Ensuring an Equitable Energy Transition: Modeling resident energy bill impacts in affordable housing to support electrification decision making and policy

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Modeling resident energy bill impacts in affordable housing to support electrification decision making and policy

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Abstract

Electrification, particularly switching out gas furnaces with electric heat pumps, is increasingly seen as an important decarbonization pathway for residential buildings but could impact low-income residents through higher energy bills. Bill impacts for rent-restricted affordable housing are particularly hard to assess due to barriers discouraging electrification and difficulties with obtaining household level bill data. This study predicts energy consumption and bill impacts using a simple linear regression model and actual bill data from 78 households across three affordable housing properties in California. Two electrification scenarios are considered: electrification of heating and cooling systems (partial electrification) and full electrification. Estimated household energy savings from electrification ranged from 2-62% across the 78 households. Despite this, 26% of the households had estimated bill increases after partial electrification, and 31% after full electrification. For one property with gas water heating, only 8% of households had predicted bill increases after full electrification, compared to 70% and 45% for the properties where cooking was the only remaining gas usage, suggesting that partial electrification may have higher bill savings potential than full electrification unless the existing gas end uses include water heating. For one property where data was available after a partial electrification retrofit, 30% of households saw bill increases despite predicted decreases. Since actual bill impacts can differ greatly from predicted, the results demonstrate the importance of property-specific and household-level analyses both pre- and post-retrofit to support electrification decision-making and policy. This study also highlights the need for electrification policy alternatives to consider difficulties with resident bill data collection, unfavorable rates, and outdated Utility Allowance policy to encourage electrification while mitigating potential bill impacts.

1. Introduction

1.1 Research Motivation

This study models energy bill impacts of electrification for low-income residents using data from three affordable housing developments in California. Considerations identified through the case studies can help inform electrification decision-making for housing providers and policy to minimize potential impacts of electrification on low-income residents.

Previous efforts to decarbonize the residential sector, which accounted for 20% of greenhouse gas emissions in the United States in 2020, focused on building energy efficiency and reducing emissions associated with electricity supply (EIA 2022). More recently, building electrification has been recognized as an impactful decarbonization approach (Leibowicz et al. 2018; Sakamoto et al., 2021). By incorporating renewable generation technologies, electricity has the potential to provide energy with lower associated carbon emissions than fossil-fuel sources such as natural gas and coal (Berrill et al. 2021). Fuel switching from less efficient, older gas equipment to more efficient electric technologies can also benefit residents through improved indoor air quality, safety, and comfort, in addition to reduced energy costs (Tonn et al. 2014; Tan and Jung 2021). Such benefits are important to prioritize for low-income households.

Low-income households are defined by the California Department of Housing and Community Development (HCD) as those whose gross income is less than 80% of the Area

Median Income (AMI) (“Income Limits," 2022). These households spend a higher proportion of their income on energy bills than any other income group (Eisenberg 2014; Drehobl and Ross 2016). High energy burdens can contribute to energy insecurity, since households that have difficulty paying energy bills are at risk of disconnection from utility supply (Berry et al. 2018). Low-income households are also more likely to trade off on health, comfort, food, and basic necessities to cover energy bills (“Residential Energy Consumption Survey,” 2020; Xu and Chen 2019; Drehobl and Ross 2016). Electrification of existing housing has the potential to address some of these issues, but many low-income households are renters who lack control over electrification decision making (Cayla et al. 2011; Langevin et al. 2013). There is also uncertainty over whether early electrification could detrimentally impact these households through increased bills, particularly in California where the energy-equivalent cost per BTU (British Thermal Unit) of electricity is higher compared to gas (Bryce 2020).

This thesis aims to help address the uncertainty surrounding residents’ bill impacts, with a focus on all-electric retrofits rather than new construction. In California, there are already demonstrated cases of new all-electric affordable housing where low-income residents benefit from utility bills that are significantly lower due to the addition of solar photovoltaic (PV) panels (Redwood Energy 2019). In existing affordable housing, there are fewer examples and studies that focus on all-electric retrofits due to additional cost barriers, difficulties with collecting resident bill data, and unfavorable rates, as outlined in the following sections.

1.1.1 Split Incentives and Challenges for Electrification

Electrification retrofits can be challenging to implement primarily due to split incentives. The issue of split incentives between housing owners and tenants is not unique to affordable housing, and can also be found across rental housing where residents pay for their own utility bills (Bird and Hernandez 2012). In these situations, tenants lack control over initiating retrofits, but would directly benefit from the associated energy, cost savings and health benefits. Landlords have the ability to install electrification technologies, but might have to cover higher upfront or maintenance costs without receiving all of the cost and other benefits. In rent-restricted affordable housing, this problem is exacerbated because providers are unable to recover costs through increased rents. This allows tenants to receive the full cost benefit of any energy upgrades, but significantly discourages providers from pursuing them in the first place (California Housing Partnership 2021).

Although electrification technologies are commonly thought to have cost premiums, all-electric new construction is increasingly cost effective compared to equivalent gas technologies, especially as building codes move towards electrification (Outcault et al.. 2022). For electrification of existing buildings, however, the cost barriers include not just capital costs, but also costs associated with new wiring, equipment housing, electrical capacity upgrades and local transformer upgrades where needed.. Other barriers to electrification retrofits include lack of time and resources, staffing capacity, space and infrastructure constraints, knowledge and experience with newer technologies, but cost remains the most common and significant issue (California Housing Partnership 2021). The split incentives and these barriers contribute to hesitancy in pursuing electrification projects, meaning there are few opportunities to study actual bill impacts after an electrification retrofit.

1.1.2 Unfavorable Rates

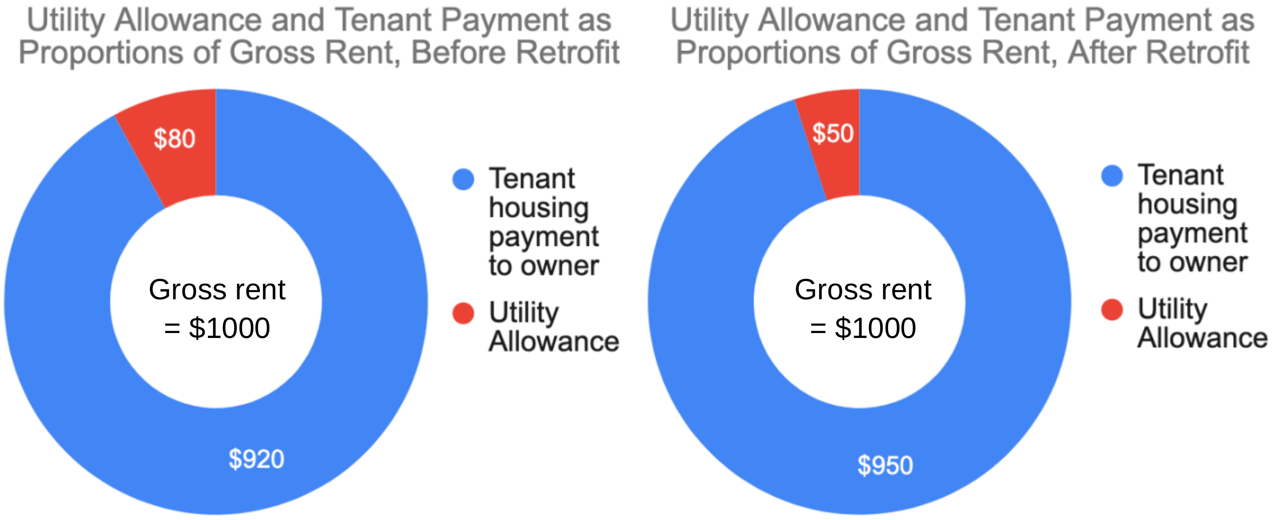
High electricity prices can further contribute to hesitancy in pursuing electrification projects (Outcault et al. 2022). Rates from Investor Owned Utilities (IOUs) in California currently do not favor electrification as customers have to pay more for electricity than gas for the equivalent energy consumption (Borenstein et al. 2021). California has high electricity rates compared to other states in the US due to the high fixed costs embedded in the prices. These costs include climate change adaptation measures like wildfire mitigation, as well as low-income assistance programs, such as California Alternate Rates for Energy (CARE) and Family Electric Rate Assistance (FERA) (Borenstein et al. 2021). The need to maintain funding for these programs makes it more difficult to reduce electricity rates to make electrification more cost-effective.

Residents' potential bill impacts are especially important to consider in light of recent announcements of rate increases from major utility providers. According to a report by the California Public Utilities Commission (CPUC), rate increases for residential customers of Pacific Gas & Electric (PG&E) are forecasted to increase by 12% more than if they had followed inflation by 2030. The increase is 10% and 12% for California's other IOUs, Southern California Edison (SCE) and San Diego Gas & Electric (SDG&E), further raising concerns for low-income energy affordability (CPUC 2021).

1.1.3 Resident Bill Payment in Affordable Housing

Since energy bills tend to be a high percentage of residents' income in affordable housing, they receive a Utility Allowance (UA) which is meant to cover the cost of their bills. The UA is not paid directly to residents but taken out of the total or gross rent they would need to pay to the housing provider. The gross rent is fixed, so any decrease in UAs is often accompanied by an increase in rent payment to the provider (California Housing Partnership 2022).

Figure 1: Relationship between Utility Allowances and amount residents pay to owners (net rent) compared to gross rent, and the impact of lowering UAs in response to retrofit bill savings (California Housing Partnership 2016).



If residents' energy consumption and bills decrease after a retrofit, the UA could be lowered to reflect this decrease (California Housing Partnership 2022). Providers would receive more money through rents, which can be used to recover costs of the retrofit. Lowering UAs to reflect upgrades can therefore help to address the split incentives issue and encourage electrification.

While UAs are meant to cover the costs of residents' bills, they may not always match what residents are actually paying since they are calculated based on the average household in a development ("Calculating Utility Allowances," n.d.). If households' energy bills exceed the monthly UA, they must pay for the excess out of pocket, which can significantly impact their continued access to energy services and even housing stability. Despite this, there is little understanding of how well UAs cover residents' utility bills, and how electrification impacts residents' out of pocket costs beyond the UA. This is in part due to difficulties with obtaining resident bill data.

For tenant-metered housing, residents pay for energy bills through their own accounts with the utility provider (California Housing Partnership 2016). Housing owners often only have access to bills for the common areas. To obtain residents' bills, they need to request permission from each resident, which can be a time consuming and difficult process due to resident turnover or complexities in account ownership. In master-metered housing where housing providers cover residents' utility expenditures, only aggregated data at the building level is available unless the building is sub metered, which is rare due to high costs (California Housing Partnership 2016). These challenges with data collection hinder resident bill analysis at the household level for calculations such as those relating to UAs, solar incentives, and electrical capacity. As such, previous electrification impact studies tend to focus on the average household (Samarripas and York 2019; Energy+Environmental Economics 2019).

In this thesis, I argue that a more granular approach to resident bill analysis helps to illustrate important nuances of electrification impacts for low-income households. Cost barriers and comparatively high electricity prices discourage providers from electrifying, leading to few examples of affordable housing that has already been electrified. In absence of such examples, I model resident utility bills after electrification in three cases where actual resident bill data is available, to understand impacts at the household level. I also examine policy alternatives that could help to overcome the challenges with electrification and maintaining energy affordability explored above. The following section highlights existing policy and how it falls short of addressing the tension between encouraging electrification and mitigating potential bill impacts.

1.2 Relevant Policy

1.2.1 Incentive programs

Previous State issued policies mainly focused on energy efficiency and electricity decarbonization to decrease associated building emissions. With AB3232 in 2018, the CEC established a target of reducing building sector emissions by 40% below 1990 levels by 2040, increasing the urgency to find more aggressive approaches to building decarbonization (California Legislative Information, 2018). Since then, incentive programs such as TECH (Technology and Equipment for Clean Heating), which primarily focuses on encouraging heat pump technologies, have been developed to support multifamily housing electrification (“About the TECH Initiative” n.d.).

Similar programs specifically targeting affordable housing include the Low-income Weatherization Program (LIWP) and the Solar on Multifamily Affordable Housing (SOMAH) program. Both have tenant protections which ensure tenants receive a majority of the benefits, but this can sometimes deter providers from using them if incentives do not cover all upfront costs (California Housing Partnership 2016). Such programs often do not cover the cost of electrical infrastructure upgrades that may be needed to support electrification (California Housing Partnership 2021). TECH and LIWP are running low on funds as of May 2022 due to higher than anticipated interest in subscription ("5/12 TECH Incentives Suspension Update" 2022). Despite the increased availability of incentives in recent years, providers often still need to use other methods, such as Utility Allowance changes, to help overcome the cost barriers to electrification.

1.2.2 Utility Allowances

For the installation of renewable energy and electrification technologies, Utility Allowances can be a pathway to recover costs for rent-restricted affordable housing. The US Department of Housing and Urban Development (HUD) and the CEC set the policy and guidelines for the calculation of UAs used in California. Previous research by the California Housing Partnership identified that most housing owners use the UA schedules provided for a particular city or county by the local Public Housing Authority (PHA), rather than calculating UAs specific to their project (2022).

When electrification technologies such as heat pumps and induction cooktops are installed, they often result in higher energy savings compared to the equivalent electric resistance technologies. Only 23 of 60 California PHAs that provide schedules online have included heat pumps in their schedules, and none account for induction cooktops or heat pump water heaters as separate from their electric resistance equivalents (California Housing Partnership 2022). Since only electric resistance technologies are reflected in most PHA schedules' allowance amounts, many providers are unable to recover the cost of retrofits by lower UAs to fully reflect electrification retrofit savings. HUD is planning to include UA reform as part of their Climate Action Plan development, which could be an opportunity to change UA policy to support electrification (HUD 2021).

1.2.3 Rates

California IOUs and the CPUC have taken a number of steps to address energy affordability for low-income residents in recent years. When the transition to Time of Use (TOU) rates began in 2018 to help reduce peak loads on the grid and lead to potential bill savings, low-income customers living in hot climate zones were exempted from default enrollment (Folks and Hathaway 2019). Instead, these customers would mostly be on tiered rates. To address additional concerns about high bills for low-income customers, in 2022 the CPUC held a series of hearings on bill affordability proposals (Trabish 2022). This included an income-based fixed charge, in which wealthier households would pay higher monthly fees to offset utility costs for low-income households. In July 2022, the CPUC approved a new public process for enabling widespread demand flexibility through electricity rates, with goals such as making electric bills more affordable and equitable, and enabling widespread building electrification ("CPUC Sets Stage to Enable Widespread Demand Flexibility," 2022).

Although solar adoption can also help with lowering customers' energy bills, customers who have historically benefited from solar incentives through Net Energy Metering (NEM) are largely higher income, single family homeowners. Existing NEM rates were found to overcompensate for solar, contributing to higher rates by passing on cost burdens to non-solar customers (Borenstein et al. 2021). In CPUC proceedings on baseline allocations, SCE model results showed that solar adoption has reduced monthly summer baseline allocations from 2-29 kWh between 2010-2019 (Cal Advocates 2022). Baseline allocations for tiered and TOU rates determine how much energy a customer can use at the lowest price and are set by the CPUC ("What is the Baseline Allowance?" N.d.). The Public Utilities Code defines the baseline quantity as 50-60% of average residential consumption, with 60-70% for all-electric customers during winter ("California Public Utilities Code - PUC § 739," 2019). Since solar adoption reduces average customer energy consumption, it can lead to higher bills for remaining customers due to reduced baselines allocations.

The properties examined in this study have lower electricity rates than PG&E customers since their electricity is instead supplied by Sacramento Municipal Utilities District (SMUD) and the City of Ukiah. PG&E baseline allocations for electricity are also lower compared to the other providers, although PG&E does offer higher all-electric baseline allocations which can be used by customers with permanently installed electric heating. All three properties receive gas service from PG&E. Even comparing the rates within baseline for electricity and exceeding baseline for gas, it is clear that gas service is cheaper on a $/BTU basis for the case study properties, as shown in Table 1. Policy reform regarding electricity rates and baseline allocations is needed to make electrification more cost-effective for housing owners and protect resident energy affordability in the energy transition, particularly in California IOU territories.

Table 1: Rates for utility providers that supply the case study properties. PG&E electricity rates are included only for comparison ("Current City of Ukiah Electric Rates" 2022; "Tariffs" 2022; "Residential Service Rate Schedule R" 2021) .

Service	Utility provider	Rate in $/BTU	
		Summer	Non summer
Electricity	SMUD	5.48E-05	3.43E-05
Electricity	City of Ukiah	4.34E-05	4.34E-05
Electricity	PG&E	9.24E-05	9.24E-05
Gas	PG&E	2.45E-05	2.45E-05

In terms of policies that both encourage electrification and mitigate residents' bill impacts, California's incentive programs with included tenant protections, such as LIWP and SOMAH, demonstrate the most balance between these two aims. The CPUC is also increasingly recognizing both issues, particularly with the new demand flexibility proceeding. Both the CPUC proceedings and HUD's recent interest in sustainable UA reform demonstrate the relevance of analyzing residents' potential bill impacts with implications for electrification policy.

2. Background

This study investigates bill impacts of electrification using a regression model to determine household energy consumption and bills after electrification. The following background helps to identify the modeling approach and factors that can affect the results. A review of existing literature is also used to supplement the case study findings when discussing policy improvements to mitigate bill impacts.

2.1 Electrification Technologies

Electrification typically refers to the replacement of fossil-fuel based equipment and appliances with equivalent electric alternatives. Beneficial or efficient electrification refers to electrification in a way that reduces carbon emissions, lowers costs, and leads to better grid demand management (Tan and Jung 2021).

Technologies that assist with beneficial electrification include heat pumps for Heating, Ventilation and Cooling (HVAC) and water heating end uses, and electric induction stoves for cooking. Heat pumps can provide both space heating and cooling in one unit, and can cool homes with greater temperature consistency and efficiency than air conditioners. High efficiency heat pumps have a coefficient of performance (COP) of 3-4, while gas furnaces are only around 80-90% efficient, so space heating electrification results in even higher savings (Redwood Energy 2019). Induction is also a high efficiency technology, as induction ranges are 90% efficient compared to 40% for gas and 70% for electric resistance (E3 2019). In addition to efficiency improvements, induction stoves can help reduce space cooling loads and increase safety since they heat specialized pots and not the surrounding area (Redwood Energy 2019). However, induction stoves are currently difficult to retrofit due to electrical constraints and induction oven technology that is still nascent. In my analysis of electrification scenarios, I use heat pumps, heat pump water heaters and electric stoves to model consumption after replacing gas equipment used for space heating, water heating, and cooking respectively.

2.2 Energy Consumption Impacts of Energy Efficient Retrofits

Either statistical or engineering approaches can be used to model the energy consumption impacts of electrification retrofits. Among the approaches, linear regression analysis is relatively easy to use and reasonably accurate for modeling individual household consumption (Raffio et al. 2007). Using actual bill data was found to improve consumption model accuracy for evaluating bill impacts, since it can be used to account for the behavioral characteristics of individual households (Fumo and Biswas 2015). Since affordable housing owners may not have the time and resources use more complex models, this study employs a simple linear regression approach for estimating consumption to evaluate electrification impacts.

Previous work on energy performance impacts of retrofits has revealed differences in estimated and actual results. In an implementation study for a multifamily energy efficiency program in the City of Austin, Kennedy et al. (2014) considered the program an overall success since most of the 21 communities saw at least some energy savings, however there were 5 communities where energy consumption increased post-retrofit. While the projected energy savings were 18-31%, actual impacts ranged from a reduction of 26% to an increase of 6%. Factors such as resident turnover, faulty equipment, improper use of equipment, and changes in energy usage behavior could play a role in differences between expected and observed savings (Langevin et al. 2013). Several researchers have also noted how the unpredictability of tenant behavior contributes to differences in expected energy consumption behavior (Moore et al. 2017; Weber and Wolff 2018). Moore et al. (2017) emphasize the importance of renewable energy measures such as solar PV to provide more guaranteed savings to residents, without having to rely on the unpredictability of behavioral factors.

These behavioral factors include the “rebound effect” after energy retrofits, in which residents can afford to increase their usage of more efficient equipment (and thereby thermal comfort) since improved energy efficiency helped to lower their bills (Sorrell and Dimitropoulos, 2008). In some cases, this effect was thought to be responsible at least partially for higher than expected energy usage or bills post retrofit (Elsharkawy and Rutherford 2018; Langevin et al. 2013). Sunikka-Blank and Galvin (2012) also highlight the “pre-bound” effect, where energy consumption pre-retrofit is overestimated due to residents consuming less than anticipated. Using actual consumption data pre-retrofit, this study aims to mitigate the pre-bound effect on results. Possible rebound effects are qualitatively discussed for one case study where both pre- and post-retrofit data were available.

2.3 Bill Impacts of Energy Efficient Retrofits

While several studies have investigated energy performance and bill impacts of low carbon retrofits, few have quantified the impacts on individual households’ bills in multifamily affordable housing. In a case study of 10 social housing buildings in Germany, Weber and Wolff (2018) found that more than half of the households (56 of 109) faced increased costs despite consuming less energy than their model predicted, although this was in part due to allowable rent increases of up to 11% of the retrofit cost. Elsharkawy and Rutherford (2018) found that bill savings after an energy efficiency retrofit program in Nottingham, England were on average £204 compared to an estimated £300. They identified that increased energy prices and the rebound effect likely played a role in this difference. In the US, a 2017 ACEEE study completed a national level review of 32 multifamily low-income energy efficiency programs and found an average cost savings of at least $103 per unit annually (Samarripas and York). It is unclear, however, how the savings were distributed between housing providers and residents, and they also note that savings varied between programs. A more granular analysis of energy bill impacts across households in the same development(s) would improve understanding of potential electrification impacts to residents.

2.4 Policy and Decision-making Support for Electrification

Previous research has identified characteristics of successful policy to overcome barriers to energy efficiency retrofits for low-income housing, although not specifically electrification retrofits. In an ACEEE study, Samarripas and York (2019) note that successful programs such as California's LIWP created a "one-stop shop" for technical assistance coordination, and provided an integrated whole-building approach to energy efficiency and solar energy systems. Other studies have suggested policy approaches beyond government programs, since a common challenge was high program costs combined with unsustainable funding sources (Tsenkova 2018). In an assessment of policy options to address split incentives affecting the energy efficiency of low-income housing, Bird and Hernandez (2012) suggest the optimal policy integrates incentives for both landlords and tenants, durability, cost addressed primarily by savings rather than government or private grants, and transparency. Reina and Kontokosta (2017) investigated the energy consumption and regulations of subsidized properties in New York. They found that providers were rarely able to adjust UAs after energy efficiency upgrades, and suggest that policymakers can look to existing regulations as "low hanging fruit" for improving energy efficiency in subsidized multifamily housing. Such information is used to discuss the costs and benefits of various policy measures to help mitigate bill impacts of electrification in Section 5.2.

There are few studies that focus on affordable housing developers’ experiences with low carbon retrofits. Through interviews with housing providers and other experts in a multi case study research, Outcault et al. (2022) identified that more resources such as access to software, building performance data and training are needed to help California developers transition to low-carbon housing. Interviewees also indicated uncertainty over how low carbon designs would impact resident bills, in particular whether residents would owe more than UAs. This study hopes to provide owners with a simple approach to analyzing bill impacts for specific properties, and an understanding of how different metrics can be used to answer these concerns.

Since electrification is a more recent decarbonization strategy, previous studies often discuss it under the umbrella of energy efficiency or low-carbon retrofits. Based on the literature, retrofits generally help to decrease overall energy consumption and bills, although the savings vary greatly. Variation in resident behavior is a major factor contributing to higher consumption and bills than expected, so incorporating actual consumption data helps to increase the accuracy of modeling. Linear regression provides an easy to use approach for understanding bill impacts, but has limited accuracy due to its simplicity. The model I use for estimating bill impacts is more suitable for demonstrating potential variations in the electrification impacts among households, rather than for usage in actual system design, UA calculations, or solar incentives. The literature on policy approaches to energy efficient retrofits highlights the importance of balancing incentives for both housing owners and tenants. The three policy alternatives I consider draw on the idea from Reina and Kontokosta (2017) that regulations are "low hanging fruit" for increasing the sustainability of affordable housing.

3. Methodology

The following section outlines the steps taken to collect data, model electrification impacts for residents in three affordable housing properties, and evaluate the impacts on residents' utility bill expenses beyond the UA. Two electrification scenarios are examined for each case study: only HVAC retrofit, and full electrification retrofit. In both cases, the energy consumption is expected to decrease, while bills could potentially increase depending on whether the rates are favorable to electrification. This study also compares post-retrofit actual data to pre-retrofit estimates where available, and analyzes the sensitivity of the results to rates, weather variations and technology efficiencies.

3.1 Data Collection

Case study participants were selected from a previous pool of interviewees for a Utility Allowances research project by the California Housing Partnership in 2021. While they were unable to send data, 8 housing developers offered their time for informal interviews. Informal interviews helped to provide insight into common electrification retrofit challenges and suggested policy changes.

Two owners were able to provide resident utility bills for analysis. This data was initially collected by the owners to calculate utility allowances due to the requirements of the USDA

Rural Development funding source. This is one of the only funding types that requires owners to base UAs on actual resident bills, requiring providers to collect, or hire third party consultants to collect, and analyze resident bills. As a result, the case studies are more relevant for relatively low-density cities, and Northern California. One of the properties is located in Sacramento (referred to as Sac-1), while the other two are located in Ukiah (Ukiah-1 and Ukiah-2). A summary of the case study properties' end use fuels and other characteristics is provided in Table 2 below.

Table 2: Property characteristics for case study properties

Property identifier	**Sac-1**	**Ukiah-1**	**Ukiah-2**
Location	Sacramento	Ukiah	Ukiah
California Climate Zone	12	2	2
Electric utility provider	SMUD	City of Ukiah	City of Ukiah
Gas utility provider	PG&E	PG&E	PG&E
Electricity end uses	Space cooling (individual)	Space cooling (centralized) Water heating (dual fuel)	Space cooling (individual) Water heating
Gas end uses	Space heating (centralized) Cooking	Space heating (centralized) Cooking Water heating (dual fuel)	Space heating (individual) Cooking

The resident bill data for this analysis was obtained from previous studies by energy contractors to determine the UAs at each property. These studies were conducted using monthly data over a 12-month period. For Ukiah-1 and Uikah-2, bills were available most recently for

2020-21. For the Sac-1 property, bills were available both pre-retrofit from 2013-14 and post HVAC electrification retrofit from 2020-21. Since resident bill data can be time-consuming and difficult to collect, the energy consultants obtained bills for a subset of the total apartment units. To protect residents' privacy, identifying information such as the property's zip code and the unit numbers of each apartment have been omitted. Individual units are instead referred to by number from 1 to the maximum number of sample units for each property.

Table 3: Household sample characteristics for case study properties

Property identifier	**Sac-1**	**Ukiah-1**	**Ukiah-2**
Total units	98	48	64
Sample units	20 (20%)	38 (79%)	20 (31%)
Pre-retrofit sample dates	July 13-June 14	Sept 20-Aug 21	Sept 20-Aug 21
Post-retrofit sample dates	June 20-May 21	N/A	N/A

3.2 Electrification Scenarios

The two electrification scenarios examined are 1) HVAC only electrification and 2) full electrification. HVAC electrification includes replacing existing gas equipment for space heating and cooling with electric heat pumps that provide both heating and cooling. Full electrification assumes HVAC electrification in addition to replacement of any other existing gas end uses with the equivalent electric equipment. For the Ukiah-2 property, full electrification includes replacement of gas water heaters with heat pump water heaters and gas stoves with electric stoves, while for the Sac-1 property and Ukiah 2 properties, full electrification only involves replacing the gas stoves, since the water heating equipment was already electric. Due to higher upfront costs for electric equipment, in addition to other barriers to affordable housing electrification noted in Section 1.1.1, it can be hard for affordable housing owners to perform full electrification at once. HVAC retrofits tend to be more common than electrification of water heating and cooking, and electrification of space heating and cooling has been identified as an important component of building decarbonization pathways. As such, housing owners might be interested in the impacts of HVAC electrification retrofits and full electrification retrofits separately.

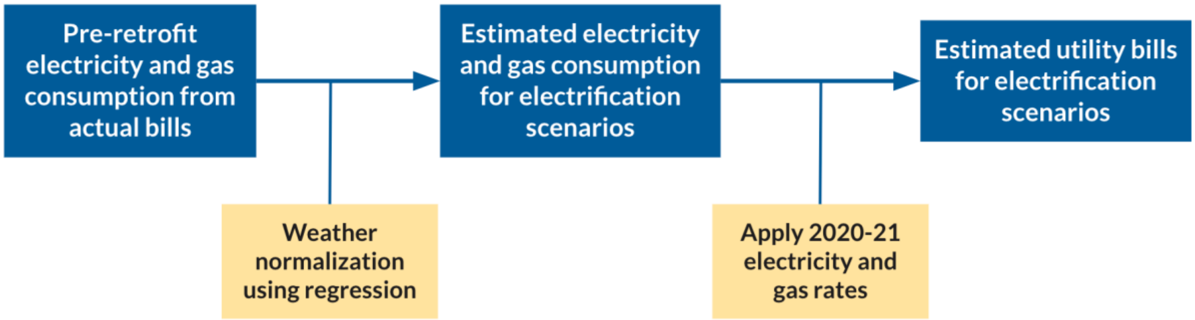
The scenarios focus on switching out gas equipment with equivalent electric technologies for the main building end uses. Reduced energy consumption from solar PV is not included in the scenario analysis to account for cases where solar potential is limited due to roof space, electrical capacity or cost constraints, although it should be noted that solar can be an effective way to mitigate bill impacts.

3.3 Modeling Approach

3.3.1 Regression

In order to estimate the bill impacts of the different electrification scenarios, the following process was used in Fig. 2.

Figure 2: Methodology for obtaining estimated bills and consumption from raw data



First, linear regression is used to separate the weather-dependent consumption used for space heating and cooling, and account for weather variations year to year in the case of Sac-1. Prior to a retrofit, electricity would be used primarily for cooling and gas for heating in all the properties. Electricity consumption is therefore expected to increase with increased cooling degree days (CDD), and gas to increase with heating degree day (HDD) values before the retrofit. The degree days are indications of how much cooling and heating is needed in a given time frame. In this case since the consumption data was provided on a monthly basis, the HDD and CDD data were obtained for Sacramento and Ukiah for each month of the billing periods.

The data is also day-normalized to account for the variation in number of days between different months. This was done by dividing degree day and consumption values by the number of days in the given month before running the regression. The weather normalization and day normalization methods follow common practice used by energy consultants when conducting studies on UA adjustment. The day-normalized degree day and consumption values for each household were used to obtain regression equations for electricity and gas usage in the form:

$$E = A_1 * CDD + B_1 * days$$

$$G = A_2 * HDD + B_2 * days$$

Where

- E and G are the electricity and gas consumption for the time period of interest
- A_1 and A_2 are the regression coefficients, representing weather-dependent energy consumption per heating or cooling degree day
- B_1 and B_2 are the regression intercepts, representing baseline energy consumption per day
- CDD and HDD are the number cooling and heating degree days respectively
- $days$ is the number of days in the time period of interest

Once these regression equations are obtained for the pre-retrofit data, they can be used to separate out the baseload energy consumption from weather dependent energy consumption for electricity and gas in a given time period. For Sac-1, since the pre-retrofit data was provided in 2013-14, this method was also used to estimate what the monthly consumption of electricity and gas would have been in 2020-21, assuming there was no retrofit and that the baseline consumption did not change.

For all the properties, regression was used to separate data used for the main end uses: Space heating, cooling, water heating and cooking. For each of the end uses, the consumption was multiplied by an efficiency factor that considers the efficiencies of the existing technology compared to the electrification technology. The efficiency assumptions are based on RMI's Economics of Electrifying Buildings report (2018), E3 Residential Building Electrification study

(2019) and Redwood Energy's Pocket Guide to All-Electric Retrofits of Single-Family Homes (2021). Electric stoves were assumed to be electric rather than induction due to the high cost currently associated with induction. Table 4 summarizes these assumptions for technology efficiencies.

Table 4: Efficiency assumptions for each end use technology used in the model

End use	**Electricity**	**Natural Gas**
Space heating	80%	3 (COP)
Space cooling	SEER 14	SEER 18
Water heating	70%	2.5 (COP)
Cooking	75%	40%

Energy consumption for the HVAC electrification scenario used only the space heating and cooling efficiency factors. The full electrification scenario additionally used an efficiency factor for cooking usage in the Sac-1 and Ukiah-2 properties since this was the only remaining usage. In the Ukiah-1 property which had non-weather dependent consumption for both water heating and cooking, the full electrification scenario used an efficiency factor for water heating, since cooking tends to account for a relatively small proportion of household energy consumption.

Bills for the electrification scenarios were calculated by using effective electricity and gas rates for each household. Many, but not all, affordable housing residents are on rates such as CARE or SMUD's Energy Assistance Program Rate (EAPR), which provides monthly discounts based on income and household size ("Income-eligible assistance," 2022). While low-income households have generally not been automatically transitioned to TOU rates, some households could have opted in. To account for this possible variation in rates between households, monthly rates for individual households were derived from actual bills and consumption pre-retrofit. For the Sac-1 property, since pre-retrofit bill data was collected 2013-14, a percentage increase of 1.08% for electricity and 5.3% for gas was applied to get effective rates for 2020-21, based on average SMUD and PG&E residential customer rate increases respectively (CPUC 2021; SMUD 2013; SMUD 2019). For all properties, bills and consumption values for each electrification scenario were then compared to the pre-retrofit case to understand bill impacts.

3.3.2 Uncertainty and Sensitivity Analysis

The regression provided confidence intervals for the coefficient and intercept values. The sensitivity of the results to variation in the coefficient was quantified by using the lower and upper values of the coefficient. The lower and upper values represented the values the coefficient would fall between with 95% confidence. The effect of this variation was plotted using error bars for the percentage changes in annual bill and consumption after each electrification scenario compared to without the retrofit.

For each case study, sensitivity analysis was conducted to determine the sensitivity of the results to changes in rates, heating and cooling degree days, and electric equipment efficiencies compared to gas equipment.

3.3.3 Utility Allowance Comparison

There has been a lack of data collected on how utility allowances compare to residents' actual bills. This study aims to address this gap and in particular understand how electrification will impact residents' out of pocket utility expenses beyond the UA.

The utility allowances for each property have been calculated based on actual residents' bill data as per USDA RD requirements. The UAs are specific to each unit type, distinguished by the number of bedrooms.

Table 5: Utility Allowances ($/month) for each case study property in 2020-21

Property identifier	**Sac-1**	**Ukiah-1**	**Ukiah-2**
1 BR	20	47	43
2 BR	27	66	94
3 BR	43	103	114
4 BR	56	N/A	N/A

UAs are set for each unit type, distinguished by the number of bedrooms. Consumption and bills will generally vary depending on the geographic region and property characteristics such as building age, efficiency features and end use fuels. They are also dependent on the residents' household sizes, demographics and energy behavior. This can help to explain the variation in UAs between the three properties.

For the three properties, these UA values are used to determine the number of households paying beyond the UA for each electrification scenario. The average value and highest amount paid out of pocket per scenario were also calculated to provide a better understanding of electrification bill impacts.

4. Results

From the regression to separate weather dependent and baseline consumption from the raw energy consumption data, coefficients and intercepts were obtained for each household (see Appendix A for the obtained values). These values were then used to estimate the post-retrofit changes in household energy consumption, and subsequently, changes to bills and out of pocket costs beyond the UA. The results for each electrification scenario are discussed by case study, as this can demonstrate the value of property-specific assessment of bill impacts. Implications of the results, including a discussion of policy alternatives that could help address challenges identified over the course of this research, are examined in further detail in Section 5.

4.1 Energy Consumption and Bill Impacts

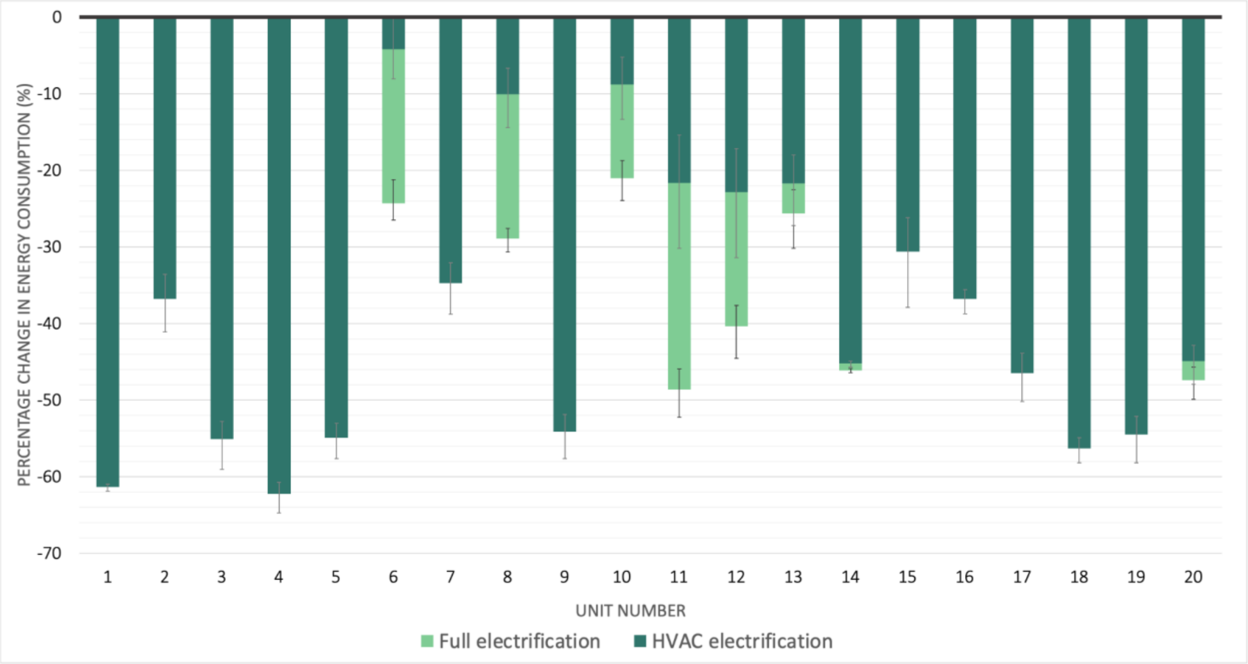
After an electrification retrofit, total energy consumption in kWh is expected to decrease in all households. The estimated household energy savings from electrification range from 2-62% across the 78 households. Predicted bills showed more mixed results and exhibited a larger variation, with a highest predicted bill savings of 73% and highest predicted bill increase of 56%. HVAC electrification is predicted to result in bill savings of 2% on average, while the average bill change for full electrification is actually close to zero. Of the 78 households examined, 26% are predicted to have bill increases after partial electrification, and 31% after full electrification.

One interpretation of these results could be that electrification, especially HVAC electrification, is overall beneficial since a majority of residents are predicted to receive bill savings. Considering each individual property, one may conclude that electrification is acceptable to pursue for Ukiah-2, where average savings are expected to be 5% and 6% for HVAC and full electrification respectively, while it should not be pursued for Sac-1 at the present time, since there are predicted average bill increases of 4% and 8%. The following breakdown of results for households in each property helps to illustrate how project-specific examination of bill impacts can provide a more nuanced answer to housing providers regarding whether and in what way they should pursue electrification for a given property. Rather than plotting averages or using statistical plots, the figures show the energy consumption and bill impacts for each individual household. This helps to capture the extent of variation in impacts among households even in the same development.

Sacramento-1

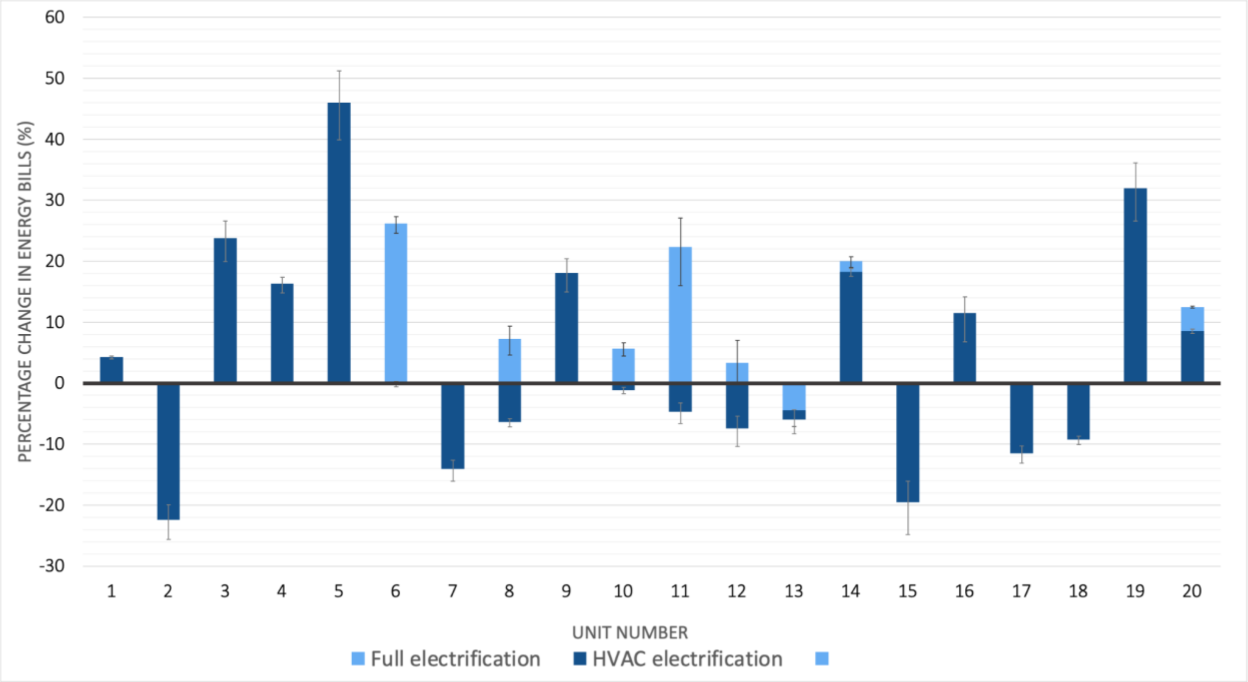
For the Sac-1 property, an average decrease of 38% after HVAC electrification, and 43% after full electrification was estimated. As shown in Fig.3, the predicted decreases vary from 4-62% between the sample households. For more than half of the households, the non-weather dependent gas consumption (cooking usage) was near zero, so full electrification did not contribute significantly to further energy reductions. However, it is notable that for a few households such as 11, 12 and 6, their gas consumption for cooking or other non-weather dependent uses is roughly equal to or even greater than for heating consumption. These households would benefit most after full electrification, from an energy efficiency standpoint.

Figure 3: Estimated percentage change in energy consumption after electrification scenarios for sample households in Sac-1



Despite energy savings of more than 20% across all the sample households, the potential bill impacts of electrification show more mixed results, with an average increase of 4% and 8% after HVAC and full electrification respectively. Of the 20 households, 9 have predicted bill increases after HVAC electrification, and this number increases to 14 after full electrification, despite full electrification decreasing these households' overall energy consumption. Surprisingly, households such as 5 and 19 with some of the highest predicted energy decreases would face the highest bill increases. These households had relatively low electricity consumption and high weather-dependent gas consumption pre-retrofit compared to other households. Transitioning to heat pumps would cause a large increase in their electricity consumption, subject to higher rates. Notably, households that were identified as "super-users," consuming far more than the average household pre-retrofit, are all expected to have bill decreases post-retrofit.

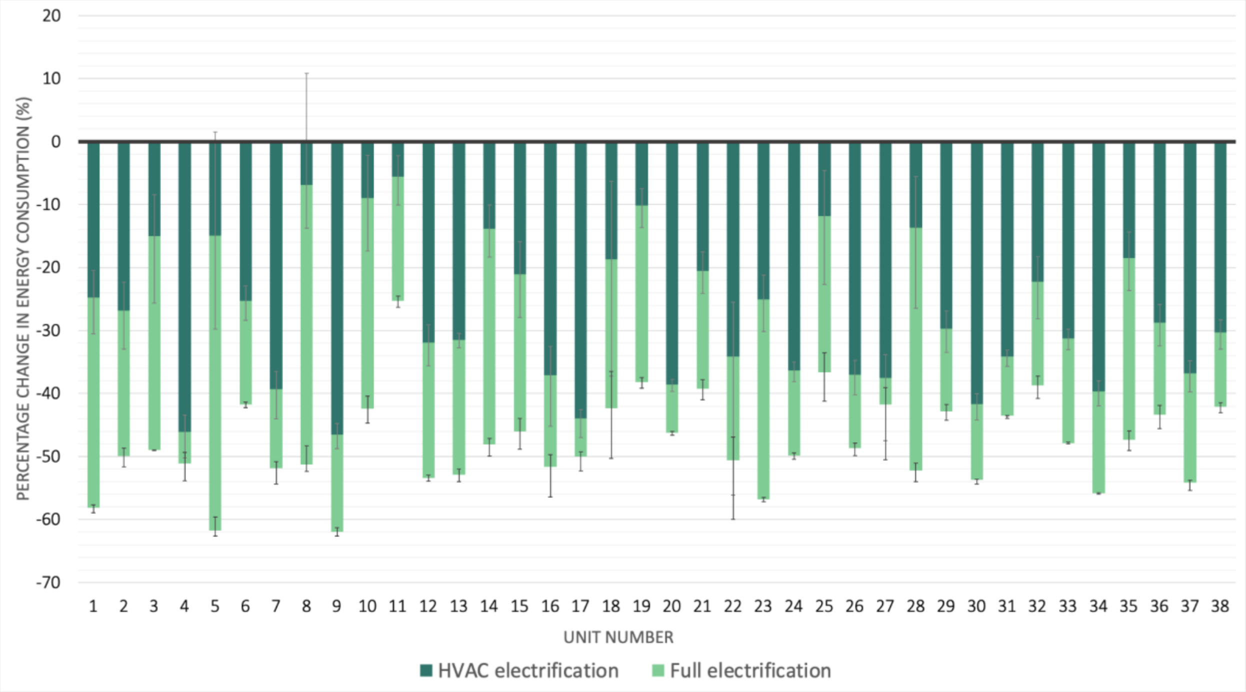
Figure 4: Estimated percentage change in energy bills after electrification scenarios for sample households in Sac-1



Ukiah-1

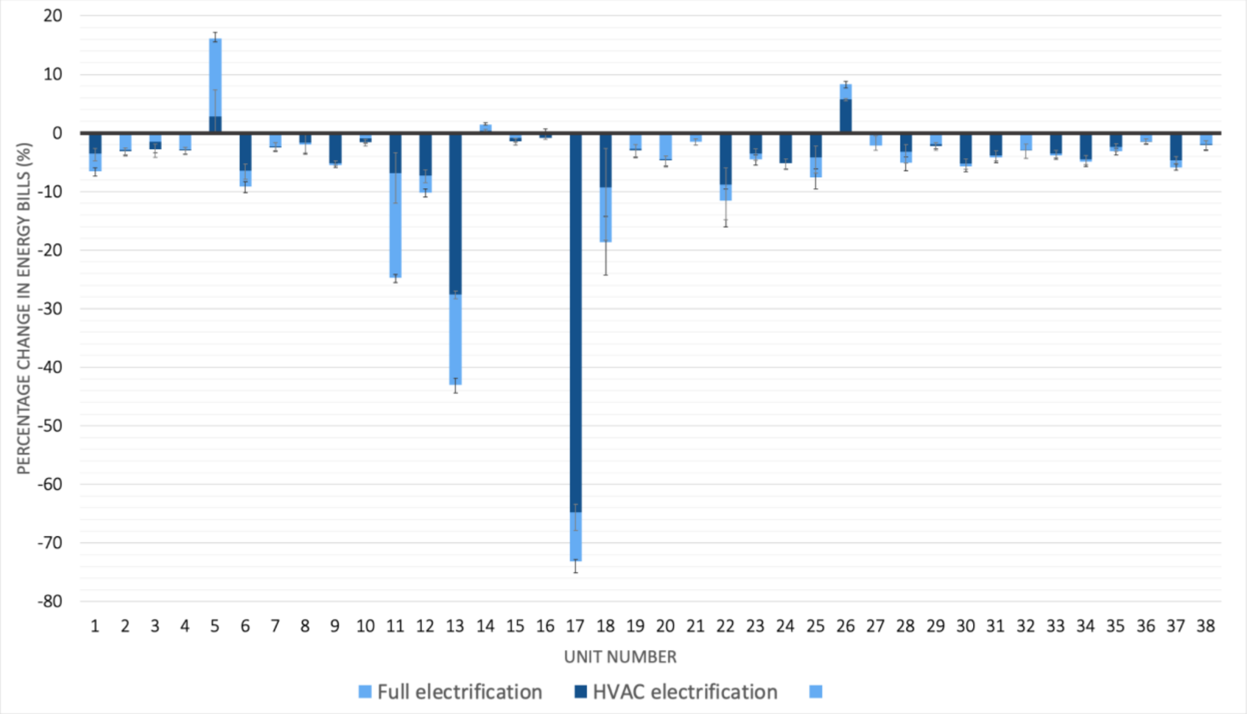
For the Ukiah-1 property, HVAC electrification would cause an average decrease in consumption of 27%. This increases to 47% for full electrification. Full electrification had an even greater energy efficiency contribution than HVAC electrification for 34% of the households, which was not observed for most of the Sac-1 households. Electrification would involve switching out the dual-fuel water heater with a heat pump water heater, producing a greater effect on overall energy efficiency than just switching out the cooking usage as in Sac-1.

Figure 5: Estimated percentage change in energy consumption after electrification scenarios for sample households in Ukiah-1



Potential bill savings from electrification are also observed among a greater proportion of households. As shown in Fig. 6, most (32) households would see bill decreases of 0-10%, while there are a few with significant savings potential. Households 13, 17 and 11 all had much lower derived rates for electricity compared to the other households, while their gas rates were comparable, suggesting they are on programs such as FERA that provide support only for electricity bills.

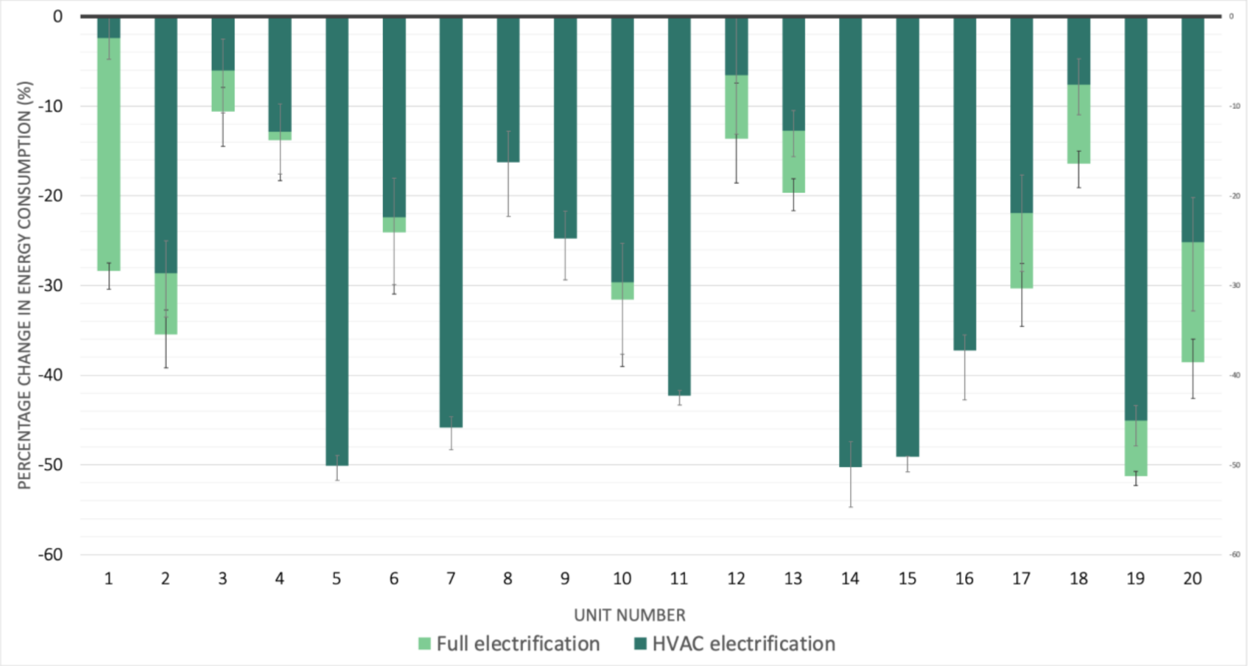
Figure 6: Estimated percentage change in energy bills after electrification scenarios for sample households in Ukiah-1



Ukiah-2

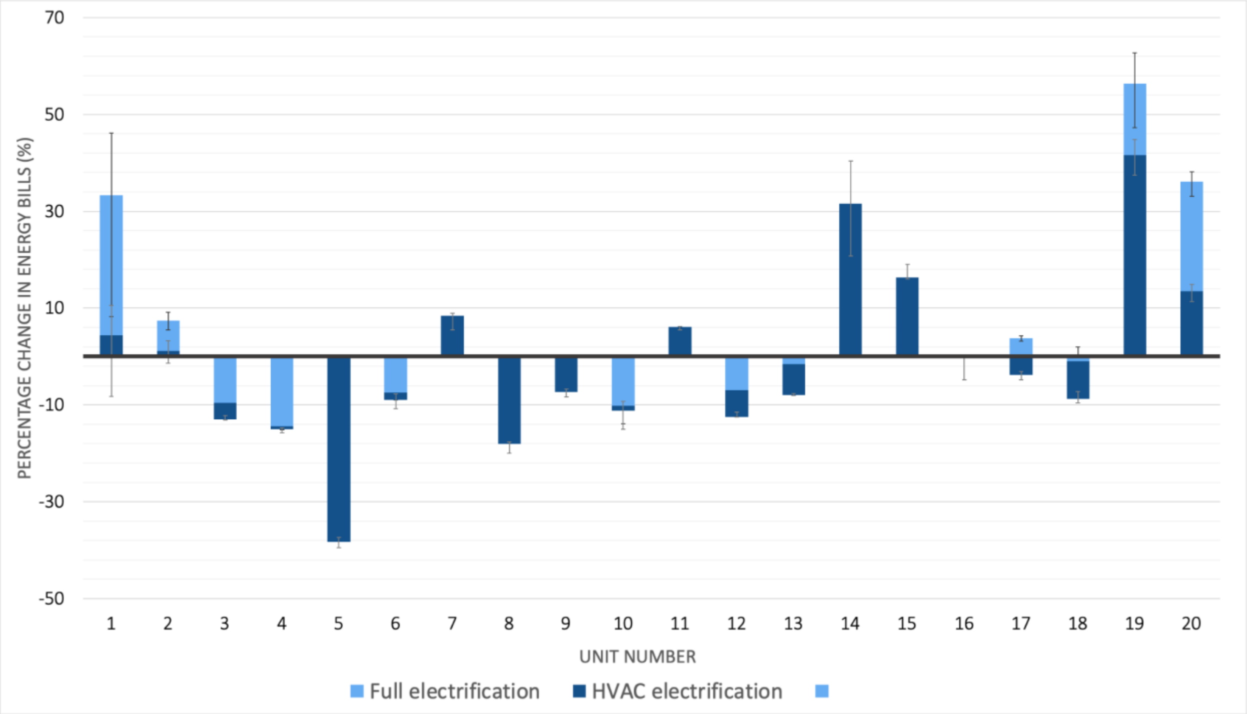
Full electrification impacts on consumption varied from savings of 10-50% for the Ukiah-2 property, as shown in Fig. 7. Similar to the Sac-1 property, cooking is the only remaining gas usage after heating is electrified, so electrification savings came mainly from HVAC electrification.

Figure 7: Estimated percentage change in energy consumption after electrification scenarios for sample households in Ukiah-2



Also like the Sac-1 property, bill impact results were mixed. This situation is an example of how averages, commonly used for decision-making, might fail to capture the extent and nuance in bill impacts for residents. While bills on average have an expected decrease of 1% after HVAC electrification, the modeling results suggest that almost half (8 of the 20 households) would see bill increases, with some as high as $267 per year.

Figure 8: Estimated percentage change in energy bills after electrification scenarios for sample households in Ukiah-2

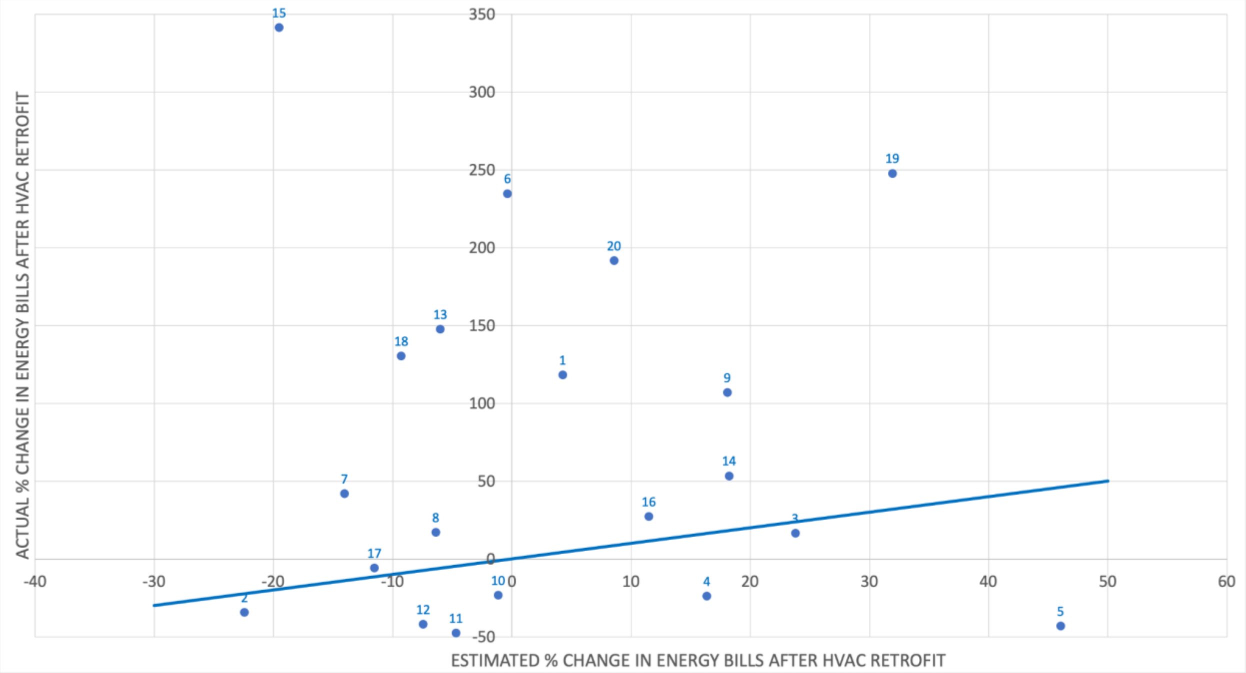


4.1.1 Comparison to Post Retrofit Bills

Since post-retrofit bills after HVAC electrification and energy efficiency measures were available for the Sac-1 property, the actual bills were compared to the modeling estimates. The model attempted to account for rate increases and weather variations between the two time periods, as well as the pre-bound effect by using actual bills. The results are suggestive of how energy behavior, including the rebound effect, may contribute to large differences between expected and actual savings, as highlighted in previous research.

Estimated bill impacts ranged from savings of 19% to an increase of 46%. Actual bill impacts showed a greater range from to 24% savings to a 341% increase. As seen from Fig. 9, most households saw greater bill increases than predicted. This is particularly true for households such as 6, 19 and 20 that are “super-users,” meaning they consume far more energy than other households with the same number of bedrooms. The most concerning are households in the top left quadrant of the graph, such as 15, 13 and 18, who saw significant bill increases despite predicted decreases. Based on feedback from the same affordable housing developer who provided the data, such large increases could be due to new residents with larger family sizes or different energy consumption habits, increased use and number of electronic devices per household, or new HVAC equipment not operating as intended. The major reason was likely the Covid-19 pandemic causing more residents to spend time at home. Water consumption data or household energy data from a similar property where a retrofit did not take place over the same time period could be used to provide an indication of the pandemic’s influence on model inaccuracies. Although data was not readily available, the housing provider for Sac-1 observed increases in residential water consumption during the pandemic and suggested residential energy consumption could have followed the same pattern.

Figure 9: Comparison of estimated and actual percentage change in bills after HVAC electrification for Sac-1, with estimate on the x axis and observation on the y axis. Data labels indicate households 1-20, and a 1:1 line is also plotted for comparison.



Given the differences between estimated and observed bill impacts, this model would not be a good fit for estimating the actual magnitude of bill increases. A more complex regression model or energy modeling software, in combination with actual pre-retrofit bill data, would provide more accurate modeling of post-retrofit household consumption. However, even a more complex model may not explain some of the differences, since they could be due to faulty equipment, resident turnover, or an increase in household size. Resident bill data before and after electrification should therefore ideally be collected as close to the period of the retrofit as possible, and additional information such as tenancy changes could be collected to provide a better understanding of outliers. Future modeling approaches to understanding electrification impacts should also rely on the most recent consumption data to account for the potential effect of the pandemic. The model is useful for demonstrating just how different actual bill impacts can be, even after accounting for weather variations, rate increases and the pre-bound effect. The approach of comparing model results to actual bill data, combined with Utility Allowances information to determine the actual out of pocket expenses, can also help housing owners identify and assist households that are paying higher bills than expected after electrification.

4.2 Comparison to Utility Allowances

Assuming the 2020-21 Utility Allowances remain in place post-retrofit, the electrification will have the following impacts shown in Tables 6-8 on how well UAs can cover bills. While the number of Sac-1 residents paying beyond the UA would decrease after electrification, the average amount paid out of pocket would increase, for some more than $30 per month. The households that would pay out of pocket for both electrification scenarios are largely the same, although there is one case where a household that would not pay out of pocket for HVAC electrification would need to for full electrification.

Table 6: Utility Allowance related impacts of electrification for Sac-1

Sac-1 Property	Number of residents paying beyond the UA per month	Average amount paid beyond the UA per month	Largest amount paid beyond the UA per month
No electrification	7	$6.52	$22.42
HVAC electrification	5	$8.51	$18.84
Full electrification	6	$9.45	$32.17

The actual effects of the HVAC retrofit were largely different than anticipated. Only one of the five households predicted to have out of pocket bill expenses after HVAC electrification actually ended up paying beyond the UA after the HVAC retrofit. An additional seven households that were not expected to pay out of pocket costs ended up paying $5-$37 monthly that was not covered by the UA. More information about resident turnover and changes to household size could help to more accurately identify households at risk from high out of pocket expenses after electrification. The differences also demonstrate the importance of continuing to track how households' actual bills compare to UAs after the retrofit to mitigate electrification bill impacts.

Similarly to Sac-1, for the Ukiah-1 property the number of households who need to pay beyond the UA would decrease for both electrification scenarios. Electrification has a relatively small impact on the average amount paid beyond the UA, although there could be higher decreases for residents who spend the most on utility bills.

Table 7: Utility Allowance related effects of electrification for Ukiah-1, per month

Ukiah-1 Property	Number of residents paying beyond the UA per month	Average amount paid beyond the UA per month	Largest amount paid beyond the UA per month
No electrification	19	$17.00	$55.54
HVAC electrification	16	$17.56	$48.14
Full electrification	16	$16.98	$46.25

For the Ukiah-2 property, full electrification would increase the number of residents paying beyond the UA and their average payment compared to HVAC electrification. For households that are already paying beyond the UA without electrification, their bills mostly would decrease with HVAC electrification but could increase beyond their current bills with full electrification.

Table 8: Utility Allowance related effects of electrification for Ukiah-2, per month

Ukiah-2 Property	Number of residents paying beyond the UA per month	Average amount paid beyond the UA per month	Largest amount paid beyond the UA per month
No electrification	9	$29.98	$59.18
HVAC electrification	8	$24.74	$40.36
Full electrification	10	$25.64	$51.85

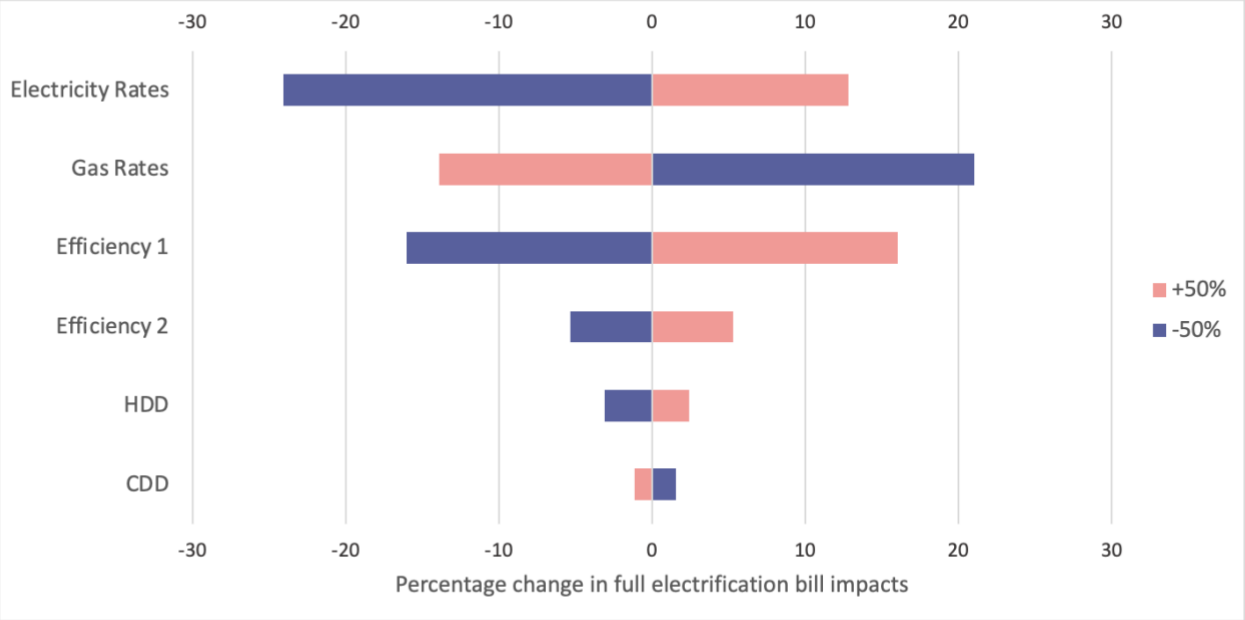
4.3 Sensitivity Analysis

The sensitivity analysis assessed how changes in the rates, equipment efficiency factors and weather variations affect the results for full electrification. Each of these inputs were increased by 50% and then decreased by 50%, and the subsequent percentage changes in the average full electrification bills were recorded.

Sacramento-1

As seen in Fig. 10, the results from Sac-1 were mostly affected by electricity and gas rates. This was expected given prior research on the importance of designing rates favorable to electrification (Borenstein et al. 2021). The gas furnace to heat pump also had a high degree of influence, since the pumps tend to be far more efficient than older gas furnaces. Interestingly, variations of heating and cooling degree days by 50% did not impact the results by more than 5%. This is reassuring given concerns that rising temperatures will impact bills especially in areas that require a lot of cooling like Sacramento.

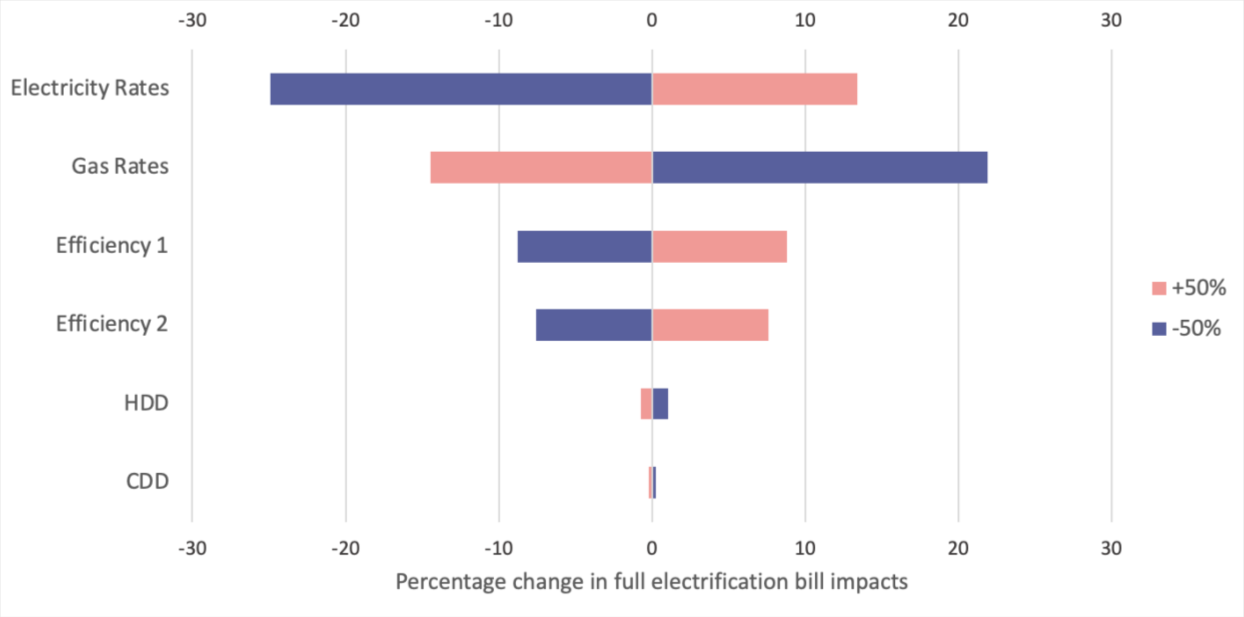
Figure 10: Sensitivity of full electrification bill impacts due to change in inputs for Sac-1



Ukiah-1

A similar order of influence for the inputs is observed for Ukiah-1. The main difference is the second efficiency factor has more of an effect on the results. This is because the remaining gas usage includes gas for water heating.

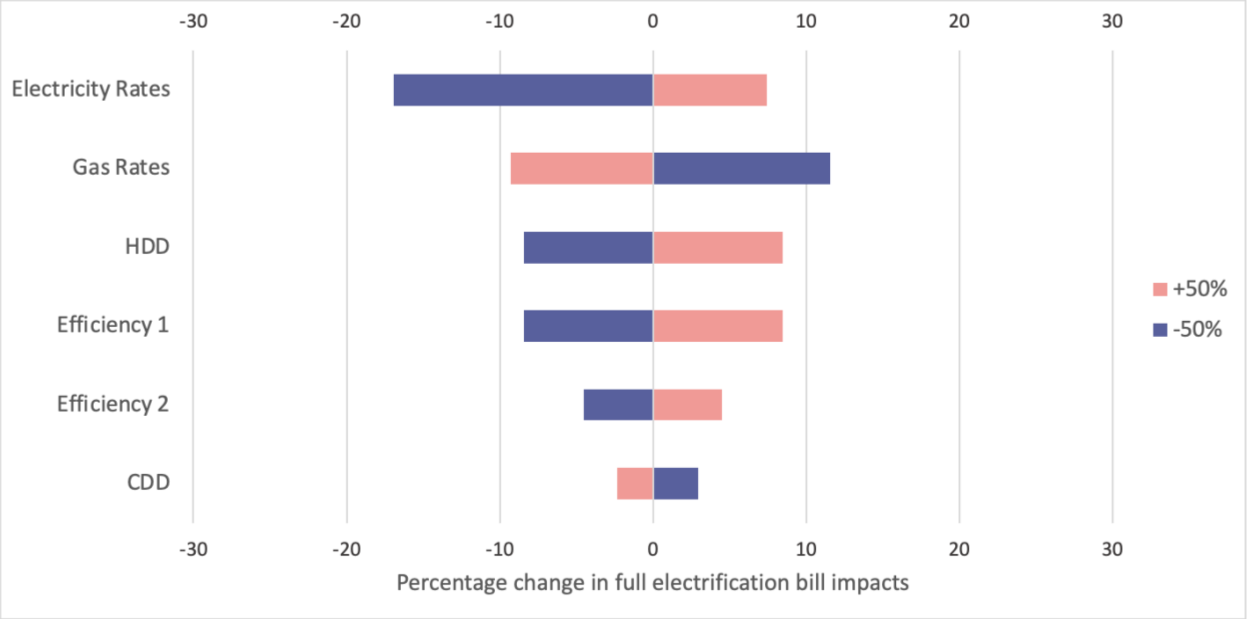
Figure 11: Sensitivity of full electrification bill impacts due to change in inputs for Ukiah-1



Ukiah-2

For the Ukiah-2 property, the results were not as sensitive to electricity and gas rates. The order of influence was also different, with heating degree days having a larger effect than the efficiency factors. On average, Ukiah-2 sample apartments' share of energy consumption on gas was 43%, compared to 60% and 65% for the Sac-1 and Ukiah-1 properties respectively, which could help to explain the differences in sensitivity.

Figure 12: Sensitivity of full electrification bill impacts due to change in inputs for Ukiah-2



5. Discussion

Across the different case study properties, modeling results suggest that HVAC electrification will contribute to a majority of electrification energy savings for most households. For two of the case studies, HVAC electrification is also expected to result in greater bill savings and ability to address difficulties with covering out of pocket utility expenses than full electrification. The main difference between the Ukiah-1 property and the others lies in the gas water heating usage. This implies that full electrification could be more favorable for utility bills if buildings have non-weather dependent gas usage for both water heating and cooking, rather than solely cooking.

The generalizability of results is naturally limited by the small number of case studies examined. The electricity suppliers for the case studies are also not one of the main IOUs in California. Since SMUD and the City of Ukiah have lower electricity rates compared to the IOUs, the bill impacts for similar properties in IOU regions would likely be higher. All the properties are also located in Northern California, where energy used for gas heating is high compared to electricity usage for air conditioning. Case studies of warmer regions in Southern California may not reveal substantial bill changes due to the minimal energy used for heating, although this could be balanced out by efficiency gains from replacing air conditioning with heat pumps for space cooling. For the Ukiah properties, the differences in estimated impacts despite having the same geographical location highlights the need for more project-specific analyses of bill impacts. Utilities are well positioned to further conduct this type of analysis, or at least assist with data dissemination, since they already have resident bill data for submetered households. Any similar analysis conducted by utilities, consultants or researchers would be most meaningful if they work closely with housing owners, who are able to apply the findings to specific households particularly vulnerable to electrification impacts.

The model attempted to account for weather variations year to year, and the rates of individual households. The comparison to actual HVAC electrification bill impacts for Sac-1 points to the need for greater understanding of energy behavior and other factors on electrification bill impacts. The pandemic also could be a significant influence that was not accounted for in the model. These differences between estimated and actual data help to highlight specific factors providers can consider in electrification decision-making.

5.1 Implications for Housing Providers

In terms of minimizing potential bill impacts from electrification, housing providers could look at additional metrics beyond average bill changes to gain a better understanding of impact variation among different households in the same property. Tracking how UAs compare to bills will also help providers decide between new or existing UA methods to balance cost effectiveness and resident impacts. Financially vulnerable households that are already paying out of pocket costs for utilities could be residents with low willingness, means or familiarity to use energy-efficient equipment as intended (Langevin et al. 2013). This information could be used in education and outreach efforts surrounding the electrification retrofit to ensure expected savings are passed on to residents. Education and outreach should also cover all households and not just target those with the highest pre-retrofit energy consumption, since the modeling results indicate even households with fairly low consumption pre-retrofit could face bill increases. Examining energy consumption at a household level can not only help to estimate and help residents prepare for retrofit impacts, it can also lead to more accurate estimation of solar credits and earlier identification of faulty equipment in individual units.

When deciding whether to electrify, housing owners can consider different approaches in terms of which equipment they would electrify first. The case studies suggest that when full electrification includes only HVAC and cooking usage, then full electrification results in less savings and potentially higher bill increases for residents than HVAC only electrification. When there is existing gas water heating, then full electrification (fuel-switching HVAC, water heating and cooking equipment) results in higher savings for most households compared to HVAC only electrification. This implies that when the existing property has both gas space and water heating, then full electrification would provide the most potential for resident bill savings. For properties where water heating is already electrified, then HVAC only electrification would maximize resident savings given the current rates. In such properties, housing providers may want to consider HVAC electrification first, and complete the electrification with cooking equipment retrofits at a later stage when gas rates increase or electricity prices are more favorable, since the results showed the highest sensitivity to these inputs.

Given the large differences in expected and actual savings post-retrofit in Sac-1, if possible solar or battery storage should be considered in addition to any kind of electrification retrofit. This would minimize unexpected impacts due to the unpredictability of energy behavior, as well as other factors like increase in household size and turnover. For properties where solar is not feasible due to available roof space or electrical capacity, providers could consider community solar. Another way to lower bill impacts apart from directly energy-related measures is to incorporate water efficiency measures. These help to reduce water consumption for end uses such as water heating, and can also lower the energy bills associated with that equipment. Such whole-building approaches combining electrification and renewable energy or energy efficiency will help to pass on the benefits of electrification to residents while minimizing impacts (Samarripas and York 2019).

5.2 Policy Implications

The literature review and case studies underscore the tension between ensuring low-income households are included in the energy transition and not left as stranded assets, while not subjecting them to higher bills. Policy therefore needs to incorporate ways to reduce potential bill impacts while still encouraging owners to electrify in the first place. For three main areas of concern this study reveals when it comes to mitigating bill impacts, a relevant policy alternative is identified and discussed in terms of costs and benefits to relevant stakeholders.

5.2.1 Increased Access to Resident Bill Data

The first issue that emerged is the difficulty in obtaining resident bill data at a reasonable granularity to assess potential impacts. Without this data, providers lack adequate information that will help them understand whether and what end uses to electrify (Outcault et al. 2022). This also puts residents at risk of higher bills without targeted education. Data is difficult to obtain due to the need to request permission from each resident, and lack of time and staff capacity on the housing providers' part to collect and analyze it. Currently only certain funding sources require the collection of individual households' bill data to calculate UAs. Beyond assessing potential retrofit impacts, increased accessibility of resident bill data would also help to ensure Utility Allowances adequately cover residents' bills, improving the energy affordability of existing housing overall. HUD, which sets the requirements and guidelines for UA calculation methods, should update their UA policy to require the collection of resident utility bills across all funding sources. Data can then be made available, on request and with permission from residents, to third parties such as researchers, consultants and housing owners interested in using it for electrification analysis.

Residents would mainly benefit through more accurate modeling of bill impacts, Utility Allowances and other calculations that would come from increased access to this data. Increased availability of this data can help with earlier identification of faulty equipment and households at higher risk of energy burden after electrification. One concern would be that providing resident information to owners could potentially risk residents' privacy. Tools such as Share My Data already offer safeguards for this, allowing for residents to give authorization to third parties for viewing their data. The burden of resident outreach to expand the use of such tools currently is still on providers. While these tools have made third party access of utility bill information easier, they require certain security certifications for API communications, and could require additional time and resources to help residents navigate the online account and authorization process ("Welcome to Share My Data N.d.). To avoid burdening individual housing owners with this process, HUD staff could instead collect the data for the main purpose of auditing Utility Allowances for accuracy, and release data to housing owners, consultants, and others for use in applications such as electrification impact analysis. Residents can be asked to indicate on portals such as ShareMyData whether and with whom they would be comfortable sharing their bills. Associated costs of the collection and authorization processes would mainly fall to HUD in that case. Given that data sharing tools already exist, costs would mostly be for increased staffing capacity to work on this data collection and dissemination. HUD also stands to potentially receive cost savings if they can use the data to set more accurate UAs in their own affordable housing stock. This method of data collection foregoes the need for housing providers and other third parties to through utility providers to access data, which can be a time consuming process. The costs of the data collection would not fall to the utilities, while any bill impact or UA comparison studies would help inform their rate making processes.

Collecting the data does not guarantee that anything will be done with it, however there is growing interest in electrification from many providers across California and an increasing number of housing organizations and consultants who are able to perform this kind of impact analysis. Combined with HUD's intention to address UA reform in their climate action plan, increasing resident bill data access in this manner would help these third parties more easily analyze the energy affordability implications of electrification and UA changes.

5.2.2 Rates Favorable to Electrification

The second issue the case studies raise is the large influence of rates on bill impacts, as demonstrated by the sensitivity analysis. Electricity rates are lower and baseline quantities are higher for the utility providers that supply electricity to the case study properties compared to PG&E, indicating higher potential for bill savings after electrification in the case study areas. This points to the need for policy reform addressing California IOUs. Recent CPUC hearings on energy affordability have focused on alternative rate structures like income-based fixed charges. However, less attention has been paid to the issue of baseline quantities, which determine how much energy a customer can use at the lowest price. As mentioned in Section 1.2.3, solar and energy efficiency adoption has increased mostly among wealthier households, and baseline quantities based on the consumption of the average customer have decreased, disproportionately impacting low-income households. To address California IOUs' high electricity rates in a more immediate way that does not involve overhauling rate design, the CPUC should look into expanding baseline allowances for electricity. They have already done so for all-electric customers, who are allowed a 10% greater baseline during winter months. However, they should also focus on increasing the electricity baseline for all customers, since full electrification may not be feasible for all properties due to cost, space constraints, electrical capacity or other barriers.

Increasing this baseline quantity across IOUs would help to lower residents' bills even before electrification. This would not affect customers outside IOU territory, such as residents in the three case study properties, although many are already subject to lower electricity rates compared to IOU customers. Increasing baseline quantities would not involve monetary costs for housing providers. Since this measure would only focus on residential customers, housing owners would not see any direct cost benefit since baselines for commercial rates would remain unchanged. However, decreased resident bills from expanded baselines could reduce concern over lowering UAs in response to electrification retrofits, encouraging more providers to electrify. The CPUC would need to hold further proceedings on baseline quantities to discuss expansion. In previous proceedings, they already noted concern over declining baseline quantities, and have been willing to discuss changes in favor of energy affordability generally as evidenced by the 2022 hearings. The main opposition to this measure would likely come from IOUs themselves, since increasing baseline quantities would reduce bills at a time when average bills have already been declining due to renewable energy and energy efficiency uptake. However, in light of recent discussions around substantial rate reform, this solution may be more palatable to IOUs for addressing energy affordability in the short term.

Rate reform discussion is necessary to ensure low-income energy affordability, but the pace at which changes will be rolled out is not enough to provide relief to residents who need it now. Expanding the electricity baseline for IOU rates could be a faster method for the CPUC to ensure resident bills are decreased, and also that rates are more supportive of electrification efforts in low-income housing.

5.2.3 Leveraging Utility Allowances for Electrification

The third issue highlighted mainly through the review of existing literature is the lack of regulations that help providers overcome cost barriers to electrification in ways other than government-funded programs. With several incentive programs currently running low on funds, lowering UAs has emerged as a viable strategy to recover costs. The case studies revealed electrification, in particular HVAC electrification, could help to decrease the number of residents who need to pay out of pocket costs beyond the UA, and the highest out of pocket cost. Unlike the case study property owners, most housing owners are not required to use residents' actual bills in calculating the allowances, and instead use schedules provided by their local Public Housing Authorities. Previous research has shown that these schedules tend to overestimate residents' energy consumption after efficiency retrofits, since they don't account for newer, more efficient electrification technologies. HUD should require that housing authorities update their schedules to include heat pumps as separate from electric resistance heating, allowing more housing owners to reduce UAs to reflect residents' actual bills after heat pump retrofits.

If the PHA schedule allowance was much higher than a households' actual bills before the retrofit, lowering the UA could reduce any extra savings households were getting out of an inaccurately high UA. However, they would receive other non-monetary benefits of the transition including increased thermal comfort. Owners would benefit most from this rule, as they would be more incentivized to pursue HVAC electrification if they are able recover costs by lowering UAs. The benefit of this measure is less clear for developments where some end uses are master-metered. For example, some owners choose to cover heat pump cooling costs when there was no existing air conditioning usage prior to the retrofit, but residents are less incentivized to use equipment efficiently when they are not paying for it. HUD would need to update existing guidelines to mandate this technology for UA schedules but would not need additional staff capacity to update the schedules since this would fall to the housing authorities. The housing authorities may be opposed to adding this technology due to time or cost associated with calculating the additional allowance and updating the schedules, although they can seek guidance from the housing authorities in California that already include heat pumps in their schedules.

There are already 23 PHAs in California that have added a separate heat pump allowance to their schedule without a HUD mandate. A rule issued by HUD would ensure that heat pump allowances are provided to encourage electrification across all housing authority regions, including those in California. In addition to mandating heat pump allowances in the schedules, equitable UA reform should explore the inclusion of tenant protections with a similar intent as those found in incentive programs like SOMAH and LIWP, to both encourage electrification and mitigate bill impacts.

6. Conclusion

Rather than attempting to determine whether electrification is overall detrimental or beneficial for residents' energy affordability, this case studies research illustrates the variation and nuances of potential impacts. The results show that impacts vary greatly even between households in the same development, between properties in the same city, and between properties with the same fuel type for each end use. These differences underscore the need for more property-specific and household by household analyses of bill impacts. There is also a need to better understand how energy behavior can be incorporated in solutions to address bill impacts. Several studies have taken a mixed methods approach to this issue for energy efficient retrofits already, as described in the literature review. A similar approach with both data analysis and resident interviews, for electrification specifically, would help contribute to a better understanding of how to manage bill impacts. Future work could also examine the impact of projected rate increases on the residents' bills post-electrification, since this was revealed to influence the results the most.

This study relies on a simple model to explore energy bill impacts, which hopefully can be easily adapted and used by housing providers whose time and resources are constrained. Similar case studies on properties in different locations with different demographics would contribute to a greater understanding of electrification impacts and help to reveal under what conditions residents would see bill increases after electrification retrofits.

There are many policy alternatives which can help to mitigate bill impacts, and the three considered draw on the idea that regulations are "low hanging fruit" for increasing the sustainability of affordable housing. During the development of HUD's Climate Action Plan and the CPUC's rate reforms to address affordability, more research on this issue will help to answer how and in what way policy can support electrification and prevent residents from paying high out of pocket costs beyond the UA.

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8. Appendix A

The following tables contain the direct outcomes from the regression used to separate weather-dependent and baseline energy consumption from the raw household energy consumption data. Negative intercept values were assumed to be indicative of negligible baseline consumption in further calculations. Households with an R squared value close to 1 had monthly energy consumption patterns that matched variation in cooling and heating degree days more closely than those with lower R squared values.

Sacramento-1

Household	Electricity			Gas		
	Coefficient	Intercept	R squared	Coefficient	Intercept	R squared
1	0.18738704	2.12623904	0.79365099	0.06312459	-0.1459522	0.95830799
2	0.21404173	5.09147816	0.82582355	0.02474854	-0.0560963	0.88737119
3	0.07766146	1.14271366	0.77239646	0.01863939	-0.0415342	0.84295184
4	0.06220256	1.87471917	0.55379591	0.05011071	-0.1422818	0.86093638
5	0.05058076	1.49711242	0.78812012	0.02130712	-0.0257073	0.91859618
6	0.03790368	1.53922615	0.68598083	0.00068477	0.04932432	0.16073134
7	0.48097793	2.99987396	0.87452027	0.01808202	-0.0114926	0.85301646

8	0.52455011	1.0129041	0.94802664	0.00268829	0.10334705	0.50370923
9	0.21383414	1.06315413	0.94752217	0.02337218	-0.0467083	0.86701065
10	0.15910192	4.22363979	0.63839611	0.00352641	0.07199759	0.59806023
11	0.15910192	4.22363979	0.63839611	0.04743685	0.77190148	0.67676952
12	0.44772412	5.50931981	0.63525177	0.0300344	0.31164691	0.66563671
13	0.28449227	8.32776061	0.36973033	0.01826326	0.04431737	0.77853491
14	0.50367551	3.50769641	0.82376784	0.03954536	0.01044989	0.96232928
15	0.15130641	3.25511237	0.569411	0.01132255	-0.0158998	0.7471841
16	0.44371865	3.59877302	0.4414744	0.02224478	-0.0295288	0.94359958
17	0.27800972	7.14022991	0.74754727	0.05970683	-0.1899862	0.89665662
18	0.21725202	4.29176742	0.81446351	0.07201395	-0.0920499	0.93665061
19	0.21725202	4.29176742	0.81446351	0.06300082	-0.1946363	0.8731889
20	0.35706209	4.5281547	0.75008037	0.04591131	0.03353175	0.90272373

Ukiah-1

	Electricity			Gas		
Household	**Coefficient**	**Intercept**	**R squared**	**Coefficient**	**Intercept**	**R squared**
1	0.17450579	8.3698267	0.24549738	0.05498542	0.72712939	0.82664999
2	0.3816928	4.5198518	0.78520499	0.02487915	0.21725002	0.79918809
3	0.43639668	3.12386759	0.54456257	0.01030001	0.25127034	0.44012039
4	0.28910569	3.59090013	0.71549825	0.03551851	0.0385237	0.86369311
5	0.09731211	1.45903701	0.42398986	0.00915095	0.2869639	0.10491862

6	0.33620506	9.31244526	0.38208154	0.03028705	0.19832976	0.90725727
7	0.06844695	5.41175029	0.09567658	0.0375689	0.11736733	0.89051194
8	0.29185256	5.07686578	0.1806627	0.00660754	0.46276351	0.02227414
9	0.08306866	5.15817479	0.68191546	0.08228256	0.26546515	0.96718693
10	0.33241789	6.38087768	0.66594592	0.00743723	0.30192699	0.28690582
11	0.55642306	7.2478794	0.64014692	0.00265891	0.13944959	0.33221308
12	0.19981866	3.02408281	0.68459161	0.02225315	0.1491175	0.90850392
13	0.40436598	6.28591923	0.52381945	0.04420394	0.30058468	0.97072702
14	0.01333168	10.6317845	0.00578223	0.02138276	0.51667527	0.77873308
15	0.09507358	4.25146561	0.57879677	0.01283306	0.15129347	0.74096976
16	0.0026926	3.95878446	0.00030996	0.02445037	0.09345316	0.78996146
17	0.02110771	7.37453668	0.00783551	0.05033211	0.06708578	0.95000124
18	0.37338297	8.448425	0.43337001	0.0211414	0.27089635	0.21811587
19	0.7009185	7.87505117	0.59683333	0.00970826	0.30979404	0.74373324
20	0.82113495	7.8696831	0.61935645	0.05671795	0.11475049	0.94246763
21	0.1391398	13.3002549	0.31104133	0.02984959	0.26816477	0.89573871
22	0.40986308	5.22698345	0.4445603	0.03724478	0.17969323	0.43829477
23	0.49390518	4.89801462	0.6190149	0.03842125	0.49043991	0.83396294
24	0.98037726	9.1840818	0.63624302	0.07294678	0.27300068	0.94038577
25	0.78245363	10.3569998	0.74974949	0.01419346	0.32880129	0.32574022
26	0.35143763	9.66078551	0.4577709	0.05981586	0.18653279	0.91820601
27	0.01522813	11.5307618	0.00035862	0.04915946	0.05419657	0.72957852
28	0.80605302	7.78939246	0.65093588	0.02516468	0.7444656	0.34111827

29	0.553123	7.18993076	0.71775751	0.03230067	0.14549283	0.88697695
30	0.28951957	11.0408842	0.21073181	0.09351677	0.26592859	0.93874445
31	0.38150746	14.7230555	0.25290104	0.06638336	0.18133123	0.96015929
32	0.54014782	9.94596803	0.49517058	0.02718618	0.20544818	0.76999136
33	0.42337736	12.4357621	0.55460944	0.06227542	0.32802666	0.96712678
34	0.31482779	6.62042007	0.44559234	0.06522178	0.26171129	0.94522848
35	0.50186956	13.3494018	0.79998204	0.03911956	0.61280429	0.79779909
36	0.1007132	15.533794	0.13708666	0.05482153	0.27347572	0.92040865
37	0.09904606	17.4057769	0.0412509	0.12357542	0.5679644	0.95324961
38	0.37866476	15.2006797	0.31717857	0.05788675	0.22380446	0.93395896

Ukiah-2

	Electricity			**Gas**		
Household	**Coefficient**	**Intercept**	**R squared**	**Coefficient**	**Intercept**	**R squared**
1	0.46371985	4.89005816	0.36698099	0.00084694	0.32007408	0.09792461
2	0.2893456	11.6483183	0.49409597	0.03815199	0.13968728	0.86086756
3	0.40259663	15.9020901	0.12674912	0.00531277	0.07163841	0.44926734
4	0.52164128	22.6922664	0.13116316	0.01809509	0.02099391	0.73083699
5	0.21841285	9.63948586	0.30264471	0.08081965	-0.0715795	0.94237527
6	1.00167621	11.9781766	0.57783479	0.02467554	0.03072796	0.66662271
7	0.23694035	11.6894261	0.17249325	0.07508906	-0.2313611	0.92677955
8	0.09832895	11.1633478	0.02030061	0.01155728	-0.0150718	0.72184045

9	0.55101058	17.4266733	0.31526337	0.03468837	-0.0298405	0.82719269
10	0.31364967	12.9825672	0.17494565	0.03655422	0.03630584	0.73066264
11	0.24037042	16.5155807	0.22943923	0.08475012	-0.1256895	0.97748466
12	0.70362474	20.6212085	0.18841075	0.00822054	0.16280476	0.1102774
13	0.45492768	23.3791535	0.28430058	0.02207085	0.18868353	0.87035838
14	0.03934212	6.55836912	0.13723332	0.05205355	-0.0705449	0.88351079
15	0.27258529	4.52395692	0.21325295	0.04073539	-0.0421867	0.86798797
16	0.14147751	21.3698337	0.01127723	0.08053084	-0.2813609	0.86444358
17	0.68653013	12.5058069	0.45297377	0.0300456	0.18249281	0.72979426
18	0.20211673	25.5298852	0.0170648	0.01328238	0.24088753	0.69653915
19	0.48295749	7.48278945	0.30624438	0.08220127	0.1732486	0.87838865
20	0.74593501	13.5974675	0.42948544	0.05406888	0.44810068	0.71806163