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

A Scoping Literature Review

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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 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

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[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.

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 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.

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[2] 2022 American Community Survey, Table B25034.

[3] 2022 American Community Survey, Table A10034.

- **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:

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

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[4] 2022 American Community Survey, Table B25003.

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 the

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

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

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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
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- 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.

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

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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).

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.

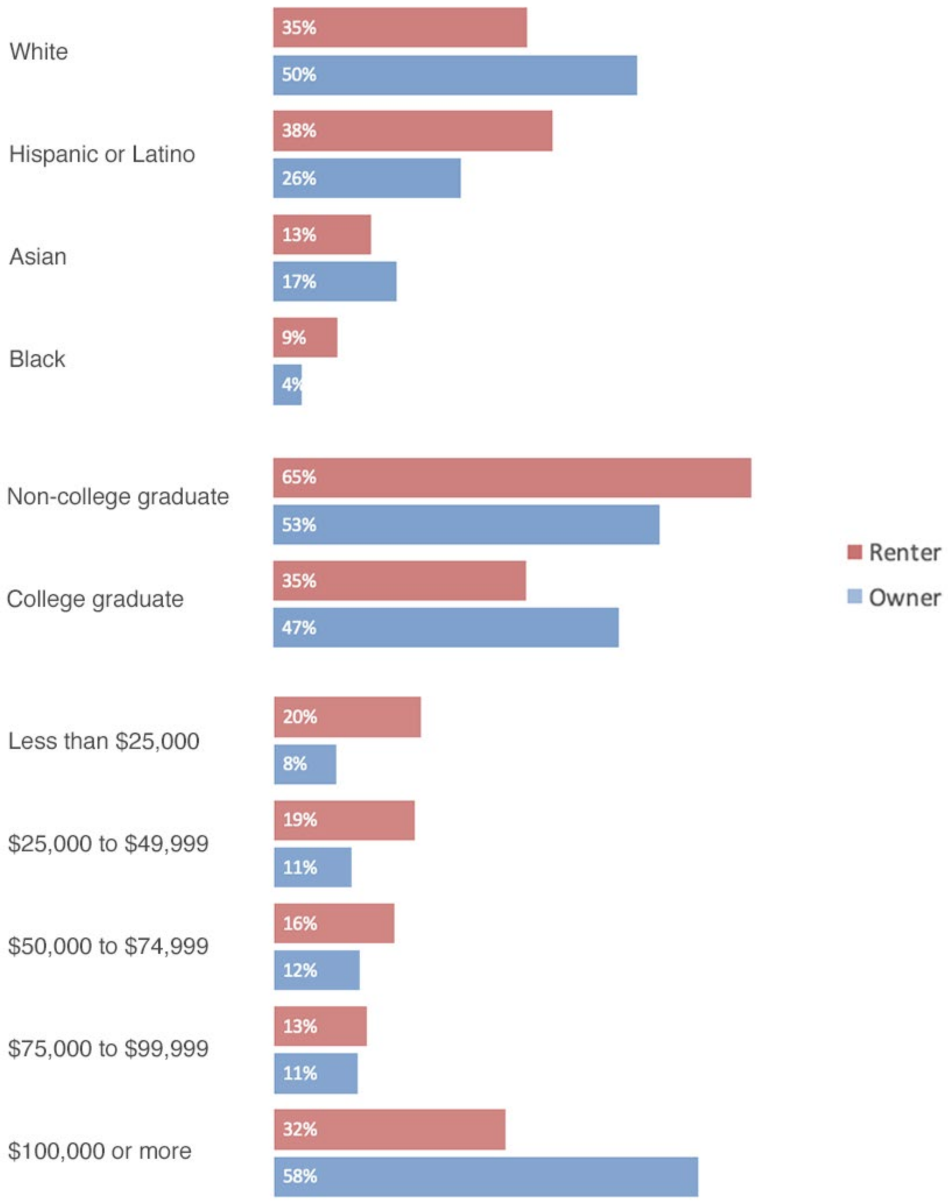
Lastly, there is a need to improve the understanding of the relationship between electrification and natural gas system decommissioning. A recent report commissioned by the CEC highlights the equity implications of electrification for the remaining natural gas costumers: “If customers depart the gas 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 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

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[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 .

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.

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[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).

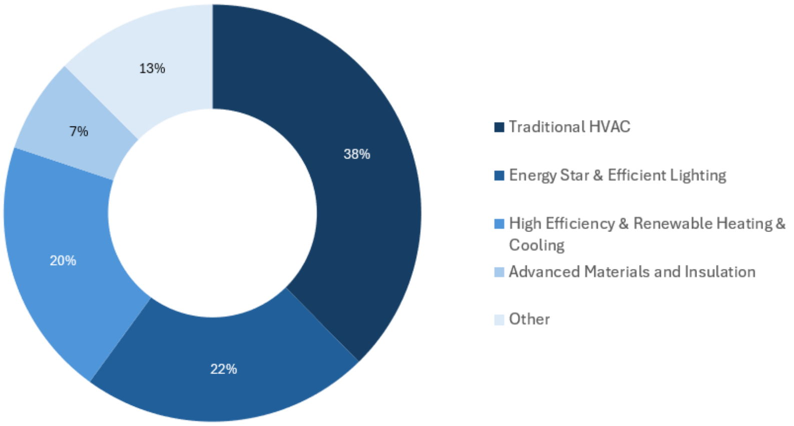
Factors explaining the shortage of skilled workforce, described in more detail below, include lock-in to familiar energy-inefficient technologies, lack of training on new technologies that further exacerbates the skills gap, uncertainty about work stability and lower wages in the construction sector, 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 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

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[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.

& 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 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:
    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.

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[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.

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 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

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[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.

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).

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[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).

- **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 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) Pilot Projects to Increase Participation Among Priority Communities

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	Protect against extreme heat and cold, indoor	Improve housing quality and stability	Improve financial security and reduce energy burden

	improve grid reliability	wildfire smoke, and flooding		
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	Prioritizing high-risk populations will have outsized benefits for those groups, contributing to reduction in health disparities	Prioritizing high-risk populations will have outsized benefits for those groups, contributing to reduction in health disparities	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.

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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.
GHG Emissions Reductions	Executive Order B-55-18 (2018)	Achieve carbon neutrality by no later than 2045 and achieve and maintain net negative emissions thereafter.
GHG Emissions Reductions	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.
GHG Emissions Reductions	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.
GHG Emissions Reductions	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.
GHG Emissions Reductions	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.
GHG Emissions Reductions	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 Decarbonization	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.

GHG Emission Reductions Relating to Building 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.
GHG Emission Reductions Relating to Building Decarbonization	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.
GHG Emission Reductions Relating to Building Decarbonization	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.
GHG Emission Reductions Relating to Building Decarbonization	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

GHG Emission Reductions Relating to Building Decarbonization	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
GHG Emission Reductions Relating to Building Decarbonization	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.
GHG Emission Reductions Relating to Building Decarbonization	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.
Investment in Disadvantaged Communities (DACs)	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.
Investment in Disadvantaged Communities (DACs)	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).