophysical Research Letters* 48, e2020GL092194. https://doi.org/10.1029/2020GL092194

Bailey, Z.D., Feldman, J.M., Bassett, M.T., 2021. How Structural Racism Works — Racist Policies as a Root Cause of U.S. Racial Health Inequities. *N Engl J Med* 384, 768–773. https://doi.org/10.1056/NEJMms2025396

Bailey, Z.D., Krieger, N., Agénor, M., Graves, J., Linos, N., Bassett, M.T., 2017. Structural Racism and Health Inequities in the USA: Evidence and Interventions. *The Lancet* 389, 1453–1463. https://doi.org/10.1016/S0140-6736(17)30569-X

Barreca, A., Park, R.J., Stainier, P., 2022. High Temperatures and Electricity Disconnections for Low-Income Homes in California. *Nat Energy* 7, 1052–1064. https://doi.org/10.1038/s41560-022-01134-2

Bednar, D.J., Reames, T.G., 2020. Recognition of and Response to Energy Poverty in the United States. *Nature Energy* 5, 432–439. https://doi.org/10.1038/s41560-020-0582-0

Bedsworth, L., Cayan, D., Franco, G., Fisher, L., Ziaja, S., 2018. California's Fourth Climate Change Assessment: Statewide Summary Report. (No. SUM-CCCA4-2018-013). California Governor's Office of Planning and Research, Scripps Institution of Oceanography, California Energy Commission, California Public Utilities Commission. Retrieved from: https://www.energy.ca.gov/sites/default/files/2019-11/Statewide_Reports-SUM-CCCA4-2018-013_Statewide_Summary_Report_ADA.pdf

BEEP Coalition, 2023. BEEP Comments on Equitable Building Decarbonization Program Draft Guidelines. Retrieved from: https://beepcoalition.org/statewide/

Bergman, N., Foxon, T.J., 2020. Reframing Policy for the Energy Efficiency Challenge: Insights from Housing Retrofits in the United Kingdom. *Energy Research & Social Science* 63, 101386. https://doi.org/10.1016/j.erss.2019.101386

Berry, R., Livesley, S.J., Aye, L., 2013. Tree Canopy Shade Impacts on Solar Irradiance Received by Building Walls and their Surface Temperature. *Building and Environment* 69, 91–100. https://doi.org/10.1016/j.buildenv.2013.07.009

Berzolla, Z., Meng, T., Reinhart, C., 2023. Homeowners' Willingness to Pay for Residential Building Retrofits. SSRN Working Paper. https://doi.org/10.2139/ssrn.4536734

Best, R., Burke, P.J., Nishitateno, S., 2021. Factors Affecting Renters' Electricity Use: More Than Split Incentives. *The Energy Journal* 42, 1–18. https://doi.org/10.5547/01956574.42.5.rbes

Bevan, G.H., Freedman, D.A., Lee, E.K., Rajagopalan, S., Al-Kindi, S.G., 2021. Association Between Ambient Air Pollution and County-Level Cardiovascular Mortality in the United States by Social Deprivation Index. *American Heart Journal* 235, 125–131. https://doi.org/10.1016/j.ahj.2021.02.005

Binet, A., Nidam, Y., Houston-Read, R., Lopez, C.G., del Rio, G.Z., Abreu, D., Baty, C., Baty, A., Genty, J., Graham, G., Joseph, J., Justice, W., Roderigues, G., Underhill, D., Gavin, V., Arcaya, M.C., 2022. Ownership of Change: Participatory Development of a Novel Latent Construct for Neighborhoods and Health Equity Research. *Social Science & Medicine* 309, 115234. https://doi.org/10.1016/j.socscimed.2022.115234

Binet, A., Zayas Del Rio, G., Arcaya, M., Roderigues, G., Gavin, V., 2021. 'It Feels Like Money's Just Flying out the Window': Financial Security, Stress and Health in

Gentrifying Neighborhoods. *Cities & Health* 6, 536–551. https://doi.org/10.1080/23748834.2021.1885250

Bird, S., Hernández, D., 2012. Policy Options for the Split Incentive: Increasing Energy Efficiency for Low-Income Renters. *Energy Policy, Special Section: Frontiers of Sustainability* 48, 506–514. https://doi.org/10.1016/j.enpol.2012.05.053

Boardman, B., 1991. *Fuel Poverty: From Cold Homes to Affordable Warmth.* Belhaven Press.

Bocian, D., Li, W., Carolina, R., Garcia, R., 2011. *Lost Ground, 2011: Disparities in Mortgage Lending and Foreclosures.* Center for Responsible Lending. Retrieved from: https://www.responsiblelending.org/research-publication/lost-ground-2011-disparities-mortgage-lending-and-foreclosures

Bohr, J., McCreery, A.C., 2020. Do Energy Burdens Contribute to Economic Poverty in the United States? A Panel Analysis. *Social Forces* 99, 155–177. https://doi.org/10.1093/sf/soz131

Bollinger, B., Gillingham, K., Kirkpatrick, A.J., Sexton, S., 2022. Visibility and Peer Influence in Durable Good Adoption. *Marketing Science* 41, 453–476. https://doi.org/10.1287/mksc.2021.1306

Borenstein, S., Bushnell, J., Mansur, E., 2023. The Economics of Electricity Reliability. *Journal of Economic Perspectives* 37, 181–206. https://doi.org/10.1257/jep.37.4.181

Borenstein, S., Davis, L.W., 2016. The Distributional Effects of US Clean Energy Tax Credits. *Tax Policy and the Economy* 30, 191–234. https://doi.org/10.1086/685597

Borenstein, S., Fowlie, M., Sallee, J., 2021. Designing Electricity Rates for An Equitable Energy Transition. University of California Berkeley Hass Energy Institute and Next 10. Retrieved from: https://haas.berkeley.edu/wp-content/uploads/WP314.pdf

Bouzarovski, S., Frankowski, J., Herrero, S.T., 2018. Low-Carbon Gentrification: When Climate Change Encounters Residential Displacement. *International Journal of Urban and Regional Research* 42, 845–863. https://doi.org/10.1111/1468-2427.12634

Bowe, B., Xie, Y., Yan, Y., Al-Aly, Z., 2019. Burden of Cause-Specific Mortality Associated with PM2.5 Air Pollution in the United States. *JAMA Network Open 2*, e1915834. https://doi.org/10.1001/jamanetworkopen.2019.15834

Braveman, P., 2006. Health Disparities and Health Equity: Concepts and Measurement. *Annual Review of Public Health* 27, 167–194. https://doi.org/10.1146/annurev.publhealth.27.021405.102103

Braveman, P., Egerter, S., Williams, D.R., 2011. The Social Determinants of Health: Coming of Age. *Annual Review of Public Health* 32, 381–398.

Braveman, P.A., Kumanyika, S., Fielding, J., LaVeist, T., Borrell, L.N., Manderscheid, R., Troutman, A., 2011. Health Disparities and Health Equity: The Issue Is Justice. *Am J Public Health* 101, S149–S155. https://doi.org/10.2105/AJPH.2010.300062

Brecha, R.J., Mitchell, A., Hallinan, K., Kissock, K., 2011. Prioritizing Investment in Residential Energy Efficiency and Renewable Energy—A case study for the U.S. Midwest. *Energy Policy* 39, 2982–2992. https://doi.org/10.1016/j.enpol.2011.03.011

Brockway, A.M., Conde, J., Callaway, D., 2021. Inequitable Access to Distributed Energy Resources Due to Grid Infrastructure Limits in California. *Nat Energy* 6, 892–903. https://doi.org/10.1038/s41560-021-00887-6

Brown, M.A., Kale, S., Cha, M.-K., Chapman, O., 2023. Exploring the Willingness of Consumers to Electrify their Homes. *Applied Energy 338*. https://doi.org/10.1016/j.apenergy.2023.120791

Brown, M.A., Soni, A., Lapsa, M.V., Southworth, K., Cox, M., 2020. High Energy Burden and Low-Income Energy Affordability: Conclusions from a Literature Review. *Progress in Energy 2.* https://doi.org/10.1088/2516-1083/abb954

Brucal, A., Roberts, M.J., 2019. Do Energy Efficiency Standards Hurt Consumers? Evidence from Household Appliance Sales. *Journal of Environmental Economics and Management* 96, 88–107. https://doi.org/10.1016/j.jeem.2019.04.005

Bruegge, C., Carrión-Flores, C., Pope, J.C., 2016. Does the Housing Market Value Energy Efficient Homes? Evidence from the Energy Star Program. *Regional Science and Urban Economics* 57, 63–76. https://doi.org/10.1016/j.regsciurbeco.2015.12.001

Bruegge, C., Deryugina, T., Myers, E., 2019. The Distributional Effects of Building Energy Codes. *Journal of the Association of Environmental and Resource Economists* 6, S95–S127. https://doi.org/10.1086/701189

Brummer, V., 2018. Community Energy – Benefits and Barriers: A Comparative Literature Review of Community Energy in the UK, Germany and the USA, the Benefits It Provides for Society and the Barriers It Faces. *Renewable and Sustainable Energy Reviews* 94, 187–196. https://doi.org/10.1016/j.rser.2018.06.013

Buonocore, J.J., Hughes, E.J., Michanowicz, D.R., Heo, J., Allen, J.G., Williams, A., 2019. Climate and Health Benefits of Increasing Renewable Energy Deployment in the United States. *Environ. Res. Lett.* 14, 114010. https://doi.org/10.1088/1748-9326/ab49bc

Buonocore, J.J., Luckow, P., Norris, G., Spengler, J.D., Biewald, B., Fisher, J., Levy, J.I., 2016. Health and Climate Benefits of Different Energy-Efficiency and Renewable Energy Choices. *Nature Clim Change* 6, 100–105. https://doi.org/10.1038/nclimate2771

CAEATFA, 2024. *2023 Annual Report to the California State Legislature.* California Alternative Energy and Advanced Transportation Financing Authority, California. Retrieved from: https://www.treasurer.ca.gov/caeatfa/publications.asp

Caferra, R., Colasante, A., D’Adamo, I., Morone, A., Morone, P., 2023. Interacting Locally, Acting Globally: Trust and Proximity in Social Networks for the Development of Energy Communities. *Sci Rep* 13, 16636. https://doi.org/10.1038/s41598-023-43608-7

Cajias, M., Piazolo, D., 2013. Green Performs Better: Energy Efficiency and Financial Return on Buildings. *Journal of Corporate Real Estate* 15, 53–72. https://doi.org/10.1108/JCRE-12-2012-0031

Cal-Heat, 2024. California Heat Assessment Tool. Retrieved from https://www.cal-heat.org/explore.

California Energy Commission, 2024. Load Management Standards. Retrieved from https://www.energy.ca.gov/programs-and-topics/topics/load-flexibility/load-management-standards.

California Energy Commission, 2022. California Utility Allowance Calculator (CUAC). Retrieved from: https://www.energy.ca.gov/programs-and-topics/programs/building-energy-efficiency-standards/california-utility-allowance.

California Natural Resources Agency, 2022. Protecting Californians from Extreme Heat: A State Action Plan to Build Community Resilience. Retrieved from: https://resources.ca.gov/-/media/CNRA-Website/Files/Initiatives/Climate-Resilience/2022-Final-Extreme-Heat-Action-Plan.pdf

Campbell, A., Lamm, T., Hoff, K., 2023. The Future of California Consumer Energy Finance. Center for Law, Energy, & the Environment (CLEE). Retrieved from: https://www.law.berkeley.edu/research/clee/research/climate/energy-efficiency/financing/

CARB, 2023. California Greenhouse Gas Emissions from 2000 to 2021: Trends of Emissions and Other Indicators. Retrieved from: https://ww2.arb.ca.gov/sites/default/files/2023-12/2000_2021_ghg_inventory_trends.pdf

CARB, 2022. 2022 Scoping Plan for Achieving Carbon Neutrality. California Air Resources Board. Retrieved from: https://ww2.arb.ca.gov/our-work/programs/ab-32-climate-change-scoping-plan/2022-scoping-plan-documents

CARB, 2005. Report to the California Legislature: Indoor Air Pollution in California. Retrieved from: https://ww2.arb.ca.gov/sites/default/files/classic/research/apr/reports/l3041.pdf

Carley, S., Engle, C., Konisky, D.M., 2021. An Analysis of Energy Justice Programs Across the United States. *Energy Policy* 152, 112219. https://doi.org/10.1016/j.enpol.2021.112219

Carr, M.F., Boyd Kramer, D., 2022. Homeowners' Associations: Barriers or Bridges to More Sustainable Residential Development? *Landscape and Urban Planning* 224, 104419. https://doi.org/10.1016/j.landurbplan.2022.104419

Casey, J.A., Karasek, D., Ogburn, E.L., Goin, D.E., Dang, K., Braveman, P.A., Morello-Frosch, R., 2018. Retirements of Coal and Oil Power Plants in California: Association with Reduced Preterm Birth Among Populations Nearby. *American Journal of Epidemiology* 187, 1586–1594. https://doi.org/10.1093/aje/kwy110

Casey, J.A., Su, J.G., Henneman, L.R.F., Zigler, C., Neophytou, A.M., Catalano, R., Gondalia, R., Chen, Y.-T., Kaye, L., Moyer, S.S., Combs, V., Simrall, G., Smith, T., Sublett, J., Barrett, M.A., 2020. Improved Asthma Outcomes Observed in the Vicinity of Coal Power Plant Retirement, Retrofit and Conversion to Natural Gas. *Nat Energy* 5, 398–408. https://doi.org/10.1038/s41560-020-0600-2

CDPH, 2022. 2022 Heat Wave Excess Mortality Report. California Department of Public Health. Retrieved from: https://www.cdph.ca.gov/Programs/OHE/CDPH%20Document%20Library/Climate-Health-Equity/CDPH-2022-Heat-Wave-Excess-Mortality-Report.pdf

Center for Energy Workforce Development, 2023. 2023 Energy Workforce Survey Results. Retrieved from: https://cewd.org/wp-content/uploads/2023/01/CEWD-2023-Workforce-Report-Executive-Summary_2023-FINAL-1.pdf

Center for Sustainable Energy, 2016. Literature Review: Housing, Energy Use, Decision-Making and Messaging among Key Ethnic Groups in California. Retrieved from: https://energycenter.org/sites/default/files/docs/ext/building-performance/literature_review_epc14037.pdf

Cha, J.M., Pastor, M., 2022. Just Transition: Framing, Organizing, and Power-Building for Decarbonization. *Energy Research & Social Science* 90, 102588. https://doi.org/10.1016/j.erss.2022.102588

Chakraborty, T., Hsu, A., Manya, D., Sheriff, G., 2019. Disproportionately Higher Exposure to Urban Heat in Lower-Income Neighborhoods: A Multi-City Perspective. *Environ. Res. Lett.* 14, 105003. https://doi.org/10.1088/1748-9326/ab3b99

CHEEF, 2021. GoGreen Home Energy Financing Program Monthly Data Summary through December 31, 2021. Retrieved from: https://www.treasurer.ca.gov/caeatfa/cheef/cheef-reports-and-additional-materials.asp

Chegut, A., Eichholtz, P., Holtermans, R., 2016. Energy Efficiency and Economic Value in Affordable Housing. *Energy Policy* 97, 39–49. https://doi.org/10.1016/j.enpol.2016.06.043

Chelsea Kirk, 2021. Los Angeles Building Decarbonization: Tenant Impact and Recommendations. Strategic Actions for a Just Economy. Retrieved from: https://www.saje.net/building-decarbonization/

Clayton, S., Manning, C., Speiser, M., Hill, A.N., 2021. Mental Health and our Changing Climate: Impacts, Inequities, Responses. American Psychological Association and ecoAmerica, Washington DC. Retrieved from: https://www.apa.org/news/press/releases/mental-health-climate-change.pdf

Cohen, O., McTarnaghan, S., Junod, A.N., 2024. Preserving, Protecting, and Building Climate-Resilient Affordable Housing: A Framework for Local Action. The Urban Institute. Retrieved from: https://www.urban.org/research/publication/preserving-protecting-and-building-climate-resilient-affordable-housing

Coley, R.L., Leventhal, T., Lynch, A.D., Kull, M., 2013. Relations between Housing Characteristics and the Well-Being of Low-Income Children and Adolescents. *Dev Psychol* 49, 1775–1789. https://doi.org/10.1037/a0031033

Copiello, S., 2015. Achieving Affordable Housing through Energy Efficiency Strategy. *Energy Policy* 85, 288–298. https://doi.org/10.1016/j.enpol.2015.06.017

Council on Environmental Quality, 2022. Methodology & data - Climate & Economic Justice Screening Tool. Retrieved from: https://screeningtool.geoplatform.gov/en/methodology#low-income.

Courtney, K., Demiris, G., Rantz, M., Skubic, M., 2008. Needing Smart Home Technologies: The Perspectives of Older Adults in Continuing Care Retirement Communities. *Journal of Innovation in Health Informatics* 16, 195–201. https://doi.org/10.14236/jhi.v16i3.694

Cox, R., Henwood, B., Rodnyansky, S., Rice, E., Wenzel, S., 2019. Road Map to a Unified Measure of Housing Insecurity. *Cityscape* 21, 93–128.

CPUC, 2023. 2021/2022 Annual Affordability Report. Retrieved from: https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/documents/affordability-proceeding/2021-2022/2021-and-2022-annual-affordability-report.pdf

CPUC, 2020. Decision Evaluating the Mobilehome Park Pilot and Establishing a Mobilehome Park Utility Conversion Program. Retrieved from: https://www.cpuc.ca.gov/regulatory-services/safety/mhp/mobilehome-park-utility-upgrade-program

CPUC, 2018. Decision Approving San Joaquin Valley Disadvantaged Communities Pilot Projects. Retrieved from: https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/infrastructure/identifying-disadvantaged-communitie

Cranmer, Z., Steinfield, L., Miranda, J., Stohler, T., 2023. Energy Distributive Injustices: Assessing The Demographics of Communities Surrounding Renewable and Fossil Fuel Power Plants in the United States. *Energy Research & Social Science* 100, 103050. https://doi.org/10.1016/j.erss.2023.103050

Cushing, L., Morello-Frosch, R., Hubbard, A., 2022. Extreme Heat and its Association with Social Disparities in the Risk of Spontaneous Preterm Birth. *Paediatr Perinat Epidemiol* 36, 13–22. https://doi.org/10.1111/ppe.12834

Cushing, L.J., Li, S., Steiger, B.B., Casey, J.A., 2023. Historical Redlining is Associated with Fossil Fuel Power Plant Siting and Present-Day Inequalities in Air Pollutant Emissions. *Nat Energy* 8, 52–61. https://doi.org/10.1038/s41560-022-01162-y

Dahlke, S., McFarlane, D., 2015. Environmental Benefits of Demand Response. Great Plains Institute. Retrieved from: https://www.betterenergy.org/wp-content/uploads/2018/03/DR-Fact-Sheet-2-Environmental-Benefits-of-DR.pdf

Daouda, M., Carforo, A., Miller, H., Ventrella, J., Tan, Y.A., Feliciano, M., Tryner, J., Hallward-Driemeier, A., Chillrud, S., Commane, R., Hernández, D., Johnson, M., Jack, D., 2024. Out of Gas, In with Justice: Findings from a Gas-to-Induction Pilot in Low-income Housing in NYC. *Energy Research & Social Science* 116, 103662. https://doi.org/10.1016/j.erss.2024.103662

Daouda, M., Henneman, L., Kioumourtzoglou, M.-A., Gemmill, A., Zigler, C., Casey, J.A., 2021. Association between county-level coal-fired power plant pollution and racial disparities in preterm births from 2000 to 2018. *Environ. Res. Lett.* 16, 034055. https://doi.org/10.1088/1748-9326/abe4f7

Davis, B.A., Arcaya, M.C., Williams, D.R., Metzger, M., Krieger, N., 2023. Examining discrimination in home improvement financing (Home Mortgage Disclosure Act 2012–2016) and neighborhood health in the United States. *Cities & Health* 7, 1029–1044. https://doi.org/10.1080/23748834.2023.2260188

Davis, L.W., 2023. The Economic Determinants of Heat Pump Adoption. National Bureau of Economics Working Paper Series, Number 31344. Retrieved from: https://doi.org/10.3386/w31344

De Souza, R., Evans-Agnew, R., Espina, C., 2019. Federal Weatherization and Health Education Team Up: Process Evaluation of a New Strategy to Improve Health Equity for People with Asthma and Chronic Obstructive Pulmonary Disease. *Journal of Public Health Management and Practice* 25, E21. https://doi.org/10.1097/PHH.0000000000000786

DECC, 2012. Low Carbon Communities Challenge Evaluation Report. United Kingdom Department of Energy and Climate Change. Retrieved from: https://www.gov.uk/government/publications/low-carbon-communities-challenge-evaluation-report.

Dedoussi, I.C., Eastham, S.D., Monier, E., Barrett, S.R.H., 2020. Premature Mortality Related to United States Cross-State Air Pollution. *Nature* 578, 261–265. https://doi.org/10.1038/s41586-020-1983-8

Deetjen, T.A., Walsh, L., Vaishnav, P., 2021. US Residential Heat Pumps: The Private Economic Potential and Its Emissions, Health, and Grid Impacts. *Environ. Res. Lett.* 16, 084024. https://doi.org/10.1088/1748-9326/ac10dc

DeFazio, P.A., 2021. H.R.3684: Infrastructure Investment and Jobs Act. Retrieved from: https://www.congress.gov/bill/117th-congress/house-bill/3684

DeLuca, S., Rosen, E., 2022. Housing Insecurity Among the Poor Today. *Annual Review of Sociology* 48, 343–371. https://doi.org/10.1146/annurev-soc-090921-040646

Department for Business, Energy & Industrial Strategy, 2022. Fuel Poverty Statistics. United Kingdom Government, London, UK.

Department of Energy, 2023. 2023 US Energy and Employment Report by State. Retrieved from https://www.energy.gov/sites/default/files/2023-06/2023%20USEER%20States%20Complete.pdf.

Department of Energy, 2017. Chapter 5: Electricity Workforce of the 21st Century: Changing Needs and New Opportunities, in: *Transforming the Nation's Electricity System: The Second Installment of the Quadrennial Energy Review*. Retrieved from: https://www.energy.gov/sites/prod/files/2017/01/f34/Transforming%20the%20Nation%27s%20Electricity%20System-The%20Second%20Installment%20of%20the%20Quadrennial%20Energy%20Review--%20Full%20Report.pdf

DePew, A.N., Outcault, S., Sanguinetti, A., Alston-Stepnitz, E., Magaña, C., 2022. Affordable Multi-family Housing Occupant Experience: All-Electric & Zero-net Energy Communities.

Desai, J., Chovanec, C., 2023. Energy Auditor Job Task Analysis (No. NREL/TP-7A40-85300). National Renewable Energy Laboratory (NREL), Golden, CO (United States). https://doi.org/10.2172/2005572

Do, V., McBrien, H., Flores, N.M., Northrop, A.J., Schlegelmilch, J., Kiang, M.V., Casey, J.A., 2023. Spatiotemporal distribution of power outages with climate events and social vulnerability in the USA. Nat Commun 14, 2470. https://doi.org/10.1038/s41467-023-38084-6

Doris, E., Cochran, J., Vorum, M., 2009. Energy Efficiency Policy in the United States: Overview of Trends at Different Levels of Government (No. NREL/TP-6A2-46532). National Renewable Energy Lab. (NREL), Golden, CO (United States). https://doi.org/10.2172/970345

Drehobl, A., Ross, L., 2016. Lifting the High Energy Burden in America's Largest Cities: How Energy Efficiency Can Improve Low-Income and Underserved Communities. American Council for an Energy-Efficient Economy. Retrieved from: https://www.aceee.org/sites/default/files/publications/researchreports/u1602.pdf.

Duncan, K., Ormiston, R., 2019. What Does the Research Tell Us about Prevailing Wage Laws? *Labor Studies Journal* 44, 139–160. https://doi.org/10.1177/0160449X18766398

Dunn, S., Quigley, J.M., Rosenthal, L.A., 2005. The Effects of Prevailing Wage Requirements on the Cost of Low-Income Housing. *ILR Review*, 59(1), 141-157. https://doi.org/10.1177/001979390505900108

E2, ACORE, CELI, 2020. Clean Jobs, Better Jobs: An Examination of Clean Energy Job Wages and Benefits. Retrieved from: https://e2.org/wp-content/uploads/2020/10/Clean-Jobs-Better-Jobs.-October-2020.-E2-ACORE-CELI.pdf

E2, Alliance to Save Energy, American Association of Blacks in Energy, Energy Efficiency for All, Black Owners of Solar Services, BW Research Partnership, 2021. Help Wanted: Diversity in Clean Energy. Retrieved from: https://e2.org/reports/diversity-in-clean-energy-2021/

E3, 2022. E3 Undertakes Analysis of Targeted Decommissioning of Natural Gas Infrastructure in California. Retrieved from: https://www.ethree.com/e3-undertakes-analysis-of-targeted-decommissioning-of-natural-gas-infrastructure-in-california/

E3, 2020. The Challenge of Retail Gas in California's Low-Carbon Future. Retrieved from: https://www.energy.ca.gov/publications/2019/challenge-retail-gas-californias-low-carbon-future-technology-options-customer

Economidou, M., Todeschi, V., Bertoldi, P., D'Agostino, D., Zangheri, P., Castellazzi, L., 2020. Review of 50 years of EU Energy Efficiency Policies for Buildings. *Energy and Buildings* 225, 110322. https://doi.org/10.1016/j.enbuild.2020.110322

EIA, 2023. U.S. Energy Insecure Households Were Billed More for Energy Than Other Households. U.S. Energy Information Administration (EIA). Retrieved from: https://www.eia.gov/todayinenergy/detail.php?id=56640

EIA, 2021. Per Capita U.S. Residential Electricity Use Was Flat In 2020, but Varied by State. U.S. Energy Information Administration (EIA). Retrieved from: https://www.eia.gov/todayinenergy/detail.php?id=49036

EIA, 2020. 2020 Residential Energy Consumption Survey. U.S. Energy Information Administration. Retrieved from https://www.eia.gov/consumption/residential/

Elmallah, S., Brockway, A.M., Callaway, D., 2022a. Can Distribution Grid Infrastructure Accommodate Residential Electrification and Electric Vehicle Adoption in Northern California? *Environ. Res.: Infrastruct. Sustain.* 2, 045005. https://doi.org/10.1088/2634-4505/ac949c

Elmallah, S., Reames, T.G., Spurlock, C.A., 2022b. Frontlining Energy Justice: Visioning Principles for Energy Transitions from Community-Based Organizations in the United States. *Energy Research & Social Science* 94, 102855. https://doi.org/10.1016/j.erss.2022.102855

Energy Futures Initiative, 2019. Optionality, Flexibility, and Innovation: Pathways for Deep Decarbonization in California. Retrieved from: https://efifoundation.org/reports/optionality-flexibility-innovation/

Energy Programs Consortium, 2013. Multifamily Energy Efficiency: Reported Barriers and Emerging Practices. Retrieved from https://www.aceee.org/files/pdf/resource/epc_%20multifamily_housing_13.pdf

Estiri, H., Zagheni, E., 2019. Age Matters: Ageing and Household Energy Demand in the United States. *Energy Research & Social Science* 55, 62–70. https://doi.org/10.1016/j.erss.2019.05.006

Evergreen Economics, 2022. SJV DAC Pilot Projects Process Evaluation. Retrieved from: https://www.calmac.org/publications/SJV_DAC_Process_Evaluation_Final_Report_102022.pdf

Ferguson, J., Bickel, S., Lachman, H., Cillo, P., Hummel, H., 2022. Pay As You Save System of Inclusive Utility Investment for Building Efficiency Upgrades: Reported and Evaluated Field Experience in the United States. Retrieved from: https://www.cleanenergyworks.org/2022/10/25/field-experience-for-pays-in-the-us/

Ferguson, L., Taylor, J., Zhou, K., Shrubsole, C., Symonds, P., Davies, M., Dimitroulopoulou, S., 2021. Systemic Inequalities in Indoor Air Pollution Exposure in London, *Buildings & Cities* 2, 425–448. https://doi.org/10.5334/bc.100

Fisk, W.J., Singer, B.C., Chan, W.R., 2020. Association of Residential Energy Efficiency Retrofits with Indoor Environmental Quality, Comfort, and Health: A Review of Empirical Data. *Building and Environment* 180, 107067. https://doi.org/10.1016/j.buildenv.2020.107067

Foley, R., 2022. Closing the Clean Technologies Skills Gap: Advancing Energy Efficiency Through Heat Pump Training for HVAC Contractors. Energy Intel: Energy Justice and Workforce Development 18–19. Retrieved from: https://www.icastusa.org/closing-the-clean-technologies-skills-gap/

Forrester, S.P., Reames, T.G., 2020. Understanding the Residential Energy Efficiency Financing Coverage Gap and Market Potential. *Applied Energy* 260, 114307. https://doi.org/10.1016/j.apenergy.2019.114307

Foster, D., Nabahe, S., Sui Hon Ng, B., 2020. Energy Workforce Development in the 21st Century, The Roosevelt Project Special Series. MIT Center for Energy and Environmental Policy Research. Retrieved from: https://ceepr.mit.edu/workingpaper/energy-workforce-development-in-the-21st-century/

Foundation for Community Association Research, 2023. Fact Book 2023 Dashboard. Retrieved from: https://foundation.caionline.org/publications/factbook/fact-book-2023-dashboard/

Fournier, E.D., Cudd, R., Federico, F., Pincetl, S., 2020. Implications Of the Timing of Residential Natural Gas Use for Appliance Electrification Efforts. *Environ. Res. Lett.* 15, 124008. https://doi.org/10.1088/1748-9326/aba1c0

Fournier, E.D., Cudd, R., Smithies, S., Pincetl, S., 2024. Quantifying The Electric Service Panel Capacities of California's Residential Buildings. *Energy Policy* 192, 114238. https://doi.org/10.1016/j.enpol.2024.114238

Fowlie, M., Greenstone, M., Wolfram, C., 2015. Are the Non-monetary Costs of Energy Efficiency Investments Large? Understanding Low Take-Up of a Free Energy Efficiency Program. *American Economic Review* 105, 201–204. https://doi.org/10.1257/aer.p20151011

Francisco, P.W., Jacobs, D.E., Targos, L., Dixon, S.L., Breysse, J., Rose, W., Cali, S., 2017. Ventilation, Indoor Air Quality, and Health in Homes Undergoing Weatherization. *Indoor Air* 27, 463–477. https://doi.org/10.1111/ina.12325

Frank, M., Nowak, S., 2016. Who's Participating and Who's Not? The Unintended Consequences of Untargeted Programs. Proceedings of the ACEEE 2016 Summer Study on Energy Efficiency in Buildings. Retrieved from: ttps://www.aceee.org/files/proceedings/2016/data/papers/2_542.pdf

Frosch, R.M., Pastor, M., Sadd, J., Shonkoff, S., 2018. The Climate Gap: Inequalities in How Climate Change Hurts Americans and How to Close the Gap, in: *Planning for Climate Change*. Retrieved from: https://dornsife.usc.edu/eri/publications/the-climate-gap-inequalities-in-how-climate-change-hurts-americans-how-to-close-the-gap/

Fuerst, F., McAllister, P., Nanda, A., Wyatt, P., 2015. Does Energy Efficiency Matter to Home-Buyers? An Investigation of EPC Ratings and Transaction Prices in England. *Energy Economics* 48, 145–156. https://doi.org/10.1016/j.eneco.2014.12.012

Gabbe, C.J., Pierce, G., 2020. Extreme Heat Vulnerability of Subsidized Housing Residents in California. *Housing Policy Debate* 30, 843–860. https://doi.org/10.1080/10511482.2020.1768574

Gallagher, C.L., Holloway, T., 2020. Integrating Air Quality and Public Health Benefits in U.S. Decarbonization Strategies. *Frontiers in Public Health* 8:563358. doi: 10.3389/fpubh.2020.563358

Galvan, E., Mandal, P., Sang, Y., 2020. Networked Microgrids with Roof-Top Solar PV and Battery Energy Storage to Improve Distribution Grids Resilience to Natural Disasters. *International Journal of Electrical Power & Energy Systems* 123, 106239. https://doi.org/10.1016/j.ijepes.2020.106239

GAO, 2020. As More Households Rent, the Poorest Face Affordability and Housing Quality Challenges. United States Government Accountability Office. Retrieved from: https://www.gao.gov/products/gao-20-427

Geller, H., Harrington, P., Rosenfeld, A.H., Tanishima, S., Unander, F., 2006. Policies for Increasing Energy Efficiency: Thirty Years of Experience in OECD Countries. *Energy Policy* 34, 556–573. https://doi.org/10.1016/j.enpol.2005.11.010

Giandomenico, L., Papineau, M., Rivers, N., 2022. A Systematic Review of Energy Efficiency Home Retrofit Evaluation Studies. *Annu. Rev. Resour. Econ.* 14, 689–708. https://doi.org/10.1146/annurev-resource-111920-124353

Gilbertson, J., Stevens, M., Stiell, B., Thorogood, N., 2006. Home is Where the Hearth Is: Grant Recipients' Views of England's Home Energy Efficiency Scheme (Warm

Front). *Social Science & Medicine* 63, 946–956. https://doi.org/10.1016/j.socscimed.2006.02.021

Gillich, A., Sunikka-Blank, M., Ford, A., 2018. Designing an 'Optimal' Domestic Retrofit Programme. *Building Research & Information* 46, 767–778. https://doi.org/10.1080/09613218.2017.1368235

Gillingham, K., Harding, M., Rapson, D., 2012. Split Incentives in Residential Energy Consumption. *The Energy Journal* 33. https://doi.org/10.5547/01956574.33.2.3

Gillingham, K., Palmer, K., 2014. Bridging the Energy Efficiency Gap: Policy Insights from Economic Theory and Empirical Evidence. *Review of Environmental Economics and Policy* 8, 18–38. https://doi.org/10.1093/reep/ret021

Gillingham, K.T., Huang, P., Buehler, C., Peccia, J., Gentner, D.R., 2021. The Climate and Health Benefits from Intensive Building Energy Efficiency Improvements. *Science Advances* 7, eabg0947. https://doi.org/10.1126/sciadv.abg0947

GIZ, 2024. Green Impact Zone of Missouri. Retrieved from: http://www.greenimpactzone.org/funding.html

Goforth, T., Nock, D., 2022. Air Pollution Disparities And Equality Assessments Of US National Decarbonization Strategies. *Nat Commun* 13, 7488. https://doi.org/10.1038/s41467-022-35098-4

Goldstein, B., Reames, T.G., Newell, J.P., 2022. Racial Inequity in Household Energy Efficiency and Carbon Emissions in the United States: An Emissions Paradox. *Energy Research & Social Science* 84, 102365. https://doi.org/10.1016/j.erss.2021.102365

Goldthau, A., 2014. Rethinking The Governance of Energy Infrastructure: Scale, Decentralization and Polycentrism. *Energy Research & Social Science* 1, 134–140. https://doi.org/10.1016/j.erss.2014.02.009

Graf-Vlachy, L., Buhtz, K., König, A., 2018. Social Influence in Technology Adoption: Taking Stock and Moving Forward. *Manag Rev Q* 68, 37–76. https://doi.org/10.1007/s11301-017-0133-3

Grannis, J., 2020. Community-Driven Climate Solutions: How Public-Private Partnerships with Land Trusts Can Advance Climate Action. *William & Mary Environmental Law and Policy Review* 44, 701. Retrieved from https://scholarship.law.wm.edu/wmelpr/vol44/iss3/3/

Gromet, D.M., Kunreuther, H., Larrick, R.P., 2013. Political Ideology Affects Energy-Efficiency Attitudes and Choices. *Proceedings of the National Academy of Sciences* 110, 9314–9319. https://doi.org/10.1073/pnas.1218453110

Gromicko, N., Shepard, K., 2016. Knob-and-Tube Wiring. Retrieved from: https://www.nachi.org/knob-and-tube.htm

Guo, S., Kontou, E., 2021. Disparities and Equity Issues in Electric Vehicles Rebate Allocation. *Energy Policy* 154, 112291. https://doi.org/10.1016/j.enpol.2021.112291

Gupta, R., Barnfield, L., Hipwood, T., 2014. Impacts of Community-Led Energy Retrofitting of Owner-Occupied Dwellings. *Building Research & Information* 42, 446–461. https://doi.org/10.1080/09613218.2014.894742

Hamilton, I., Agnolucci, P., Oreszczyn, T., 2015. Goodbye Warm Front: Evaluating the Delivery of Energy Efficiency Retrofits in Low-Income Homes in England from 2005 to 2012. Retrieved from: https://discovery.ucl.ac.uk/id/eprint/1498981/1/Hamilton%20IEPEC15%20Final.pdf

Hamilton, J., Hogan, B., Lucas, K., Mayne, R., 2019. Conversations about Conservation? Using Social Network Analysis to Understand Energy Practices. *Energy Research & Social Science* 49, 180–191. https://doi.org/10.1016/j.erss.2018.10.030

He, P., Liang, J., Qiu, Y., Li, Q., Xing, B., 2020. Increase in Domestic Electricity Consumption from Particulate Air Pollution. *Nat Energy* 5, 985–995. https://doi-org.libproxy.berkeley.edu/10.1038/s41560-020-00699-0

Healthy Neighborhoods Study, 2020. A Participatory Action Research Field Guide from the Healthy Neighborhoods Study. Retrieved from: https://www.clf.org/publication/field-guide-for-participatory-action-research/

Heleno, M., Sigrin, B., Popovich, N., Heeter, J., Jain Figueroa, A., Reiner, M., Reames, T., 2022. Optimizing Equity in Energy Policy Interventions: A Quantitative Decision-Support Framework for Energy Justice. *Applied Energy* 325, 119771. https://doi.org/10.1016/j.apenergy.2022.119771

Herbert, C., Molinsky, J.H., 2019. What Can Be Done to Better Support Older Adults to Age Successfully in Their Homes and Communities? *Health Affairs* 38, 860-864. https://doi.org/10.1377/hlthaff.2019.00203

Hernández, D., 2023. Energy Insecurity and Health: America's Hidden Hardship. *Health Affairs*, Health Policy Brief. https://doi.org/DOI: 10.1377/hpb20230518.472953

Hernández, D., 2016. Understanding 'Energy Insecurity' and Why it Matters to Health. *Social Science & Medicine* 167, 1–10. https://doi.org/10.1016/j.socscimed.2016.08.029

Hernández, D., 2013. Energy Insecurity: A Framework for Understanding Energy, the Built Environment, and Health Among Vulnerable Populations in the Context of Climate Change. AJPH 103: e32–e34. doi: 10.2105/AJPH.2012.301179

Hernández, D., Bird, S., 2010. Energy Burden and the Need for Integrated Low-Income Housing and Energy Policy. *Poverty & Public Policy* 2, 5–25. https://doi.org/10.2202/1944-2858.1095

Hills, J., 2011. Fuel Poverty: The Problem and Its Measurement (Monograph No. 69), CASEreport. Department for Energy and Climate Change, London, UK. Retrieved from: https://sticerd.lse.ac.uk/dps/case/cr/casereport69.pdf

Hobson, K., Hamilton, J., Mayne, R., 2016a. Monitoring and Evaluation in UK Low-Carbon Community Groups: Benefits, Barriers and the Politics of the Local. *Local Environment* 21, 124–136. https://doi.org/10.1080/13549839.2014.928814

Hobson, K., Mayne, R., Hamilton, J., 2016b. Monitoring And Evaluating Eco-Localisation: Lessons from UK Low Carbon Community Groups. *Environ Plan A* 48, 1393–1410. https://doi.org/10.1177/0308518X16640531

Hoffman, J.S., Shandas, V., Pendleton, N., 2020. The Effects of Historical Housing Policies on Resident Exposure to Intra-Urban Heat: A Study of 108 US Urban Areas. *Climate* 8, 12. https://doi.org/10.3390/cli8010012

Hopkins, E.A., Carswell, A.T., Love, K.R., 2020. Impacts of Energy Star Appliances on U.S. Multifamily Rents. *Family and Consumer Sciences Research Journal* 49, 37–51. https://doi.org/10.1111/fcsr.12372

Houde, S., 2018. The Incidence of Coarse Certification: Evidence from the Energy Star Program. E2e Working Paper 036. https://doi.org/10.2139/ssrn.3186492

Houde, S., Aldy, J.E., 2017. Consumers' Response to State Energy Efficient Appliance Rebate Programs. *American Economic Journal: Economic Policy* 9, 227–255. https://doi.org/10.1257/pol.20140383

Houde, S., Spurlock, C.A., 2015. Do Energy Efficiency Standards Improve Quality? Evidence from a Revealed Preference Approach. Ernest Orlando Lawrence Berkeley National Laboratory LBNL-182701. Retrieved from: https://www.osti.gov/servlets/purl/1235446.

Huang, L., Nock, D., Cong, S., Qiu, Y. (Lucy), 2023. Inequalities Across Cooling and Heating in Households: Energy Equity Gaps. *Energy Policy* 182, 113748. https://doi.org/10.1016/j.enpol.2023.113748

HUD, 2022a. The Role of Housing in Climate Change Mitigation and Adaptation. Retrieved from: https://www.huduser.gov/portal/periodicals/em/Summer22/highlight1.html

HUD, 2022b. Measuring Housing Insecurity: Index Development Using American Housing Survey Data. Retrieved from: https://www.huduser.gov/portal/publications/Measuring-Housing-Insecurity-Index-Development-Using-AHS-Data.html

HUD, 2021. Eliminating Regulatory Barriers to Affordable Housing: Federal, State, Local, and Tribal Opportunities. Retrieved from: https://www.huduser.gov/portal/publications/eliminating-regulatory-barriers-to-affordable-housing.html

HUD, 1998. Utility Allowances Guidebook: For Optional Use by Public Housing Agencies. Retrieved from: https://www.nhlp.org/wp-content/uploads/Appendix-K-HUD-UA-Guidebook.pdf

Hummel, H., Lachman, H., 2018. What is Inclusive Financing for Energy Efficiency, and Why are Some of the Largest States in the Country Calling for It Now? Retrieved from https://www.aceee.org/files/proceedings/2018/assets/attachments/0194_0286_000158.pdf

Hurley, D., Peterson, P., Whited, M., 2013. Demand Response as a Power System Resource: Program Designs, Performance, and Lessons Learned in the United States. Regulatory Assistance Project. Retrieved from: https://www.synapse-energy.com/sites/default/files/SynapseReport.2013-03.RAP_.US-Demand-Response.12-080.pdf

Hvelplund, M.M., Stephen Lacey, Frede, 2009. Stability, Participation and Transparency in Renewable Energy Policy: Lessons from Denmark and the United States. *Policy and Society*, Volume 27, Issue 4, March 2009, 379–398. https://doi.org/10.1016/j.polsoc.2009.01.007

Im, J., Seo, Y., Cetin, K.S., Singh, J., 2017. Energy Efficiency in U.S. Residential Rental Housing: Adoption Rates and Impact on Rent. *Applied Energy* 205, 1021–1033. https://doi.org/10.1016/j.apenergy.2017.08.047

Jacob, B., 2017. What We Know about Career and Technical Education in High School. Retrieved from: https://www.brookings.edu/articles/what-we-know-about-career-and-technical-education-in-high-school/

Jacobsen, G.D., 2019. An Examination of How Energy Efficiency Incentives Are Distributed Across Income Groups. *The Energy Journal* 40, 171–198. https://doi.org/10.5547/01956574.40.6.gjac

Jacobsen, G.D., Kotchen, M.J., 2013. Are Building Codes Effective at Saving Energy? Evidence from Residential Billing Data in Florida. *The Review of Economics and Statistics* 95, 34–49. https://doi.org/10.1162/REST_a_00243

Jacobsena, G.D., 2019. An Examination of How Energy Efficiency Incentives Are Distributed Across Income Groups. *The Energy Journal* 40, 171–198. https://doi.org/10.5547/01956574.40.6.gjac

Jarrah, A., Garfunkel, E., Ribiero, D., 2024. Nobody Left Behind: Preliminary Review of Strategies to Support Affordable Housing Compliance with Building Performance Standards. American Council for an Energy-Efficient Economy. Retrieved from: https://www.aceee.org/research-report/b2401

Jarvis, D., Chinn, S., Luczynska, C., Burney, P., 1996. Association Of Respiratory Symptoms And Lung Function in Young Adults with Use of Domestic Gas Appliances. *Lancet* 347, 426–431. https://doi.org/10.1016/s0140-6736(96)90009-4

Jesdale, B.M., Morello-Frosch, R., Cushing, L., 2013. The Racial/Ethnic Distribution of Heat Risk–Related Land Cover in Relation to Residential Segregation. *Environ Health Perspectives* 121, 811–817. https://doi.org/10.1289/ehp.1205919

Jessel, S., Sawyer, S., Hernández, D., 2019. Energy, Poverty, and Health in Climate Change: A Comprehensive Review of an Emerging Literature. *Frontiers in Public Health* 7. Retrieved from: https://www.frontiersin.org/journals/public-health/articles/10.3389/fpubh.2019.00357/full

Jiang, X.-Q., Mei, X.-D., Feng, D., 2016. Air Pollution and Chronic Airway Diseases: What Should People Know and Do? *J Thorac Dis* 8, E31–E40. https://doi.org/10.3978/j.issn.2072-1439.2015.11.50

Joint Center for Housing Studies of Harvard University, 2020. America’s Rental Housing 2020. Retrieved from: https://www.jchs.harvard.edu/americas-rental-housing-2020

Jollands, N., Waide, P., Ellis, M., Onoda, T., Laustsen, J., Tanaka, K., de T’Serclaes, P., Barnsley, I., Bradley, R., Meier, A., 2010. The 25 IEA Energy Efficiency Policy Recommendations to the G8 Gleneagles Plan of Action. *Energy Policy, Energy Efficiency Policies and Strategies*. 38, 6409–6418. https://doi.org/10.1016/j.enpol.2009.11.090

Jones, B., Karpman, J., Chlebnikow, M., Goggans, A., 2019. California Building Decarbonization: Workforce Needs and Recommendations. UCLA Luskin Center for Innovation. Retrieved from: https://innovation.luskin.ucla.edu/california-building-decarbonization/

Jones, M., Campagna, J., Elder, C., Bailey, S., 2022. Final 2021 Integrated Energy Policy Report: Volume III: Decarbonizing the State's Gas System (No. CEC-100-2021-001-V3). California Energy Commission. Retrieved from: https://www.energy.ca.gov/publications/2021/2021-integrated-energy-policy-report

Ju, Y., Cushing, L.J., Morello-Frosch, R., 2020. An Equity Analysis of Clean Vehicle Rebate Programs in California. *Climatic Change* 162, 2087–2105. https://doi.org/10.1007/s10584-020-02836-w

Kahn, M.E., Kok, N., 2014. The Capitalization of Green Labels in the California Housing Market. *Regional Science and Urban Economics, SI: Tribute to John Quigley* 47, 25–34. https://doi.org/10.1016/j.regsciurbeco.2013.07.001

Karvonen, A., 2017. Community Housing Retrofit in the UK and the Civics of Energy Consumption, in: *Retrofitting Cities for Tomorrow's World*. John Wiley & Sons, Ltd, pp. 17–32. https://doi.org/10.1002/9781119007241.ch2

Karvonen, A., 2013. Towards Systemic Domestic Retrofit: A Social Practices Approach. *Build. Res. Informat.* 41, 563–574. https://doi.org/10.1080/09613218.2013.805298

Kauffman, N., Hill, K., 2021. Climate Change, Adaptation Planning and Institutional Integration: A Literature Review and Framework. *Sustainability* 13, 10708. https://doi.org/10.3390/su131910708

Kenney, M., Janusch, N., Neumann, I., Jaske, M., 2021. California Building Decarbonization Assessment. California Energy Commission. Retrieved from: https://www.energy.ca.gov/publications/2021/california-building-decarbonization-assessment

Kholodilin, K.A., Mense, A., Michelsen, C., 2017. The Market Value of Energy Efficiency in Buildings and the Mode of Tenure. *Urban Studies* 54, 3218–3238. https://doi.org/10.1177/0042098016669464

Kirk, C., 2023. Decarbonizing California Equitably: A Guide to Tenant Protections in Building Upgrades/Retrofits Throughout the State. Retrieved from: https://www.saje.net/wp-content/uploads/2023/09/Decarbonizing-California-Equitably-Report-1.pdf

Kleeman, H., Fischhoff, B., Armanios, D.E., 2023. Effects Of Redesigning the Communication of Low-Income Residential Energy Efficiency Programs in the U.S. *Energy Policy* 178, 113568. https://doi.org/10.1016/j.enpol.2023.113568

Knibbs, L.D., Woldeyohannes, S., Marks, G.B., Cowie, C.T., 2018. Damp Housing, Gas Stoves, and the Burden of Childhood Asthma in Australia. *Medical Journal of Australia* 208, 299–302. https://doi.org/10.5694/mja17.00469

Kontokosta, C.E., Reina, V.J., Bonczak, B., 2020a. Energy Cost Burdens for Low-Income and Minority Households. *Journal of the American Planning Association* 86, 89–105. https://doi.org/10.1080/01944363.2019.1647446

Kontokosta, C.E., Spiegel-Feld, D., Papadopoulos, S., 2020b. The Impact of Mandatory Energy Audits on Building Energy Use. *Nat Energy* 5, 309–316. https://doi.org/10.1038/s41560-020-0589-6

Kumar, S.S., California Housing Partnership, 2021. Prioritizing California's Affordable Housing in the Transition Towards Equitable Building Decarbonization. California

Housing Partnership. Retrieved from: https://chpc.net/resources/ah-building-decarb-report-2021/

Lamb, Z., Shi, L., Silva, S., Spicer, J., 2022. Resident-Owned Resilience: Can Cooperative Land Ownership Enable Transformative Climate Adaptation for Manufactured Housing Communities? *Housing Policy Debate* 0, 1–23. https://doi.org/10.1080/10511482.2021.2013284

Lebel, E.D., Finnegan, C.J., Ouyang, Z., Jackson, R.B., 2022. Methane and NOx Emissions from Natural Gas Stoves, Cooktops, and Ovens in Residential Homes. *Environ. Sci. Technol.* 56, 2529–2539. https://doi.org/10.1021/acs.est.1c04707

Lee, L.N., Kim, M.J., 2020. A Critical Review of Smart Residential Environments for Older Adults with a Focus on Pleasurable Experience. *Frontiers in Psychology* 10. Retrieved from: https://www.frontiersin.org/journals/psychology/articles/10.3389/fpsyg.2019.03080/full

Leinartas, H.A., Stephens, B., 2015. Optimizing Whole House Deep Energy Retrofit Packages: A Case Study of Existing Chicago-Area Homes. *Buildings* 5, 323–353. https://doi.org/10.3390/buildings5020323

Leon, W., Burnham, K., Hausman, N., Schieb, L., 2021. Solar for Manufactured Homes An Assessment of the Opportunities and Challenges in 14 States | Volume 1. Clean Energy State Alliance, Montpelier, VT. Retrieved from: https://www.cesa.org/resource-library/resource/solar-for-manufactured-homes/

Li, H., Carrión-Flores, C.E., 2017. An Analysis of the ENERGY STAR® Program in Alachua County, Florida. *Ecological Economics* 131, 98–108. https://doi.org/10.1016/j.ecolecon.2016.08.014

Li, H., Yi, H., 2014. Multilevel Governance and Deployment of Solar PV Panels in U.S. Cities. *Energy Policy* 69, 19–27. https://doi.org/10.1016/j.enpol.2014.03.006

Liang, J., Qiu, Y., James, T., Ruddell, B.L., Dalrymple, M., Earl, S., Castelazo, A., 2018. Do Energy Retrofits Work? Evidence From Commercial and Residential Buildings in Phoenix. *Journal of Environmental Economics and Management* 92, 726–743. https://doi.org/10.1016/j.jeem.2017.09.001

LibertyHomes, Energy Efficiency Institute, Inc., 2022. 2022 PAYS Status Update.

Liddell, C., Morris, C., McKenzie, S.J.P., Rae, G., 2012. Measuring and Monitoring Fuel Poverty in the UK: National and Regional Perspectives. *Energy Policy, Special Section: Fuel Poverty Comes of Age: Commemorating 21 Years of Research and Policy* 49, 27–32. https://doi.org/10.1016/j.enpol.2012.02.029

Loeff, B., 2022. Shortage Changed: How Utilities Are Adapting to Supply Chain Issues. American Public Power Association. Retrieved from: https://www.publicpower.org/periodical/article/shortage-changed-how-utilities-are-adapting-supply-chain-issues

Lucas, K., Hamilton, J., Mayne, R., 2017. Building Capacity Through Action Research: Reflections on Working with Low-Carbon Communities in the UK. *Local Environment* 22, 725–745. https://doi.org/10.1080/13549839.2016.1259294

Lutzker, L., Tobacman, J., 2013. The Overlapping Issues of Health and Housing: A Report on California Statewide Data and Healthy Housing Indicators. California

Department of Public Health. Retrieved from: https://www.cdph.ca.gov/Programs/CCDPHP/DEODC/EHIB/CPE/CDPH%20Document%20Library/Mold/HealthyHousingIndicators.pdf

Maneta, D., 2023. Equitable Building Decarbonization Direct Install Program Guidelines (Adopted) (No. CEC-400-2023-003-CMF). California Energy Commission. Retrieved from: https://www.energy.ca.gov/publications/2023/equitable-building-decarbonization-direct-install-program-guidelines

Mango, M., Casey, J.A., Hernández, D., 2021. Resilient Power: A Home-Based Electricity Generation and Storage Solution for the Medically Vulnerable During Climate-Induced Power Outages. *Futures* 128, 102707. https://doi.org/10.1016/j.futures.2021.102707

Manisalidis, I., Stavropoulou, E., Stavropoulos, A., Bezirtzoglou, E., 2020. Environmental and Health Impacts of Air Pollution: A Review. *Front Public Health* 8, 14. https://doi.org/10.3389/fpubh.2020.00014

Marin Clean Energy, 2021. Low-Income Families and Tenants Pilot Program Evaluation. Retrieved from: https://www.mcecleanenergy.org/wp-content/uploads/2022/08/MCE-Low-Income-Families-and-Tenants-Pilot-Program-Evaluation_08262022.pdf

Marmot, M., 2005. Social Determinants of Health Inequalities. *The Lancet* 365, 1099–1104. https://doi.org/10.1016/S0140-6736(05)71146-6

Marmot, M., Friel, S., Bell, R., Houweling, T.A., Taylor, S., 2008. Closing the Gap in a Generation: Health Equity Through Action on the Social Determinants of Health. *The Lancet* 372, 1661–1669. https://doi.org/10.1016/S0140-6736(08)61690-6

Maxim, A., Grubert, E., 2023. Highly Energy Efficient Housing Can Reduce Peak Load and Increase Safety Under Beneficial Electrification. *Environ. Res. Lett.* 19, 014036. https://doi.org/10.1088/1748-9326/ad114d

McCarthy, J.J., Canziani, O., Leary, N.A., Dokken, D.J., White, K.S., 2001. *Climate Change 2001: Impacts, Adaptation, and Vulnerability.* Cambridge University Press, Cambridge, UK ; New York.

McGrath, K., Dugger, P., 2024. Mobile and Manufactured Housing Market Characterization Study. CalNEXT. Retrieved from: https://calnext.com/wp-content/uploads/2023/12/ET23SWE0017_Mobile-and-Manufactured-Housing-Market-Characterization-Study_Final-Report.pdf

Meng, T., Hsu, D., Han, A., 2017. Estimating Energy Savings from Benchmarking Policies in New York City. *Energy* 133, 415–423. https://doi.org/10.1016/j.energy.2017.05.148

Mims, N., Schiller, S.R., Stuart, E., Schwartz, L., Kramer, C., Faesy, R., 2017. Evaluation of U.S. Building Energy Benchmarking and Transparency Programs: Attributes, Impacts, and Best Practices. Lawrence Berkeley National Lab. (LBNL), Berkeley, CA (United States). https://doi.org/10.2172/1393621

Montgomery, B., Palmeira, M., 2023. Bluelining: Climate Financial Discrimination on the Horizon. The Greenlining Institute. Retrieved from: https://greenlining.org/publications/bluelining-climate-financial-discrimination-on-the-horizon/

Moore, R., 2012. Definitions of Fuel Poverty: Implications for Policy. *Energy Policy, Special Section: Fuel Poverty Comes of Age: Commemorating 21 Years of Research and Policy* 49, 19–26. https://doi.org/10.1016/j.enpol.2012.01.057

Morales, D., Nadel, S., 2022. Meeting the Challenge: A Review of Energy Efficiency Program Offerings for Low-Income Households. American Council for an Energy-Efficient Economy, Washington DC. Retrieved from: https://www.aceee.org/research-report/u2205

Morello-Frosch, R., Pastor, M., Sadd, J., Shankoff, S.B., 2009. The Climate Gap: Inequalities in How Climate Change Hurts Americans & How to Close the Gap. University of Southern California Program for Environmental and Regional Equity. Retrieved from: https://dornsife.usc.edu/eri/publications/the-climate-gap-inequalities-in-how-climate-change-hurts-americans-how-to-close-the-gap/

Murray, A.G., Mills, B.F., 2011. Read The Label! Energy Star Appliance Label Awareness and Uptake among U.S. Consumers. *Energy Economics* 33, 1103–1110. https://doi.org/10.1016/j.eneco.2011.04.013

Myers, E., Puller, S.L., West, J., 2022. Mandatory Energy Efficiency Disclosure in Housing Markets. *American Economic Journal: Economic Policy* 14, 453–487. https://doi.org/10.1257/pol.20200539

Nardone, A., Rudolph, K.E., Morello-Frosch, R., Casey, J.A., 2021. Redlines and Greenspace: The Relationship between Historical Redlining and 2010 Greenspace across the United States. *Environmental Health Perspectives* 129, 017006. https://doi.org/10.1289/EHP7495

Newsom, G., Ghaly, M., Scribner, D., 2022. DRAFT Bipartisan Infrastructure Law State Plan and Application to the U.S. Department of Energy.

Newsome, M., 2023. Discrimination Has Trapped People of Color in Unhealthy Urban “Heat Islands” *Scientific American*. Retrieved from: https://www.scientificamerican.com/article/discrimination-has-trapped-people-of-color-in-unhealthy-urban-heat-islands/

Nidam, Y., 2019. Retrofit for Resilience (Thesis). Massachusetts Institute of Technology.

Norton, R.A., Brown, B.W., 2014. Green & Healthy Homes Initiative: Improving Health, Economic, and Social Outcomes Through Integrated Housing Intervention. *Environmental Justice* 7, 151–157. https://doi.org/10.1089/env.2014.0033

Novan, K., Smith, A., Zhou, T., 2022. Residential Building Codes Do Save Energy: Evidence from Hourly Smart-Meter Data. *The Review of Economics and Statistics* 1–18. https://doi.org/10.1162/rest_a_00967

OEHHA, 2021. Analysis of Race/Ethnicity and CalEnviroScreen 4.0 Scores. California Environmental Protection Agency, Office of Environmental Health Hazard Assessment. Retrieved from: https://oehha.ca.gov/sites/default/files/media/downloads/calenviroscreen/document/calenviroscreen40raceanalysisf2021.pdf

Ohler, A.M., Loomis, D.G., Ilves, K., 2020. A Study of Electricity Savings from Energy Star Appliances Using Household Survey Data. *Energy Policy* 144, 111607. https://doi.org/10.1016/j.enpol.2020.111607

Olsthoorn, M., Schleich, J., Gassmann, X., Faure, C., 2017. Free Riding and Rebates for Residential Energy Efficiency Upgrades: A Multi-Country Contingent Valuation Experiment. *Energy Economics, Seventh Atlantic Workshop in Energy and Environmental Economics* 68, 33–44. https://doi.org/10.1016/j.eneco.2018.01.007

Opinion Dynamics, 2021. SJV DAC Data Gathering Plan Findings Report. Retrieved from: https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/documents/infrastructure/disadvantaged-communities/sjv_dac_data-gathering_findings-report_vol1_final.pdf

O'Shaughnessy, E., Grayson, A., Barbose, G., 2023. The Role of Peer Influence in Rooftop Solar Adoption Inequity in the United States. *Energy Economics* 127, 107009. https://doi.org/10.1016/j.eneco.2023.107009

Owusu, P.A., Asumadu-Sarkodie, S., 2016. A Review of Renewable Energy Sources, Sustainability Issues and Climate Change Mitigation. *Cogent Engineering* 3, 1167990. https://doi.org/10.1080/23311916.2016.1167990

Palensky, P., Dietrich, D., 2011. Demand Side Management: Demand Response, Intelligent Energy Systems, and Smart Loads. *IEEE Transactions on Industrial Informatics* 7, 381–388. https://doi.org/10.1109/TII.2011.2158841

Patel, S., Ceferino, L., Liu, C., Kiremidjian, A., Rajagopal, R., 2021. The Disaster Resilience Value of Shared Rooftop Solar Systems in Residential Communities. *Earthquake Spectra* 37, 2638–2661. https://doi.org/10.1177/87552930211020020

Paulin, L., Diette, G., Scott, M., Mccormack, M., Matsui, E., Curtin-Brosnan, J., Williams, D., Taylor, A., Shea, M., Breysse, P., Hansel, N., 2013. Home Interventions Are Effective at Decreasing Indoor Nitrogen Dioxide Concentrations. *Indoor Air* 24. https://doi.org/10.1111/ina.12085

Pigg, S., Cautley, D., Francisco, P.W., 2018. Impacts Of Weatherization on Indoor Air Quality: A Field Study of 514 Homes. *Indoor Air* 28, 307–317. https://doi.org/10.1111/ina.12438

Pigman, M., Deason, J., Murphy, S., 2021. Who Is Participating in Residential Energy Efficiency Programs? Exploring Demographic and Other Household Characteristics of Participants in Utility Customer-Funded Energy Efficiency Programs. Retrieved from: https://emp.lbl.gov/publications/who-participating-residential-energy

Piser, K., 2021. Fear Of Reprisal Kept Immigrants from Accessing Federal Aid in Pandemic. Food and Environment Reporting Network. Retrieved from: https://thefern.org/ag_insider/report-fear-of-reprisal-kept-immigrant-families-from-accessing-federal-assistance-during-pandemic/

PODER and Emerald Cities, 2020. Climate Equity & Community Engagement in Building Electrification. Retrieved from: https://emeraldcities.org/wp-content/uploads/2021/05/Climate-Equity-and-Community-Engagement-Toolkit_Nov102020.pdf

Putnam, T., Brown, D., 2021. Grassroots Retrofit: Community Governance and Residential Energy Transitions in the United Kingdom. *Energy Research & Social Science* 78, 102102. https://doi.org/10.1016/j.erss.2021.102102

Raissi, S., Reames, T.G., 2020. "If We Had a Little More Flexibility." Perceptions of Programmatic Challenges and Opportunities Implementing Government-Funded

Low-Income Energy Efficiency Programs. *Energy Policy* 147, 111880. https://doi.org/10.1016/j.enpol.2020.111880

Ramos, A., Gago, A., Labandeira, X., Linares, P., 2015. The Role of Information for Energy Efficiency in the Residential Sector. *Energy Economics, Frontiers in the Economics of Energy Efficiency* 52, S17–S29. https://doi.org/10.1016/j.eneco.2015.08.022

RAMP, 2018. Energy Efficiency and Health: A Guide for Public Health and Health Care Professionals on Connecting Medically Vulnerable Residents with Energy Efficiency Services. Regional Asthma Management & Prevention. Retrieved from: https://www.asthmacommunitynetwork.org/resources/energy-efficiency-and-health-guide-public-health-and-health-care-professionals-connecting

Rauh, V.A., Landrigan, P.J., Claudio, L., 2008. Housing and Health. *Annals of the New York Academy of Sciences* 1136, 276–288. https://doi.org/10.1196/annals.1425.032

Reames, T.G., 2016. A Community-Based Approach to Low-Income Residential Energy Efficiency Participation Barriers. *Local Environment* 21, 1449–1466. https://doi.org/10.1080/13549839.2015.1136995

Reames, T.G., Reiner, M.A., Stacey, M.B., 2018. An Incandescent Truth: Disparities In Energy-Efficient Lighting Availability and Prices in an Urban U.S. County. *Applied Energy* 218, 95–103. https://doi.org/10.1016/j.apenergy.2018.02.143

RECS Survey, 2020. Table HC11.1 Household Energy Insecurity. U.S. Energy Information Administration (EIA), Washington DC, USA. Retrieved from: https://www.eia.gov/consumption/residential/data/2020/hc/pdf/HC%2011.1.pdf

Reid, C.E., Brauer, M., Johnston, F.H., Jerrett, M., Balmes, J.R., Elliott, C.T., 2016. Critical Review of Health Impacts of Wildfire Smoke Exposure. *Environ Health Perspect* 124, 1334–1343. https://doi.org/10.1289/ehp.1409277

Reid, C. K., 2021. Crisis, Response, and Recovery: The Federal Government and the Black/White Homeownership Gap. Terner Center for Housing Innovation UC Berkeley, Oakland, CA. Retrieved from: https://ternercenter.berkeley.edu/wp-content/uploads/2021/03/Crisis-Response-Recovery-March-2021-Final.pdf

Reid, C. K., 2005. Achieving The American Dream? A Longitudinal Analysis of the Homeownership Experiences of Low-Income Households. Center for Social Development Washington University. Retrieved from: https://csde.washington.edu/downloads/reid_discussion.pdf

Reinhart, C., Berzolla, Z., Jacoby, H.D., Reilly, J.M., Schuler, C., 2021. Thoughts on a Federal Government Stimulus Package for Buildings (SSRN Scholarly Paper No. ID 3832381). Social Science Research Network, Rochester, NY. https://doi.org/10.2139/ssrn.3832381

Relf, G., York, D., Kushler, M., 2018. Keeping the Lights On: Energy Efficiency and Electric System Reliability (No. U1809). American Council for an Energy-Efficient Economy.

Research Into Action, Inc., 2015. Spotlight on Key Program Strategies from the Better Buildings Neighborhood Program Final Evaluation. U.S. Department of Energy Office of Energy Efficiency and Renewable Energy. Retrieved from: https://www.energy.gov/eere/analysis/articles/spotlight-key-program-strategies-better-buildings-neighborhood-program-final

Research into Action, Nexant, NMR, Evergreen Economics, 2015. Evaluation of the Better Buildings Neighborhood Program, Final Synthesis Report. U.S. Department of Energy Office of Energy Efficiency and Renewable Energy. Retrieved from: https://www.energy.gov/eere/analysis/articles/evaluation-better-buildings-neighborhood-program-final-synthesis-report

Rosenfeld, A.H., McAuliffe, P., 2008. Opportunities in the Building Sector: Managing Climate Change. *AIP Conference Proceedings* 1044, 3–14. https://doi.org/10.1063/1.2993736

Rupp, R.F., Vásquez, N.G., Lamberts, R., 2015. A Review of Human Thermal Comfort in the Built Environment. *Energy and Buildings* 105, 178–205. https://doi.org/10.1016/j.enbuild.2015.07.047

Ryan, L., Campbell, N., 2012. Spreading the Net: The Multiple Benefits of Energy Efficiency Improvements. OECD, Paris. https://doi.org/10.1787/5k9crzjbpkkc-en

Sandova, G., Toney, M., 2018. Living without Power: Health Impacts of Utility Shutoffs in California. The Utility Reform Network (TURN), California. Retrieved from: https://downloads.ctfassets.net/ntcn17ss1ow9/2AXQK5Lv4gwQkgD88IAGDY/f9b42f76d4d3bde79c4e84060bce9710/2018_TURN_Shut-Off-Report_FINAL.pdf

Sarah Bohn, Sara Kimberlin, Patricia Malagon, Christopher Wimer, 2023. Poverty in California. Retrieved from: https://inequality.stanford.edu/california-poverty-measure-data

Scavo, J., Korosec, S., Guerrero, E., Pennington, B., Doughman, P., 2016. Low-Income Barriers Study, Part A: Overcoming Barriers to Energy Efficiency and Renewables for Low-Income Customers and Small Business Contracting Opportunities in Disadvantaged Communities (No. EC-300-2016-009-CMF). California Energy Commission, California. Retrieved from: https://resilientca.org/projects/cd20c6c2-ac95-4fae-ba9d-1a5c94982506/

Schafran, A., Lee, T., Magofna, G., Briones, A., 2024. California's Missing Middle: Middle-Income CA Is Large, Diverse, & Left Out of the Housing Conversation. Retrieved from: https://www.ccbuilders.org/moderate-middle-income-california-racial-wealth-gap

Scheier, E., Kittner, N., 2022. A Measurement Strategy to Address Disparities Across Household Energy Burdens. *Nat Commun* 13, 288. https://doi.org/10.1038/s41467-021-27673-y

Schipper, L., 1996. Life-Styles and the Environment: The Case of Energy. *Daedalus* 125, 113–138. https://www.jstor.org/stable/20027373

Schnake-Mahl, A.S., Jahn, J.L., Subramanian, S.V., Waters, M.C., Arcaya, M., 2020. Gentrification, Neighborhood Change, and Population Health: A Systematic Review. *J Urban Health* 97, 1–25. https://doi.org/10.1007/s11524-019-00400-1

Schwarz, L., Hansen, K., Alari, A., Ilango, S.D., Bernal, N., Basu, R., Gershunov, A., Benmarhnia, T., 2021. Spatial Variation in the Joint Effect Of Extreme Heat Events and Ozone on Respiratory Hospitalizations in California. *Proceedings of the National Academy of Sciences* 118, e2023078118. https://doi.org/10.1073/pnas.2023078118

Sekar, A., Williams, E., Hittinger, E., Chen, R., 2019. How Behavioral and Geographic Heterogeneity Affects Economic and Environmental Benefits of Efficient Appliances. *Energy Policy* 125, 537–547. https://doi.org/10.1016/j.enpol.2018.10.035

Seth Nowak, Martin Kushler, Patti Witte, Dan York, 2013. Leaders of the Pack: ACEEE's Third National Review of Exemplary Energy. American Council for an Energy-Efficient Economy, Washington, DC. Retrieved from: https://www.aceee.org/sites/default/files/publications/researchreports/u132.pdf

Severin Borenstein, Meredith Fowlie, James Sallee, 2022. Paying for Electricity in California: How Residential Rate Design Impacts Equity and Electrification. Energy Institute at the UC Berkeley Haas School of Business, California. Retrieved from: https://haas.berkeley.edu/wp-content/uploads/WP330.pdf

Seyfang, G., Hielscher, S., Hargreaves, T., Martiskainen, M., Smith, A., 2014. A Grassroots Sustainable Energy Niche? Reflections on Community Energy in the UK. *Environmental Innovation and Societal Transitions* 13, 21–44. https://doi.org/10.1016/j.eist.2014.04.004

Seyrfar, A., Ataei, H., Derrible, S., 2020. A Review of Building Energy Benchmarking Policies Across the U.S. Cities. Presented at the Applied Energy Symposium, Cambridge, USA. Retrieved from: https://www.energy-proceedings.org/wp-content/uploads/2020/12/aeab2020_paper_325.pdf

Shenassa, E.D., Daskalakis, C., Liebhaber, A., Braubach, M., Brown, M., 2007. Dampness and Mold in the Home and Depression: An Examination of Mold-Related Illness and Perceived Control of One's Home as Possible Depression Pathways. *Am J Public Health* 97, 1893–1899. https://doi.org/10.2105/AJPH.2006.093773

Sherman, E., 2023. Pathways to Equity and Savings for Low-Income Households. RMI. Retrieved from: https://rmi.org/pathways-to-equity-and-savings-for-low-income-households/

Shrestha, P.M., 2018. Impacts of Energy-Efficiency Retrofits on Ventilation and Indoor Air Quality in Low-Income Households. University of Colorado at Boulder, United States -- Colorado. Retrieved from: https://www.academia.edu/67232873/Impacts_of_Energy_Efficiency_Retrofits_on_Ventilation_and_Indoor_Air_Quality_in_Low_Income_Households

Siano, P., 2014. Demand Response and Smart Grids - A Survey. Renewable and Sustainable *Energy Reviews* 30, 461-478. https://doi.org/10.1016/j.rser.2013.10.022.

Singhal, P., Pahle, M., Kalkuhl, M., Levesque, A., Sommer, S., Berneiser, J., 2022. Beyond Good Faith: Why Evidence-Based Policy is Necessary to Decarbonize Buildings Cost-Effectively in Germany. *Energy Policy* 169, 113191. https://doi.org/10.1016/j.enpol.2022.113191

Singla, V., Kane-Ritsch, K., Kirk, C., Jones, B., Ahkiam, L., 2022. Integrating Housing, Workforce, Health and Energy Equity in Building Decarbonization in Los Angeles, California. Retrieved from: https://www.nrdc.org/sites/default/files/integrating-equity-building-decarbonization-los-angeles-report-202208.pdf

Sintov, N.D., Schultz, P.W., 2015. Unlocking The Potential of Smart Grid Technologies with Behavioral Science. *Front. Psychol.* 6. https://doi.org/10.3389/fpsyg.2015.00410

Smit, B., Wandel, J., 2006. Adaptation, Adaptive Capacity and Vulnerability. *Global Environmental Change, Resilience, Vulnerability, and Adaptation: A Cross-Cutting Theme of the International Human Dimensions Programme on Global Environmental Change* 16, 282–292. https://doi.org/10.1016/j.gloenvcha.2006.03.008

Solis, A., Díaz, A., Miller, C., White, C.G., Tovar, J., Arguello, M.D., 2022. BEEP Preliminary Report: Community Priorities for Equitable Building Decarbonization. Retrieved from: https://www.psr-la.org/resources/beep-preliminary-report

Song, B., Jiao, W., Cen, K., Tian, X., Zhang, H., Lu, W., 2021. Quantitative Risk Assessment of Gas Leakage and Explosion Accident Consequences Inside Residential Buildings. *Engineering Failure Analysis* 122, 105257. https://doi.org/10.1016/j.engfailanal.2021.105257

Souza, M.N.M., 2018. Why Are Rented Dwellings Less Energy-Efficient? Evidence From a Representative Sample of the U.S. Housing Stock. *Energy Policy* 118, 149–159. https://doi.org/10.1016/j.enpol.2018.03.013

Sovacool, B., Nadesan, M., Pasqualetti, M.J., Keahey, J., 2023. *Energy Democracies for Sustainable Futures.* Elsevier.

Sovacool, B.K., 2022. Beyond Science and Policy: Typologizing and Harnessing Social Movements for Transformational Social Change. *Energy Research & Social Science* 94, 102857. https://doi.org/10.1016/j.erss.2022.102857

Sovacool, B.K., 2015. Fuel Poverty, Affordability, and Energy Justice in England: Policy Insights from the Warm Front Program. *Energy* 93, 361–371. https://doi.org/10.1016/j.energy.2015.09.016

Sovacool, B.K., 2009. The Cultural Barriers to Renewable Energy and Energy Efficiency in the United States. *Technology in Society* 31, 365–373. https://doi.org/10.1016/j.techsoc.2009.10.009

Spurlock, C.A., Fujita, K.S., 2022. Equity Implications of Market Structure and Appliance Energy Efficiency Regulation. *Energy Policy* 165, 112943. https://doi.org/10.1016/j.enpol.2022.112943

Stange, D.K., Kevin, 2019. Depth Over Breadth. Education Next. Retrieved from: https://www.educationnext.org/depth-over-breadth-value-vocational-education-u-s-high-schools/

Steven Nadel, Lowell Ungar, 2019. Halfway There: Energy Efficiency Can Cut Energy Use and Greenhouse Gas. American Council for an Energy-Efficient Economy, Washington DC, USA. Retrieved from: https://www.aceee.org/fact-sheet/halfway-there

Strategic Actions for a Just Economy, 2022. Equitable Building Decarbonization Focus Group Report Low Income Tenant Perspectives. Retrieved from: https://www.climate4la.org/wp-content/uploads/2022/09/CELA-Equitable-Building-Decarbonization-Focus-Group-Reports_SAJE-NHHA_April-2022.pdf

Stutz, M., Rivas-Lopez, V., Lonquich, B., Baig, A.A., 2019. Health Repercussions of a Culture of Fear Within Undocumented Immigrant Communities. *J Gen Intern Med* 34, 1903–1905. https://doi.org/10.1007/s11606-019-05161-w

Sunter, D.A., Castellanos, S., Kammen, D.M., 2019. Disparities in Rooftop Photovoltaics Deployment in the United States by Race and Ethnicity. *Nat Sustain* 2, 71–76. https://doi.org/10.1038/s41893-018-0204-z

Swope, C.B., Hernández, D., 2019. Housing as a Determinant of Health Equity: A Conceptual Model. *Social Science & Medicine* 243, 112571. https://doi.org/10.1016/j.socscimed.2019.112571

Thomason, S., Jan, S., Bryant, C., Haines, K., Huang, K., 2024. Economic Impacts of a Wage and Benefit Labor Standard for the Bay Area Residential Decarbonization Industry. Rising Sun Center for Opportunity in partnership with Construction Trades Workforce Initiative (CTWI), California. Retrieved from: https://risingsunopp.org/wp-content/uploads/Residential-Decarb-Ecomonic-Impact-Assessment-FINAL-Aug-8-2024.pdf

Tonn, B., Eisenberg, J., 2007. The Aging US Population and Residential Energy Demand. *Energy Policy* 35, 743–745. https://doi.org/10.1016/j.enpol.2005.12.011

Tonn, B., Hawkins, B., Rose, E., Marincic, M., 2021. Income, Housing and Health: Poverty in the United States Through the Prism of Residential Energy Efficiency Programs. *Energy Research & Social Science* 73, 101945. https://doi.org/10.1016/j.erss.2021.101945

Tonn, B., Rose, E., Hawkins, B., 2018. Evaluation of the U.S. Department of Energy's Weatherization Assistance Program: Impact Results. *Energy Policy* 118, 279–290. https://doi.org/10.1016/j.enpol.2018.03.051

Tosado, G.A., Matos, M., Ahumada-Paras, M., Chapko, M.K., Pozzo, L.D., Group, the P.R.S.H.S., 2021. Evaluation of Solar-Powered Battery Systems for Individuals Using Electricity-Dependent Medical Devices in Puerto Rico Following Hurricane Maria. *Disaster Medicine and Public Health Preparedness* 1–4. https://doi.org/10.1017/dmp.2021.114

Tozer, L., MacRae, H., Smit, E., 2023. Achieving Deep-Energy Retrofits for Households in Energy Poverty. *Buildings and Cities* 4, 258–273. https://doi.org/10.5334/bc.304

Truitt, S., Williams, J., Clarke, A., 2022. Building a More Diverse, Equitable, and Inclusive Energy Efficiency Workforce (No. NREL/TP-5500-81498, 1861407, MainId:82271). https://doi.org/10.2172/1861407

United States Census Bureau, 2020. DP04: Selected Housing Characteristics. Retrieved from: https://data.census.gov/cedsci/table?tid=ACSDP5Y2020.DP04&g=0400000US06&hidePreview=true

US EPA, 2023. Inclusive Utility Investment. Retrieved from: https://www.energystar.gov/products/inclusive_utility_investment

US EPA, 2022. Case Study: Making Efficient Electrification Upgrades More Accessible. Retrieved from: https://www.energystar.gov/sites/default/files/2024-11/Case%20Study%20-

%20Making%20Efficient%20Electrification%20Upgrades%20More%20Accessible_1.pdf

US EPA, 2013. U.S. Federal Bans on Asbestos. Retrieved from: https://www.epa.gov/asbestos/us-federal-bans-asbestos

U.S Government Publishing Office, 1978. Lead-Based Paint Poisoning Prevention in Certain Residential Structures, Electronic Code of Federal Regulations. Retrieved from: https://www.ecfr.gov/current/title-40/chapter-I/subchapter-R/part-745?toc=1

Walker, I.S., Less, B.D., Casquero-Modrego, N., 2022. Carbon and Energy Cost Impacts of Electrification of Space Heating with Heat Pumps in the US. *Energy and Buildings* 259, 111910. https://doi.org/10.1016/j.enbuild.2022.111910

Walls, M., Gerarden, T., Palmer, K., Bak, X.F., 2017. Is Energy Efficiency Capitalized into Home Prices? Evidence from Three U.S. Cities. *Journal of Environmental Economics and Management* 82, 104–124. https://doi.org/10.1016/j.jeem.2016.11.006

Wang, L., Xie, J., Hu, Y., Tian, Y., 2022. Air Pollution and Risk of Chronic Obstructed Pulmonary Disease: The Modifying Effect of Genetic Susceptibility and Lifestyle. *eBioMedicine* 79. https://doi.org/10.1016/j.ebiom.2022.103994

Wang, T., Jiang, Z., Zhao, B., Gu, Y., Liou, K.-N., Kalandiyur, N., Zhang, D., Zhu, Y., 2020. Health Co-Benefits of Achieving Sustainable Net-Zero Greenhouse Gas Emissions in California. *Nat Sustain* 3, 597–605. https://doi.org/10.1038/s41893-020-0520-y

Wilkinson, P., Smith, K.R., Davies, M., Adair, H., Armstrong, B.G., Barrett, M., Bruce, N., Haines, A., Hamilton, I., Oreszczyn, T., Ridley, I., Tonne, C., Chalabi, Z., 2009. Public Health Benefits of Strategies to Reduce Greenhouse-Gas Emissions: Household Energy. *The Lancet* 374, 1917–1929. https://doi.org/10.1016/S0140-6736(09)61713-X

Wilkinson, R., Marmot, M., 2003. Social Determinants of Health: The Solid Facts. World Health Organization. Retrieved from: https://iris.who.int/items/41fe3a4a-cd63-4ce9-a1bd-495f978e612c

Willand, N., Ridley, I., Maller, C., 2015. Towards Explaining the Health Impacts of Residential Energy Efficiency Interventions – A Realist Review. *Part 1: Pathways. Social Science & Medicine* 133, 191–201. https://doi.org/10.1016/j.socscimed.2015.02.005

Wolske, K.S., Gillingham, K.T., Schultz, P.W., 2020. Peer Influence on Household Energy Behaviours. *Nat Energy* 5, 202–212. https://doi.org/10.1038/s41560-019-0541-9

Yarmuth, J.A., 2022. H.R.5376: Inflation Reduction Act of 2022.

Yim, E., Subramanian, S., 2023. Equity and Electrification-Driven Rate Policy Options. Retrieved from: https://www.aceee.org/white-paper/2023/09/equity-and-electrification-driven-rate-policy-options

York, D., Cohn, C., Morales, D., Tolentino, C., 2022. Building Decarbonization Solutions for the Affordable Housing Sector. Retrieved from: https://www.aceee.org/research-report/u2204

Young, S.D., Mallory, B., McCarthy, G., 2021. Memorandum for the Heads of Departments and Agencies: Interim Implementation Guidance for the Justice40 Initiative.

Retrieved from: https://www.whitehouse.gov/wp-content/uploads/2021/07/M-21-28.pdf

Zanocco, C., Flora, J., Rajagopal, R., Boudet, H., 2021. When the Lights Go Out: Californians' Experience with Wildfire-Related Public Safety Power Shutoffs Increases Intention to Adopt Solar and Storage. *Energy Research & Social Science* 79, 102183. https://doi.org/10.1016/j.erss.2021.102183

Zhao, B., Wang, T., Jiang, Z., Gu, Y., Liou, K.-N., Kalandiyur, N., Gao, Y., Zhu, Y., 2019. Air Quality and Health Cobenefits of Different Deep Decarbonization Pathways in California. *Environ. Sci. Technol.* 53, 7163–7171. https://doi.org/10.1021/acs.est.9b02385

Zhu, S., Mac Kinnon, M., Carlos-Carlos, A., Davis, S.J., Samuelsen, S., 2022. Decarbonization Will Lead to More Equitable Air Quality in California. *Nat Commun* 13, 5738. https://doi.org/10.1038/s41467-022-33295-9

Zhu, Y., Koutra, S., Zhang, J., 2022. Zero-Carbon Communities: Research Hotspots, Evolution, and Prospects. *Buildings* 12, 674. https://doi.org/10.3390/buildings12050674

Appendix Table 1: Key legislation and regulatory frameworks for housing decarbonization and environmental justice in California

Goal	Law / Regulation	Description
GHG Emissions Reductions	Assembly Bill 1279 (Muratsuchi, chapter 337, 2022)	Reduce GHG emissions at least 85 percent below 1990 levels by 2045 and achieve carbon neutrality as soon as possible. Pathways for compliance were investigated in the CARB 2022 scoping plan.
	Executive Order B-55-18 (2018)	Achieve carbon neutrality by no later than 2045 and achieve and maintain net negative emissions thereafter.
	Assembly Bill 398 (Garcia, chapter 135, 2017)	Extends and strengthens California's cap-and-trade program established by AB 32 by ten years until 2030.
	Assembly Bill 617 (Garcia, chapter 136, 2017)	Requires CARB to develop statewide reporting, monitoring, and reductions plans for emissions, air pollutants and toxic contaminants by stationary (non-vehicular) sources. CARB established the Community Air Protection Program to reduce exposure among disadvantaged communities most impacted by air pollution and contaminants.
	Senate Bill 1383 (Lara, chapter 395, 2016)	CARB regulates the emission of short-lived climate pollutants, including leakage of methane and fluorinated gases from energy use and refrigeration in buildings.
	Senate Bill 32, chapter 249 (Pavley, 2016)	Reduce GHG emissions 40 percent below 1990 levels by 2030. Near-term strategies for compliance were adopted in the 2022 Scoping Plan Update.
	Assembly Bill 32 (Nunez, chapter 488, 2006)	Reduce GHG emissions to 1990 levels by 2020. Appoints CARB to develop policies to achieve this goal, assessed in "Scoping Plan" updates every 5 years.
GHG Emission Reductions Relating to Building	Assembly Bill 209 (Ting, chapter 675, 2022)	Develop and implement an Equitable Building Decarbonization Program. Reduce greenhouse gas emissions in homes and advance energy equity via two California Energy Statewide Direct Install Programs.

Decarbonization	SB 49 (Skinner, chapter 697, Statues of 2019)	Senate Bill 49 authorizes the CEC to adopt standards for appliances to facilitate the deployment of flexible demand technologies. The standards shall reduce greenhouse gas emissions by scheduling, shifting, or curtailing appliance operations with consumer consent.
	Assembly Bill 3232 (Friedman, chapter 373, 2018)	Requires the State Energy Resources Conservation and Development Commission (CEC), in collaboration with the CPUC, CARB, and the Independent System Operator (ISO), to assess the potential for the state to reduce GHG emissions of buildings 40 percent below 1990 levels by 2030.
	Senate Bill 1477 (Stern, chapter 378, 2018)	Low-emissions Buildings and Sources of Heat Energy: This law tasked the California Public Utilities Commission (CPUC) and the California Energy Commission (CEC) with developing two programs: • Building Initiative for Low-emissions Development (BUILD): Incentives and technical assistance for the electrification of new residential buildings. • The Technology and Equipment for Clean Heating (TECH) Initiative: Grants and financing to increase the accessibility of electric heat pumps to low-income households.
	Senate Bill 350 (de León, chapter 547 2015)	• Increases California's renewable electricity procurement goal from 33 percent by 2020 to 50 percent by 2030. This target was superseded by SB 100 (de León, 2018) which increases the Renewable Portfolio Standard (RPS) to 60 percent by 2030 and 100 percent by 2045. • Double statewide energy efficiency savings in electricity and natural gas end uses by 2030. • Directed the CEC to prepare a study of the barriers to LMI communities in accessing housing and transportation decarbonization • Requires the CPUC to help improve air quality and economic conditions in disadvantaged communities. • Requires that the CPUC and the CEC create a Disadvantaged Communities Advisory Group

	Title 24	Cost-effective energy efficiency: Building energy efficiency standards for new constructions & major renovations require that new buildings need to electric ready and EV ready
	Title 20	Cost-effective energy efficiency: Gives the California Energy Commission authority to adopt energy efficiency standards for appliances and equipment. Since 1974, California has adopted standards on over 50 products.
	Assembly Bill 970 (Ducheny, chapter 329, 2000), Assembly Bill 1002 (Wright, chapter 932, 2000), and Assembly Bill 1890 (Brulte, chapter 854, 1996)	Utilities efficiency programs: The CPUC approves and oversees Utilities' energy efficiency program offerings and investments.
Investment in Disadvantaged Communities (DACs)	Assembly Bill 197 (Garcia, chapter 250, 2016)	Companion bill to Senate Bill 32 (2016). The bill emphasized the need to equitably implement all climate change policies so that benefits reach all Californians, including those in disadvantaged communities.
	Assembly Bill 1550 (Gomez, chapter 369, 2016)	Established the currently applicable minimum funding levels out of the Greenhouse Gas Reduction Fund (GGRF): • At least 25 percent of funds must be allocated toward disadvantaged communities (DACs). • At least 5 percent must be allocated toward projects within low-income communities or benefiting low-income households. • At least 5 percent must be allocated toward projects within and benefiting low-income communities, or low-income households, that are outside of a CalEPA-defined DAC but within ½ mile of a disadvantaged community.

	Senate Bill 535 (De Leon, chapter 830, 2012)	• Mandates that California use certain Cap-and-Trade auction proceeds to fund investments in DACs. • Charges the California Environmental Protection Agency (CalEPA) with the responsibility to designate DACs. CalEPA utilizes the California Communities Environmental Health Screening Tool (CalEnviroScreen) to designate DAC census tracts.
Long-Term Gas Planning and Cost Control	CPUC 2020a R.20-01-007	Requires long-term changes to policies, processes, and compliance standards for California's natural gas utilities to reduce the demand for natural gas. Aims to connect gas and electric planning to maximize opportunities for electrification to result in ratepayer cost savings. Additional resources: R.20-01-007 joint agency white paper, staff proposal; CEC research initiatives (discussed in their gas research plans; individual funded projects incl PIR-20-002, PIR-20-008, PIR-20-008); PG&E Alternative Energy Program, which received additional funding per CPUC initiative in PG&E's last general rental case (GRC).