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Residential heating electrification in Northern California: locating transitions in infrastructures and institutions

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# Residential heating electrification in Northern California: locating transitions in infrastructures and institutions

by

Salma Elmallah

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Committee in charge:

Professor Charisma Acey, Co-chair

Professor Duncan Callaway, Co-chair

Professor Alastair Iles

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# Abstract

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Professor Charisma Acey, Co-chair

Professor Duncan Callaway, Co-chair

Climate change mitigation policy in California increasingly centers residential heating electrification: the transition from using gas or other combustible fuels to using electricity to heat homes, heat water, and cook. How does the residential heating transition in Northern California interact with physical and institutional networks of electricity and gas provision, home upgrade provision, and planning imperatives and ideals? The first part of this dissertation uses geospatial and statistical analyses of utility, census, and climate data to explore two spatial distributions that will shape the impacts and meanings of residential electrification in Northern California. Chapter 1 assesses the ability of the electric distribution grid – designed for a population that largely uses non-electric fuels, including gas, for heating – to accommodate increasing electric loads due to residential electrification. Chapter 2 investigates the socio-economic distribution of heating and cooling use in the study area to understand the extent to which the services that residential electrification is meant to deliver – space heating and cooling – is, itself, uneven. The second part of this dissertation uses qualitative data, including semi-structured interviews, participant and event observation, and document analysis, to explore the turn to "equitable electrification" as a local climate planning imperative in the Bay Area in Northern California. Chapter 3 studies how concepts of equity are constructed in cities, focusing particularly on how planning relationships – between cities, community-based organizations, and consultants – shape equitable electrification imperatives. Chapter 4 looks at how local actors, particularly those that adopt framings or pledges of equitable electrification, interact with wider structures on which they have seemingly limited authority, focusing on structures of corporate utility energy provision and home retrofit funding. The dissertation concludes with a discussion of how these four chapters, taken together, point to the importance of a broadened understanding of participation and democratization in (equitable) transition, and to the importance of furthering an understanding of energy as a relational system, interdependent with people and places.

To my parents.

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# Acknowledgements

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For most of my PhD, I also worked as a Graduate Student Research Assistant (GSRA) at Lawrence Berkeley National Lab (LBNL). I am grateful particularly to Ben Hoen and Joe Rand, as well as Ryan Wiser and the rest of the Electricity Markets and Policy group, for keeping me employed, training me despite my limited initial experience with electricity markets and policy, supporting my research pursuits, and being thoughtful and reflective research partners. For about 8 months of my time as a GSRA, I split my time between LBNL and the Department of Energy (DOE); at the DOE, I am especially thankful to Tony Reames, Anna Spurlock, and Shalanda Baker for their mentorship and trust.

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# Introduction

> "I think what makes it feel challenging is thinking about how big everything feels. You know, sometimes when I'm just driving around, and I see, like, mobile homes, or low-income housing that's built way back before there were energy efficiency standards in California, I'm just like, holy cow. This is gonna be insane. And what makes me hopeful is when I see people who are just as confused as I am, but we're kind of just doing this. We are here because we care about the health of our families, and we care about the state and the city doing right by our communities." *Oakland-based energy equity advocate*

Climate change mitigation policy in California increasingly centers residential electrification: the transition from using gas or other combustible fuels to using electricity to heat homes, heat water, and cook. In 2019, the City of Berkeley, California became the first US city to ban natural gas in new buildings, followed by over 50 California cities that have since adopted similar policies[1]. In 2022, the California Air Resources Board voted to ban the sale of new gas furnaces and water heaters by 2030. In July 2023, the Governor of California prescribed another 2030 target of 6 million homes with electric space and water heating – nearly half of all homes in California (Building Decarbonization Coalition 2023; Har 2023; S&P Global 2021). These snapshots of California climate mitigation policy in the past five years reflect the growing discursive and policy commitment in California to residential electrification.

Those five years also more or less coincide with the years in which research, analysis, and writing occurred for this dissertation. When I moved to California in 2017, the concept of residential electrification was increasingly commonplace in California climate policy discussions but felt foreign and confusing to me personally: I had moved from a place that was more directly and transparently fossil fuel-dependent than the Bay Area, where mainstream discussions of energy transition hardly extended to uses like heating. Like the interviewee above, I was overwhelmed by the magnitude of the project: what would need to happen to electric infrastructure, to gas infrastructure, to homes of all types – rented, owned, old, new, multi and single family – and would people's abilities to access heating and cooling change? By 2020, early in my PhD, discussions about residential electrification increasingly became discussions about *equitable* residential electrification, both from organizations that had long framed climate mitigation as a question of equity and from institutions that had newly adopted

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[1] Gas bans offer a window into the broader politics, both within and beyond California, of a gas-to-electric building transition: at least 20 US states have prohibited gas bans altogether, precluding cities in those states from adopting all-electric new construction policies, and the City of Berkeley's ordinance was struck down in 2023 by a federal appeals court, though environmental groups might appeal the decision (Har 2023).

this framing. This shifting framing raised a host of other questions, like what does equitable electrification even mean, and on whose terms is equitable electrification defined and enacted?

Policy moments like the ones above – prescribing new electric buildings, new electric appliances, and renewed electric homes – can feel clear and decisive, but these measures are also entangled with much bigger, murkier, and more uncertain institutional and infrastructural contexts. A home – whether heated by gas, electricity, propane, or wood – depends on socially, institutionally, and physically accessible networks of energy provision and structures for home maintenance and upgrades. The form that residential electrification will take – who electrifies and how – will also be shaped by the planning imperatives and forms of knowledge that are prioritized in California's energy policymaking. This dissertation explores these contexts, positioning residential electrification as a transition that shapes – and is shaped by – physical and institutional networks of electricity and gas provision, home upgrade provision, and planning imperatives and ideals.

The first part of this dissertation uses geospatial and statistical analyses of utility, census, and climate data to explore two spatial distributions that will shape the impacts and meanings of residential electrification in Northern California. Chapter 1 assesses the ability of the electric distribution grid – designed for a population that largely uses non-electric fuels, including gas, for heating – to accommodate increasing electric loads due to residential electrification. Chapter 2 investigates the socio-economic distribution of heating and cooling use in the study area to understand the extent to which the services that residential electrification is meant to deliver – space heating and cooling – is, itself, uneven.

The second part of this dissertation uses qualitative data, including semi-structured interviews, participant and event observation, and document analysis, to explore the turn to "equitable electrification" as a local climate planning imperative in the Bay Area in Northern California. Chapter 3 studies how concepts of equity are constructed in cities, focusing particularly on how planning relationships – between cities, community-based organizations, and consultants – shape equitable electrification imperatives. Chapter 4 looks at how local actors, particularly those that adopt framings or pledges of equitable electrification, interact with wider structures on which they have seemingly limited authority, focusing on structures of corporate utility energy provision and home retrofit funding.

Together, the two parts of this dissertation combine quantitative and qualitative data and methods to further an understanding of residential electrification – and, more broadly, decarbonization and climate mitigation transitions – as co-constitutive with their infrastructural and institutional contexts.

# Chapter 1 | Residential electrification and distribution grid limits

## Introduction

Transitioning from direct fossil fuel combustion to using electricity to meet energy needs is a pillar of many climate change mitigation strategies. Electrifying residential space and water heating, which makes up about 10% of greenhouse gas (GHG) emissions from the U.S. energy sector, is key to meeting climate goals nation-wide and in individual states (Deason et al. 2018). Electric heating is increasingly prevalent in California, having doubled over the last 10 years in cooler regions of the state (DNV GL 2020; Kema, Inc. 2010).

Residential electrification - replacing gas-burning appliances with electric space and water heating appliances - necessitates multiple infrastructure transitions. These transitions, which include preparing electric infrastructure for increased demand while phasing out gas infrastructure, are shaped by workforce transition and supply chain dynamics, concerns about financing, affordability and access to technologies; and questions of how quickly infrastructure can be deployed (Building Decarbonization Coalition 2019; Emerald Cities Collaborative 2020; Greenlining Institute 2019; National Renewable Energy Lab 2021).

Because electrification may change the timing or geography of electricity use, its impact on the electricity grid is particularly important to understand. As Figure 1 shows, the electricity grid can be partitioned into generation, transmission, and distribution components. Electrification has implications for each: for instance, investments in electricity generation and the expansion of long-distance transmission infrastructure will be needed to serve new loads (National Renewable Energy Lab 2021; Waite and Modi 2020). The distribution grid, or the periphery of the grid located closest to customers, has received less attention than generation and transmission, in part due to the difficulty of capturing the uniqueness of each individual circuit (Murphy et al. 2021:25). In this paper, we take a spatially and temporally resolved approach to understanding how residential electrification might impact the distribution grid. Our spatial units of analysis are distribution feeders, which are electric circuits that extend from a distribution substation and deliver electricity to end users. One feeder is composed of multiple line segments and includes the conductors themselves along with equipment such as transformers, voltage regulators, and monitoring devices (PG&E 2017).

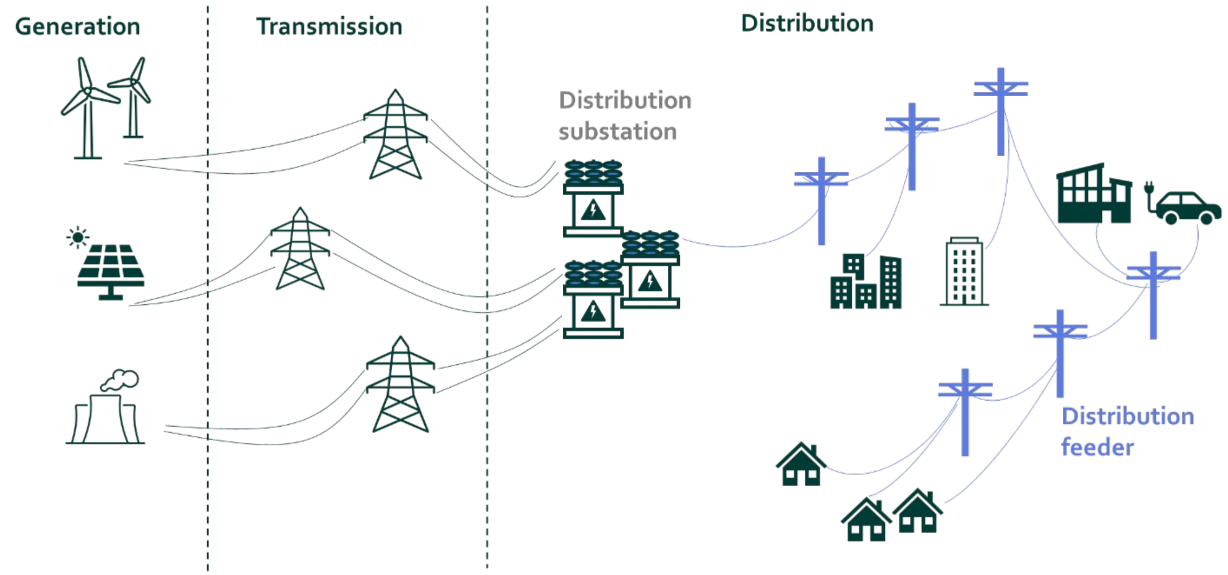

Figure 1 Simplified diagram showing the main components of the electric grid, highlighting distribution feeders (the unit of infrastructure on which this paper focuses); figure adapted from (Pacific Gas & Electric 2015; US EPA 2015).

Specifically, we address the following question: in what ways will utilities need to upgrade the electric distribution grid to accommodate electrified loads, and what will those upgrades cost? We focus our study on light-duty transportation and residential electrification in the Pacific Gas & Electric (PG&E) service area in Northern California. We choose PG&E both because California has aggressive decarbonization goals and policies to support electrification, and because rich data on PG&E's distribution infrastructure are available. We use these data, which include a range of spatio-temporally explicit characterizations of energy consumption and distribution system capacity, to assess the extent to which distribution grid infrastructure within PG&E's utility territory can serve projected electricity needs. We provide a spatially and temporally explicit and system-specific analysis of the potential changes in electricity usage in PG&E's utility territory due to electrification. We compare these load shape changes to available distribution grid capacity. Where that capacity falls short of the estimated need, we report the amount by which distribution infrastructure needs to be expanded, including the potential cost of those expansions and the number of distinct upgrade projects that will need to be performed.

In what follows, we review the scholarship on grid upgrades related to electrification (Residential electrification and the distribution grid), discuss the policy context in our study area (Electrification in Northern California) describe our data and modeling approach (Methods), present and discuss the results (Results and discussion) and conclude by discussing the implications of our results for electrification transitions in Northern California (Conclusion).

## Residential electrification and the distribution grid

There is a growing body of work characterizing grid-related impacts from electrification, including impacts on grid operations (Blonsky et al. 2019), interconnection practices and standards (Das et al. 2020), and power generation and transmission (Murphy et al. 2021; Waite and Modi 2020). Blonsky et al. (2019) divide the distribution grid impacts of electrification into operations impacts (for instance, voltage regulation violations) and planning impacts (for instance, increasing the capacity of distribution lines). Researchers have studied the former by using local distribution feeder models, finding that heat pumps may contribute to voltage violation issues, and by proposing voltage control strategies (Al-Awami et al. 2016; Mufaris and Baba 2013; Protopapadaki and Saelens 2017). For the latter issue of grid planning, however, existing studies on electrification-driven distribution grid upgrade needs are generally spatially and temporally coarse. For example, studies of impacts in California project that residential electrification may shift peak demand from the summer to the winter (Hopkins, Asa S. et al. 2018; Mahone et al. 2019), potentially leading to fuller utilization of California's electric distribution grid infrastructure year-round (Mahone et al. 2019). Yet these analyses do not estimate the specific type and magnitude of upgrades needed.

Because home heating will create demands for electricity that vary spatially and temporally, estimating distribution grid impacts due to electrification requires spatially and temporally explicit models of electricity consumption. The characteristics of distribution grid infrastructure also vary spatially: research on distribution grid substations (Allen et al. 2016; Burillo et al. 2018; Sathaye et al. 2013) has identified correlations with geography and demographics, including the vulnerability of substations to climate change (Burillo et al. 2018) and the ability of distribution circuits to accommodate distributed energy resources (Brockway, Conde, and Callaway 2021). Investigating the distribution grid impacts of electrification in a spatially and temporally coarse manner, then, is insufficient given the importance of the timing and location of new electric loads as well as the timing and location of the distribution grid's ability to serve them.

We are aware of four studies that use distribution model outputs to provide spatially explicit estimates of distribution grid upgrade needs due to electrification. Two of these studies simulate distribution grids directly to identify available capacity. First, using building models and assumptions on EV penetration and charger locations, Gupta et al. (2021) investigated how photovoltaic, heat pump, and EV deployment impact distribution grid reinforcement needs in Switzerland. This study used representative distribution feeder models from three municipalities to extrapolate grid upgrade needs for the entirety of Switzerland and found grid upgrade needs could total as much as 11 billion Swiss Francs. Second, in a project conducted by the Electric Power Research Institute (EPRI) (2022) for the municipal utility Seattle City Light (SCL), researchers assessed the distribution grid impacts of building, transportation, and industrial decarbonization. They found that, without load flexibility, SCL's distribution grid would need about 2 GW of upgrades, or nearly a doubling of its existing capacity. However, the study also found that nearly every circuit has sufficient capacity to meet daily *energy* needs, suggesting that with aggressive load flexibility nearly all grid upgrades could be avoided.

Two other prior studies focus on PG&E's distribution grid and use publicly available Integration Capacity Analysis (ICA) data from California investor-owned utilities, which we describe in more detail in the Methods section. First, Brockway et al. (2021) found wide variation in per-household grid capacity for new load in PG&E and Southern California Edison

(SCE) territory, and estimate that roughly 50 and 20% of households served by PG&E and SCE respectively are connected to circuits that can support more than 3 kW growth in peak demand per customer[2]. However, they did not study the location-specific nature and timing of new load shapes. Second, focusing on EV impacts, Jenn & Highleyman (2022) studied upgrade needs for a 2030 scenario with 6 million statewide EVs. Using the Grid Needs Assessment data - a data set similar to the ICA, generated to evaluate near term upgrade needs rather than hosting capacity for new loads - along with EV charging profiles constructed from real EV charging sessions to study distribution capacity needs, they concluded that 443 of PG&E's feeders showed deficiencies that would likely require capacity upgrade projects by 2030.

Our paper aims to refine and expand on the methods of these prior studies by examining spatially resolved load shapes for residential electrification and by examining estimates of higher electrification rates associated with longer term decarbonization goals.

## Electrification in Northern California

Our study is based in the PG&E service area in Northern California. PG&E is a combined natural gas and electricity investor-owned utility (IOU) in Northern California, with over 4 million natural gas and electricity customer accounts (Pacific Gas & Electric 2015). The market share of electric heating technologies is poised to grow further in the study area due to ongoing investments and regulations. To date, building electrification has been pursued through incentives, building code amendments (CARB n.d.), and municipal gas phaseouts (Gough 2021); state-level investment in building electrification is expected to total $1 billion over the next two years (Velez and Borgeson 2022).

Northern California's shifting regulatory and planning context also provides an opportunity to investigate the distribution grid impacts of electrification. While a lack of data has posed a barrier to detailed analyses of the distribution grid, IOUs in California are now required to provide detailed, publicly-available data on distribution infrastructure, including the ability of distribution lines and substations to accommodate new loads, in their ICA maps (CPUC 2021b). These data are published to enable project developers to identify parts of the distribution grid where new resources can likely be sited without additional grid upgrades. However, because these data are public, they also provide an opportunity for researchers to assess not merely the potential of an individual project, but also utility-scale capacity for new loads. We discuss these data in more detail in the section Calculating distribution circuit upgrade requirements and costs. Changes in regulation also extend to considerations of electrification in grid planning. In California, electrification projections are just beginning to be incorporated into the state's electricity planning processes (CEC 2021; CPUC 2021a) with respect to both systematic

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[2] This is roughly equal to the combined power draw from level 1 EV charging and space heating via an electric heat pump, but significantly less than the approximately 7 kW needed to support level 2 EV charging (Brockway, Conde, and Callaway 2021).

assessments of upgrade needs (CEC 2021; PG&E 2021b) and upgrades undertaken through geographically targeted pilot projects (CPUC n.d.; Southern California Edison n.d.).

# Methods

This study investigates if and where the capacity of electric distribution networks might be exceeded by residential electrification. We simulate a range of scenarios representing diversity in electric heating adoption rates. For each scenario, we found the difference between the projected demand increase due to residential heating electrification and the current hosting capacity limits of the distribution system. We additionally used utility filings to determine the cost of potential upgrades and compare upgrade needs to current upgrade practices. This section summarizes the datasets and modeling approach, and points to more detailed information in the appendices when needed.

Our approach is summarized in Figure 2. We constructed spatially and temporally granular estimates of electricity demand due to residential electrification with a combination of gas usage data, simulated load shapes, population density and distribution feeder locations. We then combined these load shapes in a variety of scenarios to explore the implications of different electrification timelines and spatial distributions. Then, using the ICA data, we evaluated if and by how much distribution circuit and substation capacities could be exceeded; we examined a range of scenarios to capture uncertainty in ICA capacity numbers.

The data sources used to determine distribution circuit upgrade needs are summarized in Table 1. We conclude this section with a description of our approach to estimating upgrade costs.

Table 1 Data sources, descriptions, and spatial and temporal resolutions for data used to calculate distribution circuit and substation upgrade needs

| Dataset | Spatial resolution | Temporal resolution | Description | Source |
|---|---|---|---|---|
| Gas usage | ZIP codes | Monthly | Residential customer gas usage data (total therms) from January - December 2019 for ZIP codes that intersect with PG&E's gas and electricity service area | (Pacific Gas & Electric n.d.-b) |
| Space and water heating load shapes | 10 simulated locations in CA | Hourly | Load shapes for a one-year period, disaggregated by end use, created by the U.S. Department of Energy (DOE) from building simulations as well as surveyed residential energy usage data; last updated in 2013. | (Department of Energy n.d.) |
| Population density | 100 m grid cells, upsampled | n/a | 2020 California population density estimates, constructed from census | (Depsky, Cushing, and |

|  |  |  |  |  |
|---|---|---|---|---|
|  | to 10m x 10m resolution |  | data, tax parcel boundaries, and building footprint data. | Morello-Frosch 2022) |
| Heating appliance efficiencies | CA | n/a | Median, 5th, and 95th percentiles of efficiencies, energy factors, and coefficients of performance (COPs) of appliances certified by the California Energy Commission (CEC) for both gas and electric space and water heating. | (CEC n.d.) |
| Projected heating penetration | CA | Annual | Reference, medium, and high heating electrification scenarios from the National Renewable Energy Laboratory's Electrification Futures Study; calculated demand growth to 2030, 2040, and 2050. | (Mai et al. 2018) |
| Distribution circuit locations | Distribution circuit | n/a | Location of individual distribution circuits. | (Pacific Gas & Electric 2020b) |
| Distribution line segment integration capacity limit | Distribution line segment | Month-hourly | The additional demand (MW) that can be connected to a line segment without any thermal or voltage violations. | (Pacific Gas & Electric 2020b) |

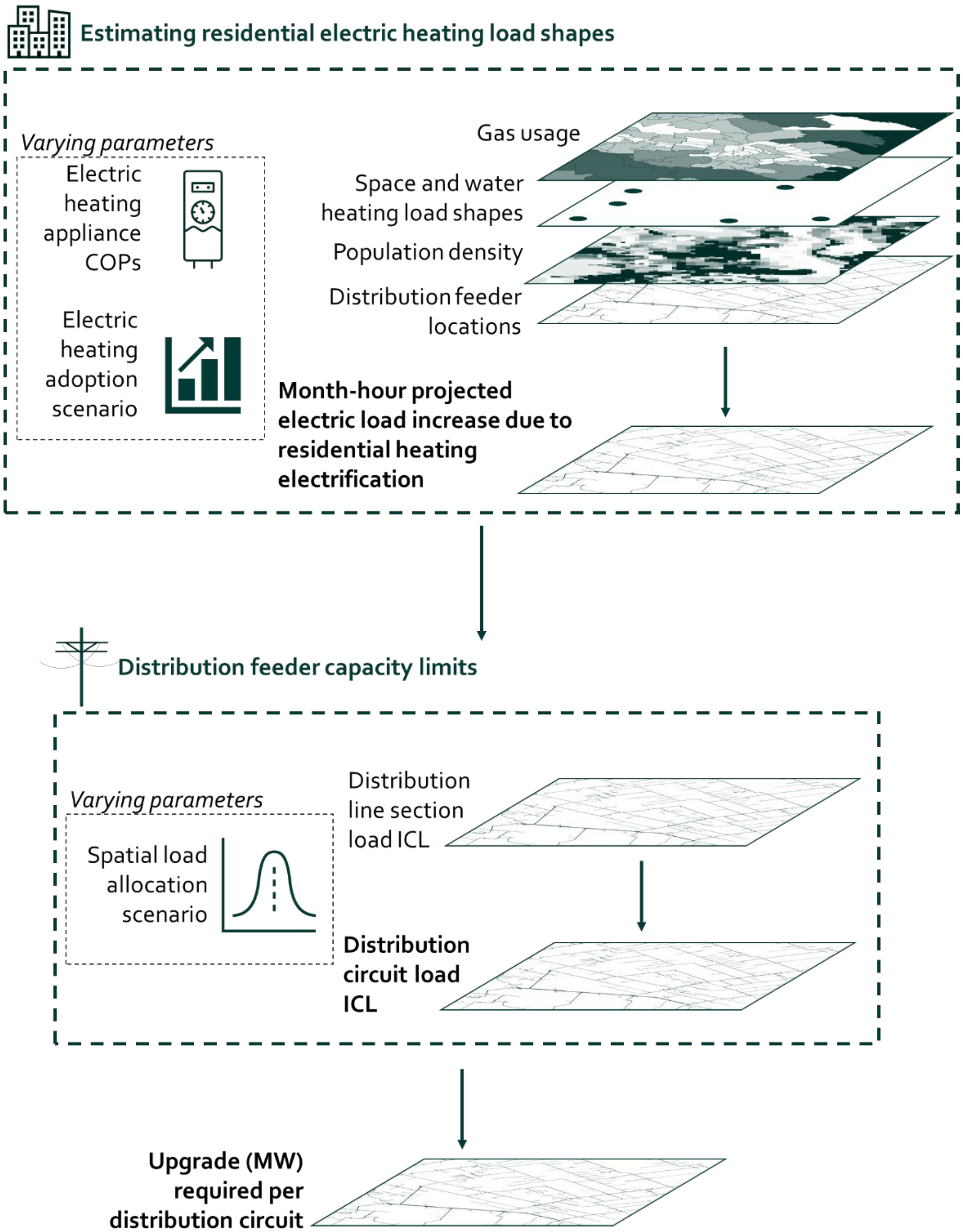

Figure 2 High-level overview of datasets and process used to calculate distribution circuit upgrade needs.

## Estimating residential heating load shapes

The load shapes we constructed for electrified residential loads were spatially aggregated to the distribution circuit-level and computed with month-hourly resolution. A month-hourly temporal resolution refers to the 288 unique combinations of months and hours in a year (e.g., January at 3 PM). We chose these spatial and temporal resolutions to facilitate comparison to the ICA data, which we describe below.

To estimate load shapes for residential electrification, we used a combination of (i) residential gas usage data reported by PG&E to understand the spatial resolution of current non-electrified residential energy demands for heating within the study area, (ii) space and water heating load shapes (the hourly usage of energy) to understand how heating needs are distributed temporally, (iii) a population density grid upsampled to a 10 m x 10 m resolution to allocate heating demands to circuits, and (iv) location data for distribution circuits. This process is similar to earlier efforts to allocate EV charging demand to circuits based on population density (Hecht et al. 2020).

We assumed that all the gas used by residential customers follows the load shapes of space and water heating. This assumption is supported both by the relative share of gas usage and appliance saturation for space and water heating versus other end uses, and by prior findings on the load shapes of other major end uses, including cooking, which find that peak energy usage for cooking is coincident with water heating. We discuss the data behind this assumption further in the appendix (Gas end uses beyond space and water heating).

We layered the ZIP codes on the gridded population data. Where ZIP codes spanned more than one grid cell, we assumed that gas usage within a ZIP code was distributed proportionally to the 10 m x 10 m gridded population within that ZIP code. To obtain month-hour estimates of electricity load shapes due to electrification, space and water heating load shapes were first normalized over each month, and then combined with monthly gas usage data and appliance specifications (see appendix: Using OpenEI load shapes to construct an estimate of electricity load shapes for details). We utilized median efficiency and energy factor values (for gas appliances) as well as median COP values (electric appliances) specified in the appendix (Space and water heating equipment efficiencies). This process yielded a month-hour electricity load shape for each grid cell; to obtain results at a circuit level, each grid cell was assigned to the nearest circuit, and the demand was summed across each circuit (see appendix:

Reconciling spatial representations for details).

This process allowed us to identify the projected increase in electricity use per circuit and month-hour if all residential electricity use for heating is electrified, but residential electrification will not happen all at once: technology uptake depends on costs, appliance turnover rates, market readiness, and consumer willingness to electrify. To estimate possible rates of electrification we used scenarios from the National Renewable Energy Laboratory's Electrification Futures Study (Mai et al. 2018). Focusing on the reference, medium, and high cases, we applied the projected percentage changes in electricity demand under those scenarios to the total expected new demand under full electrification to estimate new circuit-level demand in 2030, 2040, and 2050 (appendix Residential electrification scenarios describes these cases in more detail). We multiply the total new load by circuit due to residential electrification by these percentages to calculate the estimated new loads in each year of our analysis.

Effectively, this approach can be interpreted as assuming that, for example, under the Reference scenario in 2040, 13% of residential households with gas heating in PG&E's territory electrify their space and water heating. Table 2 shows the percentage change in electric heating adoption for each year and scenario, while Figure 3 shows the resulting modeled demand for electricity for residential electrification for each year and scenario.

Table 2 Calculated percentage change from 2021 in electricity usage for residential space and water heating in California, from (Mai et al. 2018)

| Scenario | 2030 (%) | 2040 (%) | 2050 (%) |
|---|---|---|---|
| Reference | 3.68 | 13.0 | 17.5 |
| Medium | 7.92 | 21.2 | 33.2 |
| High | 10.8 | 35.4 | 43.5 |

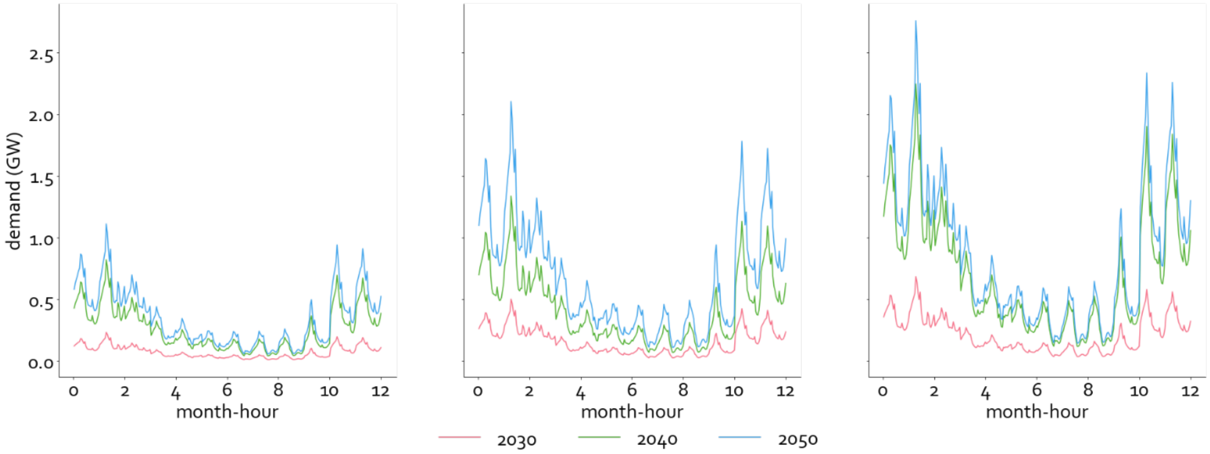

Figure 3 Projected load shapes for residential electrification, for which magnitudes vary based on yearly adoption projection, residential electrification scenario, and temporally

We recognize that warmer temperatures due to climate change might (a) reduce the need for electric heating and (b) increase the use of heat pumps for space cooling. While we do not, in this paper, aim to construct possible load shapes for different warming scenarios, we do use historical and projected temperature data to identify where in the study area we may see impacts on electricity demand and, in turn, upgrade needs due to warming temperatures. Our process is described in the appendix (Considering the impacts of warming temperatures on heat pump energy usage).

## Calculating distribution circuit upgrade requirements and costs

PG&E's Integration Capacity Analysis (ICA) data set (Pacific Gas & Electric 2020b) was generated for project developers to understand what parts of the distribution grid are likely to be suitable for new electricity loads and generation sources. We use this data to obtain the locations of distribution circuits and the capacity limit in MW, which refers to the ability of distribution circuits to host additional demand without upgrades at each month-hour. Here we describe the ICA data and our approach to using it, including our method for addressing uncertainty in the limits provided by the data.

To produce ICA data, PG&E divides each of the 3043 feeders on its system into hundreds to thousands of individual segments. PG&E computes segment-level load limits by running power flow studies on distribution feeder models: after adding existing hourly loading taken from customer meter data along the length of each feeder, PG&E adjusts the simulation to incrementally raise the load on the segment in question until a voltage or thermal limit is exceeded[3] in the simulation (PG&E 2022). PG&E reports the maximum amount by which they incrementally increased load before exceeding a limit on a given segment as that segment's voltage or thermal load limit. In our study, we treated the minimum of the two limits at a given hour as the overall hosting capacity for new load on that segment in that hour.

Importantly, the ICA data provide maximum allowable demand per segment under the assumption that no additional demand appears on any other segment. Yet in high electrification scenarios, most segments will host new electricity loads, though there is uncertainty regarding where on a segment residential gas loads may be electrified. To manage this uncertainty, we observed that segments nearest to the head of a feeder will have the most capacity for new load (because voltage drops along the length of a feeder, and feeders are sized with the largest conductors nearest to the feeder head), and conversely the segments nearest to the end of a feeder will have the least capacity for new demand. Therefore, we assumed that the maximum and minimum reported feeder segment load limits are upper and lower bounds, respectively, to the capacity an entire feeder could host when load is distributed along its length. We further assumed that, because all new loads are unlikely to be concentrated on a single segment, these bounds are wider than likely hosting capacity limits. We therefore report our results at the 90th, 50th, and 10th percentiles of the segment hosting capacities within each circuit. To calculate circuit capacity upgrade needs, we subtracted the remaining capacity on each circuit from the new load estimated in our electrification scenarios at each month-hour, and we found the maximum difference to evaluate the greatest need across the year, recording negative differences as zero (i.e., no upgrade need). To obtain PG&E-wide upgrade needs in different scenarios, we summed the need across all circuits, following the process described in detail in Elmallah, Brockway, & Callaway (2022).

We also used data from PG&E's DDOR (PG&E 2021a) to estimate the cost of performing circuit and substation upgrades to mitigate identified needs. This data contains estimates of grid needs and the investments needed to address them. Using the process described in Elmallah, Brockway, & Callaway (2022), we calculated estimates of upgrade costs in $/kW based on the size (MW) of upgrade needed as shown in Table 3.

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[3] Exceeding a voltage limit implies the simulation records an out of range voltage somewhere on the circuit; PG&E currently uses a lower limit of 118V. Exceeding a thermal limit implies any piece of equipment is predicted to experience a power flow amount in excess of its rated capacity.

Table 3 Circuit upgrade costs from PG&E's DDOR for planned distribution grid investments, as compiled in Elmallah, Brockway, & Callaway (2022)

| Grid need (MW) | Circuit upgrade costs ($/kW) | | |
|---|---|---|---|
| | 25th percentile | Median | 75th percentile |
| <1 | 445.71 | 1,875.00 | 9,935.00 |
| ≥ 1 and < 2 | 351.84 | 1,368.89 | 2,092.89 |
| ≥ 2 and < 4 | 196.76 | 673.35 | 1,447.55 |
| ≥ 4 and < 8 | 268.65 | 438.14 | 785.30 |
| ≥ 8 | 237.24 | 367.85 | 586.32 |

# Results and discussion

For each electrification scenario, we report grid upgrade needs for PG&E's distribution circuits in gigawatts (GW), the number of circuits requiring upgrades, and estimated upgrade costs using PG&E's reported per-kW project costs. Our results are summarized in Figure 4.

Our estimations of distribution circuit and substation upgrade needs vary based on a number of assumptions and parameters. In reporting results, we show the variation of results based on scenarios outlined in Table 2 for each yearly adoption projection as well as based on spatial load allocation scenarios.

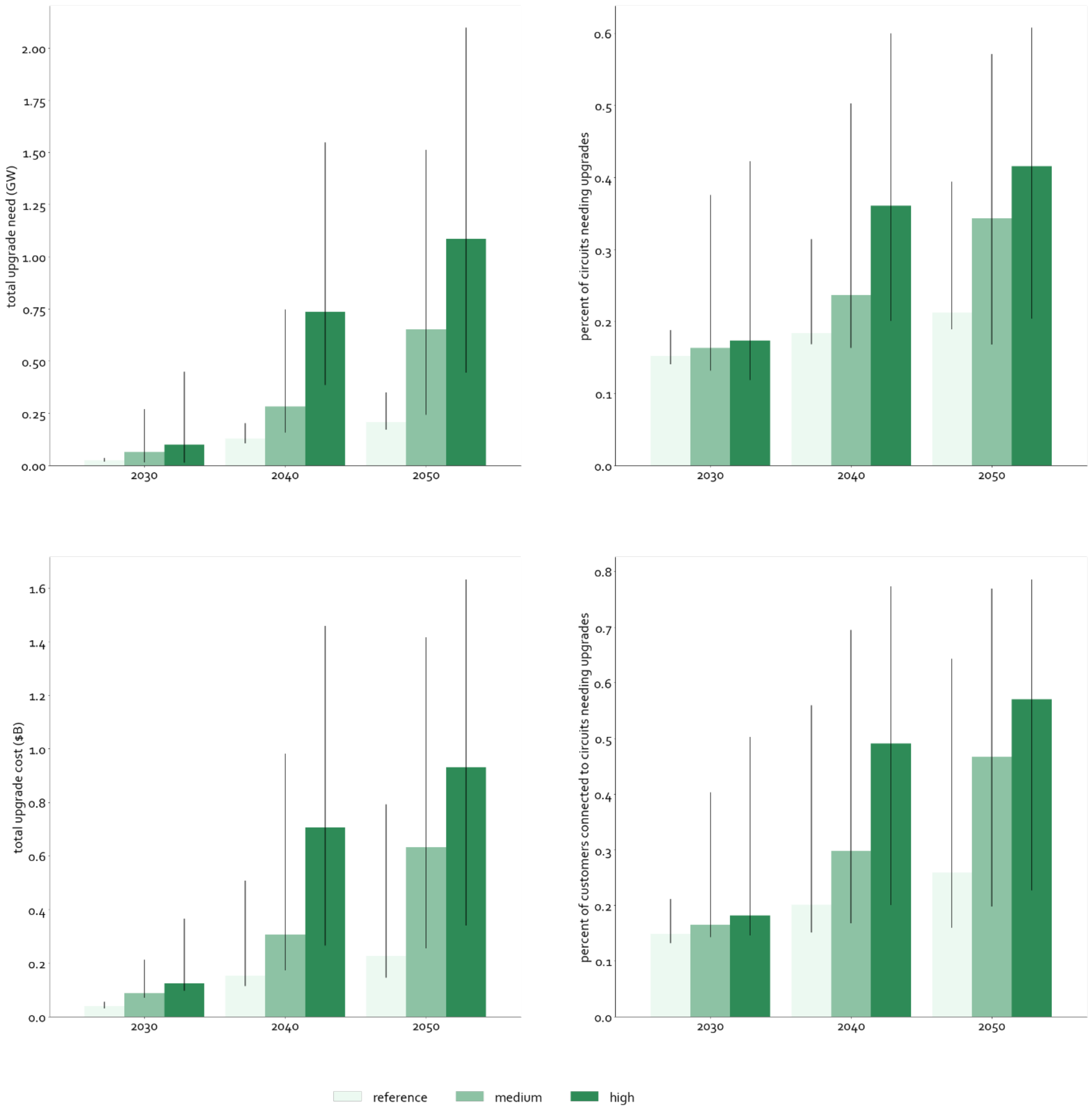

Figure 4 Upgrade needs for PG&E distribution circuits. There are 3043 circuits in total. Results capture the potential uncertainty of where new load might connect within a circuit: column heights depict the median load allocation scenario, and the lower and upper error bars indicate the 90th and 10th percentiles, respectively.

Total GW upgrade needs increase in time for each electrification scenario considered across all metrics evaluated, and upgrade needs for residential electrification are lower than other potential electrified technologies like electric vehicles (Elmallah et al. 2022). We find that circuits needing upgrades serve a large portion of the PG&E service area – in the high case in 2050, for instance, 20 to 60% of circuits require upgrades, to which 20 to 80% of PG&E's residential customers are connected. As with capacity needs, the number of circuits whose capacity is exceeded due to electrification also increases in time, as more customers electrify. The near-term upgrade needs in terms of number of circuits requiring upgrades does not vary significantly with electrification scenarios: that is, in reference, medium, and high scenarios, just above 15% of circuits will consistently require upgrades, indicating that many circuits are currently very near their load integration limits. Still, we see wide uncertainty – for instance, in the reference case, the upper bound on the percent of circuits requiring upgrades is under 20%, but in the high case, over 40% of circuits may require upgrades.

We also observe regional variation in GW of capacity upgrades, with the highest need in counties within the more densely populated 9-county San Francisco Bay Area as well as within Fresno County, as shown in Figure 5, which maps total needs by county in a 2050 high residential electrification adoption scenario.

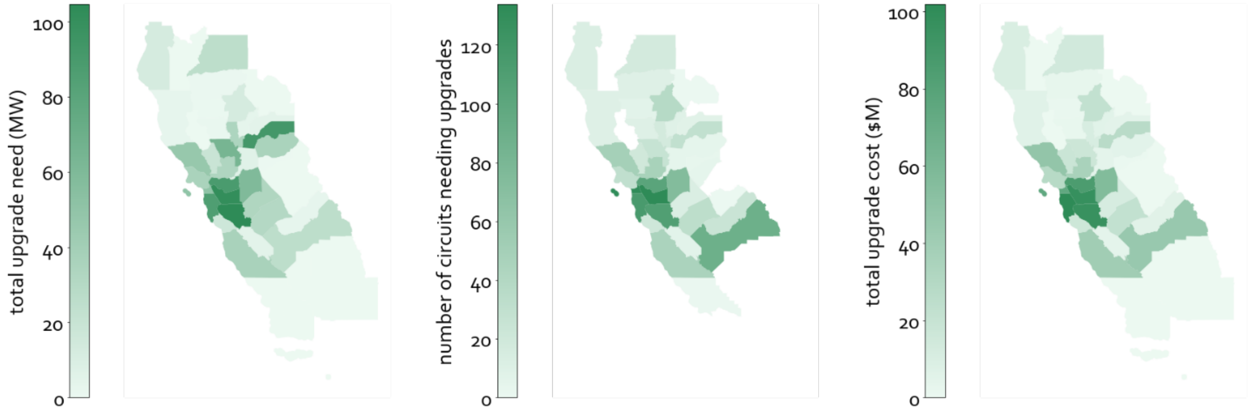

Figure 5 From left to right, county-level sum of circuit MW upgrade need, number of circuits requiring upgrades, and upgrade cost in millions of dollars. Results are shown for the year 2050 for the high residential electrification scenario, using the median load allocation scenario.

## Pace of upgrades

These results prompt us to consider the magnitude of this work effort relative to PG&E's existing pace of upgrades. To better visualize the pace of needed upgrades, we plot the number of circuits needing upgrades per year for each time period of analysis (Figure 6) assuming two potential approaches to upgrading circuits: a gradual approach, where the utility upgrades circuits just enough to meet demand within each time period, and a proactive approach, where the utility begins upgrading circuits now in anticipation of future load by 2050. We find that, with both a gradual and proactive approach, near-term upgrade needs, using a median load allocation scenario, are about 50 circuits per year. However, the gradual and proactive approaches significantly differ in later years: a gradual upgrade approach would necessitate up to 125 circuit upgrades per year (using a median load allocation) from 2040-2050, but a proactive approach would keep the number of circuit upgrades needed around or less than 50 in the same time period. To put these numbers in context, in their 2021 DDOR report, PG\&E estimated needing to complete approximately 56, 87, and 53 feeder and line section upgrades in 2021, 2022, and 2023, respectively (PG&E 2021a).

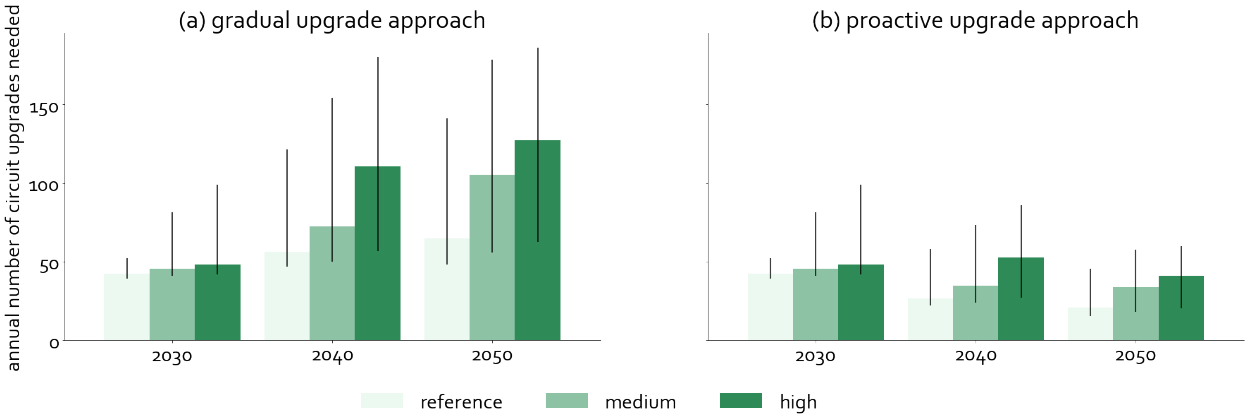

Figure 6 Circuit upgrades needed per year with a (a) gradual upgrade approach, calculated by dividing the number of circuits needing upgrades within each time period by the years between time periods[4], and a (b) proactive upgrade approach, calculated by dividing the total number of circuits requiring upgrades within each time period by the target year – 2019. Results capture the potential uncertainty of where new load might connect within a circuit: column heights depict the median load allocation scenario, and the lower and upper error bars indicate the 90th and 10th percentiles, respectively.

With a gradual upgrade approach, our projections for the number of annual circuit upgrades needed are higher, and significantly higher at the top end of our range of estimates, than PG&E's expected pace of upgrades, suggesting the importance of planning ahead for increased electrification. However, we also note that our estimates have a broad range: at the low end of the range, the impacts to PG&E's distribution system may be manageable within their typical three-to-five-year planning cycle, and at the top end of the range PG&E would likely have a very large backlog of projects.

The need for accelerated upgrades raises questions about supply chains and labor in the electric distribution sector. Successfully performing distribution upgrades requires having access to equipment (e.g., transformers, circuit breakers, cables, switches) as well as the staff to plan and implement these investments. Nationwide, electric utilities are increasing their investments in transmission and distribution infrastructure (Aniti 2021). These efforts have already been hampered both by the availability of equipment and trained workers.

In particular, supply chain shortages and service delays have made it more difficult for utilities to obtain the equipment they need (Loeff 2022), impeding progress on grid modernization and decarbonization efforts (Thomson and Motyka 2021). Moreover, energy sector labor shortages created challenges for electric utilities even before the pandemic (Maize 2018). These results point to the importance of demand-side workforce policies like apprenticeship programs in facilitating electrification and climate goals. Assessments of labor practices in the energy sector

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[4] For instance, to get 2030 values, we take the number of circuits needing upgrades based on 2030 demand values and divide it by 11 (2030-2019). To get 2040 values, we take the number of additional circuit upgrades needed between 2030 and 2040 (i.e. the number of circuits where upgrades performed by to meet 2030 demand are insufficient to meet 2040 demand) and divide by 10 (2040-2030).

in California point to the Los Angeles Department of Water and Power (LADWP)'s Utility Pre-Craft Training Program, for instance, as a model to train entry-level workers for utility careers, including careers as line workers (Zabin et al. 2020). The variation in upgrade needs by geography, as shown in Figure 5, indicates that in some regions, municipal and county governments and local labor and environmental organizations may have an added role to play in facilitating workforce policies alongside state and utility actors.

The pre-existing and separate trends in utility equipment supply chains and labor already pose risks for grid investments even in the absence of a significant ramp-up of circuit upgrades, suggesting that we may observe increasing bottlenecks, longer timelines, and higher costs for grid modernization efforts. However, our results also suggest that widespread heating electrification presents an opportunity for added investment in demand-side workforce programs.

## Cost of upgrades

Figure 4 shows that upgrade costs increase roughly in proportion to capacity upgrade needs, and that the total investment requirements total up to about 1.6 billion dollars. In this section we explore these costs in more detail. To further evaluate the potential cost impacts, we consider how investment needs might change under both lower and higher cost scenarios and annualize these costs to consider how much PG&E might need to spend per year to perform these grid upgrades. Specifically, we compare the result of using the median reported values for circuit feeder costs to the 25th and 75th percentiles of the costs of PG&E's planned investments. These results are shown in Figure 7.

We note again that these cost estimates are based on utility-projected near-term costs, and they are intended to give only a plausible range. Further, the appropriate percentiles of costs (or alternative values) to use in this analysis merit further investigation. Relative to near-term estimates, actual future costs could fall as more technologies are scaled and deployed, but they could also rise due to bottlenecks, including equipment and staff shortages, as utilities seek to prepare their grids for demand growth due to electrification. While both impacts are plausible, we posit that the magnitude of needed investments alongside the other bottleneck trends discussed above are more likely to lead to increasing costs, potentially even beyond what we can predict on the basis of historical cost patterns.

Due to the broad range of uncertainty we incorporate in our feeder cost models, the distribution of costs we report in Figure 7 is quite large: for instance, annual costs in 2040 range from $5 million to $350 million in a gradual upgrade approach and high adoption scenario. These cost numbers are substantial, but they are a small fraction of PG&E's current annual distribution spending: the California Public Utilities Commission approved PG&E to spend $2.23 billion on electric distribution capital projects in 2020 (CPUC 2020).

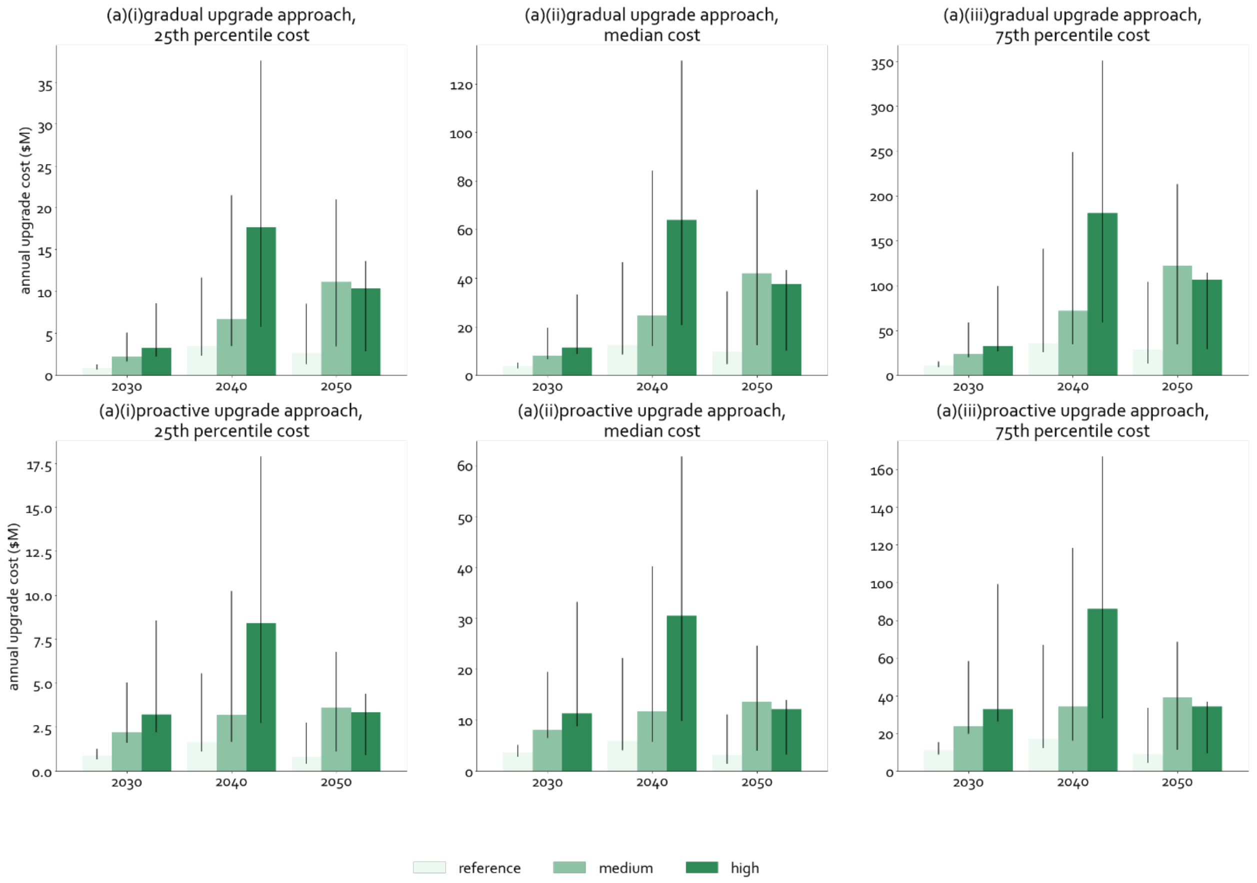

Figure 7 Estimated total costs in PG&E's territory for distribution circuit upgrades using (a) a gradual upgrade approach and (b) a proactive upgrade approach, using (i) 25th percentile, (ii) median, and (iii) 75th percentile cost estimates. Results capture the potential uncertainty of where new load might connect within a circuit: column heights depict the median load allocation scenario, and the lower and upper error bars indicate the 90th and 10th percentiles, respectively.

## Sources of underestimation, overestimation, and uncertainty

Our approach is subject to several assumptions and modeling omissions that may lead to underestimates, overestimates, and/or uncertainties in upgrade need and cost assessments. In this section, we qualitatively discuss how each of these modeling choices might impact results and point to avenues for future work.

### Reasons our estimates could be low

Our approach assumes that background demand growth - loads that are not attributable to residential heating - can be neglected in PG&E's service area. However, demand growth is known to increase over time, in part due to growing population (Johnson, McGhee, and Mejia 2022), but also due to the impacts of other electrification transitions (to see these results alongside upgrade needs due to EV adoption, see (Elmallah et al. 2022)). Additionally, we do not consider that electric heat pump adoption will enable space cooling as well as space heating, which will increase electricity demands and might create additional peak demands for electricity in summer months, which may prompt more upgrades. As we show in the appendix (Considering the impacts of warming temperatures on heat pump energy usage), which explores temperature projections from 10 General Circulation Models (GCMs), peak hot temperatures as well as cooling degree days are projected to increase throughout PG&E's service area in 2030, 2040, and 2050, which will exacerbate electricity demand for space cooling. These rising temperatures will also contribute to electric equipment derating (Brockway and Dunn 2020), another factor that would increase upgrade needs. Finally, we calculate upgrade needs assuming that utilities will upgrade feeders to provide just enough electricity to meet projected demands, but utilities may plan upgrades with additional headroom in case of unforeseen demand growth; planning for this headroom would lead to greater upgrade needs.

### Reasons our estimates could be high

We assume that only distribution grid upgrades can address integration capacity limits that are exceeded by projected electricity demands. In reality, other operational changes can be made, including load transfer and switching (where the load is transferred to a different, nearby feeder than the one nearing its limit) as well as changes to voltage regulation equipment. However, publicly available distribution system data does not make known where these operational changes are possible (particularly load transfer or switching); a more detailed understanding of both distribution system configurations and operator and distribution engineer decision-making would be needed to explore the potential of these operational changes to avoid upgrades. Additionally, non-wires alternatives, including either rooftop or community solar paired with energy storage, could mitigate the need for upgrades by providing electricity on-site for electrified loads. This impact could be significant (Gupta et al. 2021), and it is an area that merits concerted future work. Furthermore, our current method for constructing EV charging demand response scenarios is not feeder-specific; greater reductions in capacity need could be possible if demand from electrified loads is shifted strategically to hours with the most room for new demand on each feeder.

### Major sources of uncertainty

Finally, our estimates are subject to several sources of uncertainty. Notably, the trajectories of electric heating, policies, incentive and rebate program design and funding, and the upfront costs of electric heating appliances may accelerate or delay the scenarios outlined in this paper and could lead to regional concentrations of technology adoption. This analysis was conducted before the California Governor’s office set a 2030 target of 6 million electric homes (about 45% of homes in California) (Building Decarbonization Coalition 2023), a target that is more ambitious than even our “high” scenario. Whether these targets will be met is an open question, but if they are, they may require significantly more short-term investment in the distribution grid.

Additionally, uncertainties exist in the underlying ICA data. To manage this uncertainty, we compared different methods of spatially allocating load along distribution feeders, and we found that using the 90th percentile of ICA segments as the feeder load integration limit gave us results that are roughly aligned with GNA data. Still, because the ICA data generation process is constantly reevaluated, these results should be re-assessed as PG&E refines their data generation process. Finally, we do not consider the impact of climate change on heating needs. As we show in the appendix (Considering the impacts of warming temperatures on heat pump energy usage), the median coldest temperature in 2030, 2040, and 2050 is projected to be colder than current cold peaks in some parts of the study area, and warmer in others. Thus, some parts of the study area may have higher peak electricity demands for heating in future years, prompting more upgrades, while others may have lower peak electricity demands.

These sources of under- and over-estimation and uncertainty point to avenues for future empirical and modeling work. Specifically, future empirical work might investigate how electricity load shapes change for residents who install space heating and consequently have additional access to space cooling. Future modeling work might explore potential future load shapes for space heating and cooling alongside climate change projections, assess the potential of solar and storage to avoid grid upgrades, and consider feeder-specific DR schemes.

# Conclusion

Residential electrification is a necessary measure for climate change mitigation that requires additional electricity usage. This electricity demand will vary spatially, temporally, and based on technology adoption rates. Many aspects of infrastructure planning need to adapt to electrification; among them is distribution grid planning.

This paper evaluates how distribution infrastructure planning needs to change by constructing load shapes for electrified residential heating using a combination of bottom-up modeling and existing projections. We combined these load shapes with data on PG&E's distribution circuit load integration capacity limits to quantify where and when residential heating electrification might exceed infrastructure limits, prompting upgrades. We calculated the potential cost of upgrades using existing cost data from PG&E and compared the projected rate of upgrades to current upgrade practices. We determined upgrade needs and costs for the years 2030, 2040, and 2050, and observed differences in results based on adoption timelines and cost estimates.

Our analysis leads to three key conclusions. First, residential electrification will prompt upgrades primarily on circuits that serve larger populations – we find that up to 60% of circuits that serve up to 80% of customers might require upgrades. Second, our analysis projects that the number of feeder upgrade projects needed to meet electrification goals could exceed PG&E's current rate of upgrades, especially in the absence of proactive planning approaches. Distribution grid upgrades, then, may pose a bottleneck to electrification goals, necessitating workforce expansion or investment in non-wires alternatives like demand response and storage to reduce the required volume of infrastructure upgrade projects. Finally, the projected upgrade needs are spatially heterogeneous; we find that they are more concentrated in counties in the San Francisco Bay Area and in parts of the Central Valley, including Fresno County.

Our modeling approach is subject to some limitations and opportunities for future analysis, as discussed in detail in the section Sources of underestimation, overestimation, and uncertainty .

In particular, when we capture known sources of uncertainty in distribution system capacity and upgrade costs, the range of potential future impacts is substantial, and new modeling processes need to identify ways to reduce this uncertainty. Another critical opportunity for future analysis is to consider the value of feeder-specific demand response, storage and distributed energy resources. These types of measures could be deployed quickly and in a modular way and could significantly offset the distribution capacity expansion work and costs projected in this study.

Our results prompt two main recommendations for practices and policies to support future electrification. First, utilities can reduce the uncertainty of future capacity upgrade needs by updating their load integration modeling processes to capture plausible scenarios for electrification along distribution circuits, as well as likely mitigation strategies (such as low-cost switching operations versus higher cost infrastructure upgrades). Second, our findings are relevant to ongoing discussions on resourcing, labor, and pricing in the electric utility sector. Distribution grid infrastructure is subject to pre-existing trends of lack of equipment availability and a shrinking workforce that could contribute to bottlenecks in electrification, particularly considering that we find that many circuit upgrade needs are relatively near-term. Our results suggest that programming and research on measures that can ease these bottlenecks, including workforce training, is essential to facilitate electrification.

# Appendices

## Gas end uses beyond space and water heating

According to California-wide surveys, 91% of residential gas consumption is used for space and water heating, while the remaining 9% is used for cooking (5%), pool heating (2%), and dryers (2%) (DNV GL 2020). 80% of homes with a gas connection in the PG&E service area use gas space and water heating, 63% use gas ranges or ovens for cooking, 30% have gas-powered dryers, and only 3% have gas-heated pools (DNV GL 2020). Cooking, then, represents the most substantial end-use other than space and water heating. Estimates of load shapes find that energy usage for cooking peaks in the late afternoon, coinciding with water heating peaks (Baroiant et al. 2019). Thus, our assumption that all gas usage follows space and water heating load shapes is reflective of appliance saturation (gas usage is largely attributable to space and water heaters) and is consistent with the temporal patterns of energy usage for cooking, which is the most substantial end-use that is not directly incorporated in our approach.

## Using OpenEI load shapes to construct an estimate of electricity load shapes

OpenEI electricity load shapes are provided for 10 simulated locations in California. For each ZIP code, the closest simulated location to the ZIP code centroid (Euclidean distance) was identified. For privacy reasons, PG&E aggregates natural gas consumption data for any ZIP codes with less than 100 residential customers. PG&E presents those ZIP codes as having zero gas usage and zero customers, flags those ZIP codes as "combined", and aggregates those ZIP code's gas usage data with a neighboring ZIP code until aggregation requirements (a minimum of 100 customers) are met (Pacific Gas & Electric n.d.-b). To address the ZIP code aggregation in the raw data, for each ZIP code with a "combined" flag and zero gas usage, a neighboring ZIP code with a "combined" flag and non-zero data was identified; the geometries of those ZIP codes were then merged, and the combined ZIP codes were treated as one unit.

Because PG&E gas usage data is aggregated at the monthly level, to create an electricity load shape based on gas usage and OpenEI load shapes we first normalize the OpenEI hourly loads over each month. OpenEI load shapes are given hourly for each hour in the year. For a given month $m$, simulated location $sl$, and end use $e_i$ (where $e_i$ can be space or water heating), the total energy usage $l$ for space and water heating for that month is the sum of all hourly energy usage values:

$$l_{m,sl,e_i}^{OpenEI} = \sum_h l_{h,sl,e_i}^{OpenEI}$$

The normalized OpenEI hourly load for hour $h$ and end use $e_i$ in month $m$ is:

$$l_{h,sl,e_i}^{OpenEI,norm} = \frac{l_{h,sl,e_i}^{OpenEI}}{l_{m,sl,e_i}^{OpenEI}}$$

Put in words, the normalized hourly load shape for a given month is determined by dividing the hourly load for that month by the total load for the month, which is determined by summing all the hourly load values for that month. Additionally, the total electricity usage for space and water heating for each month can be used to determine the proportion of energy that goes to space or water heating in each month, defined as:

$$prop_{m,sl,e_i}^{OpenEI} = \frac{l_{m,sl,e_i}^{OpenEI}}{\sum_e l_{m,sl,e_i}^{OpenEI}}$$

The normalized hourly load can then be combined with the end-use energy proportion, total gas usage in a ZIP code (converted from therms to MW), and appliance specifications (space and water heating coefficients of performance, and gas furnace and water heater energy factors) to estimate hourly electricity usage for heating. The equation below calculates the estimated load increase due to electrification based on load shapes by month, hour, ZIP code, and end use, while $g_{m.z}$ represents the total gas usage (therms) for a given month and ZIP code. The variables $ef_{e_i}$ and $COP_{e_i}$ represent the energy factor of a gas space or water heater and the coefficient of performance of an electric space or water heat pump, respectively. The notation $sl_z$ indicates the simulated location closest to ZIP code z.

$$e_{m,h,z,e_i}^{OpenEI} = g_{m.z} \times \frac{1\,MW}{34.13\,therms} \times prop_{m,sl,e_i}^{OpenEI} \times ef_{e_i} \times \frac{1}{COP_{e_i}} \times l_{h,sl_z,e_i}^{OpenEI,norm}$$

Finally, the hourly load increases above were aggregated to month-hour values by finding the peak projected increase due to electrification for every month-hour combination; in the formula below, $m-h$ represents a month-hour combination (e.g., the first hour of January):

$$e_{m-h,,z,e_i}^{OpenEI} = \max_{m.h} e_{m,h,z,e_i}^{OpenEI}$$

## Space and water heating equipment efficiencies

Table 4 Equipment efficiencies, energy factors, and COPs based on querying the CEC Appliance Efficiency Database.

| Parameter | CEC Appliance Efficiency Database search terms | Median | 5th percentile | 95th percentile |
|---|---|---|---|---|
| Gas space heating efficiency | Natural gas furnaces and boilers; approved models | 0.81 | 0.80 | 0.94 |
| Gas water heating energy factor | Natural gas residential water heaters; approved models | 0.66 | 0.58 | 0.95 |
| Electric space heating COP | Electric air source heat pumps; approved models | 3.3 | 3 | 3.6 |
| Electric water heating COP | Electric heat pump water heaters; approved models | 3.45 | 3.35 | 4 |

## Reconciling spatial representations

To reconcile the spatial representations of the ZIP code-level load shapes and the circuit-level data, we use a gridded population density dataset (Depsky et al. 2022) to allocate load to circuits. The original dataset has a 100 m x 100 m resolution. The population in each 100 m x 100 m cell was assumed to be equally distributed across the area of that cell to obtain a 10 m x 10 m resolution, consistent with the spatial resolution used in prior studies that utilize utility-provided circuit limit data (Brockway et al. 2021).

For each month-hour combination *m-h* and feeder *f*, the load ICL (MW) is determined as described in the section Calculating distribution circuit upgrade requirements and costs. This value is denoted as $ICL_{m\text{-}h,\,f}$. For each ZIP code $z$ and month-hour combination *m-h*, the total electricity load increase due to electrification is $e^{OpenEI}_{m-h,,z,e_i}$.

To assign the ICL and electricity load increase MW values to grid cells, first, each grid cell is assigned to a ZIP code and to a feeder. Grid cells are assigned to overlapping ZIP codes; if a grid cell intersects with more than one ZIP code, it is assigned to the ZIP code that contains the majority of that grid cell's area. Grid cells are also assigned to intersecting feeders; if a grid cell does not intersect a feeder, it is assigned to the nearest feeder. A grid cell $c$, then, is associated with both a ZIP code $z$ and feeder $f$ and has a population density *pop*.

For each grid cell, a weight $w_{c,z}$ is used to determine the electricity usage increase due to electrification (MW) in that grid cell. The weight is determined using the following formula:

$$w_{c,z} = \begin{cases} 0 \text{ if } c \text{ is outside of PG\&E's electric service area} \\ \dfrac{pop_c}{\sum_{c \in f} pop_c} \text{ otherwise} \end{cases}$$

In words, the weighting factor $w_{c,z}$ for a grid cell $c$ assigned to a ZIP code $z$ with population $pop_c$ is equal to that grid cell's population divided by the total population in all grid cells assigned to that ZIP code, unless that grid cell falls outside of PG&E's electric service area, in which case it is set to 0 so that gas usage from that region is not considered throughout the remainder of the analysis.

The electricity usage increase in each grid cell can then be determined using the following formula:

$$e_{m-h,c} = e_{m-h,z} \times w_{c,z}$$

In words, the electricity usage increase due to electrification (MW) in a grid cell $c$ is equal to the electricity usage increase for the ZIP code assigned to $c$ multiplied by the ZIP code population-weighting for that cell. This value is temporally resolved at the month-hour level (i.e., there are 288 load ICL and electricity usage increase MW estimates per grid cell).

For each raster cell $c$ and month-hour combination *m-h*, the load increase due to electrification is $e_{m-h,c}$. To obtain the load increase at a feeder level rather than at a raster cell level, for each feeder, the load increase due to electrification is summed among the cells assigned to that feeder ($c \in f$). This process is represented in the following formula:

$$e_{m-h,f} = \sum_{c \in f} e_{m-h,c}$$

## Residential electrification scenarios

To estimate the potential load impacts due to residential electrification, we start with total electrification load profiles.

These load profiles assume that all gas usage by residential customers served by PG&E circuits is converted to electric space and water heating. However, residential heating will not electrify all at once. We use technology adoption rates from Mai et al. (2018) to estimate how quickly residential customers will electrify heating. Specifically, we use the accompanying data resource from the NREL Electrification Futures Study on the projected final energy demand by state, sector, subsector, and energy source. We filter this data to California and residential space heating and water heating and sum the energy consumption of different heating technologies by energy source and year. Then, we calculate the percentage change in electricity usage from 2021 for the Reference, Medium, and High scenarios.

## Considering the impacts of warming temperatures on heat pump energy usage

To explore the extent to which warmer temperatures due to climate change might (a) reduce the need for electric heating and (b) increase the use of heat pumps for space cooling, we use historic and projected temperature data to understand how hot and cold temperature peaks as well as heating degree days (HDDs) and cooling degree days (CDDs) might change throughout the study area. We use the maximum and minimum temperatures as a proxy to understand how we might expect peak electricity usage due to electric heating adoption to change over time, and we use HDDs and CDDs as a proxy to understand how total energy usage electricity usage due to electric heating adoption might change over time.

Our modeled electric heating load shapes are based on 2019 gas usage data, so we obtained 2019 temperatures from gridMET, a dataset of daily, ~4 km resolution minimum and maximum surface air temperature data (Abatzoglou 2013; Climatology Lab n.d.). To understand projected temperatures in 2030, 2040, and 2050 (the years for which we report results), we obtained data from 10 General Circulation Models (GCMs) for an RCP8.5 scenario, as recommended by the California Energy Commission (CEC) for grid planning (Brockway and Dunn 2020) and provided by Cal-Adapt (Cal-Adapt 2018).

We aggregated both the gridMET and the GCM data at the county level, finding the mean minimum and maximum surface air temperature in 2019 for each county and day, as well as the mean overall temperature (the mean of the minimum and maximum surface air temperature). We then determined the monthly cold peak for each county (the lowest minimum surface air temperature for all days of the month) and the monthly warm peak for each county (the highest minimum surface air temperature for all days of the month). For each county, we determine the monthly heating and cooling degree days by finding, for each day, the HDDs (65 F - daily mean temperature or 0, whichever is larger) and the CDDs (daily mean temperature - 65 F or 0, whichever is larger) and summing the HDDs and CDDs for the whole month.

Figure 8 shows an example of the data, showing the cold peak temperature, warm peak temperature, HDD, and CDD per month for one county in our study area.

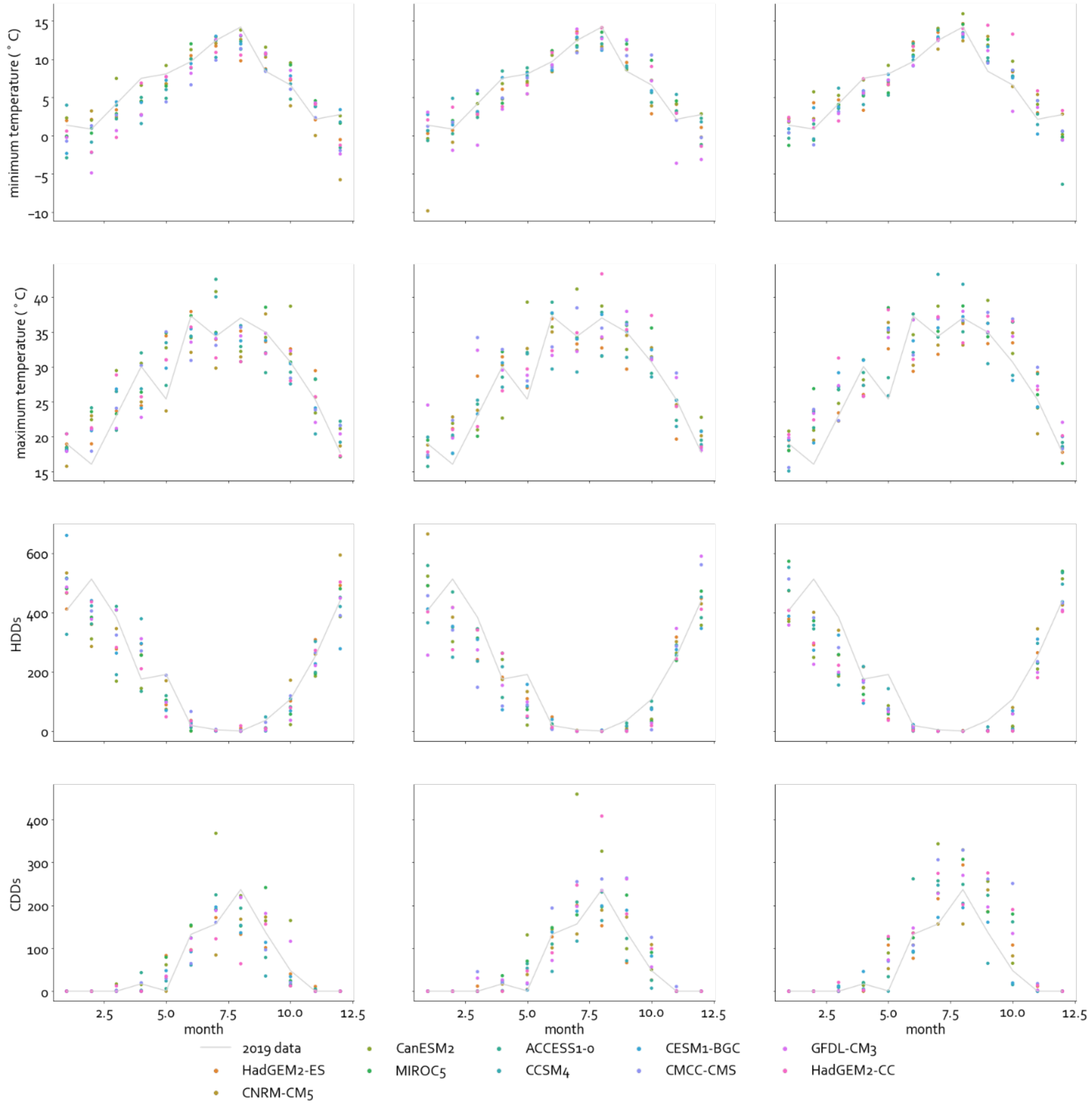

Figure 8 For one county in the study area, from top to bottom, the (a) coldest temperature, (b) warmest temperature, (c) count of HDDs, and (d) count of CDDs per month in 2019 and for a range of GCM outputs assuming RCP8.5 for the years 2030, 2040, and 2050 (from left to right)

To understand geographic and temporal differences in temperature, we determined the change in coldest temperature, warmest temperature, HDDs, and CDDs for each year, as shown in Figure 9. For each county and projected year (2030, 2040, and 2050), we first determined the overall difference in peaks by subtracting the 2019 coldest temperature from the median coldest temperature of the values given by the 10 GCMs; we do the same for the warmest temperature. We also determine the overall difference in annual HDDs and CDDs by summing the HDD and CDD count over the year and subtracting the 2019 count from the median count of the values given by the 10 GCMs.

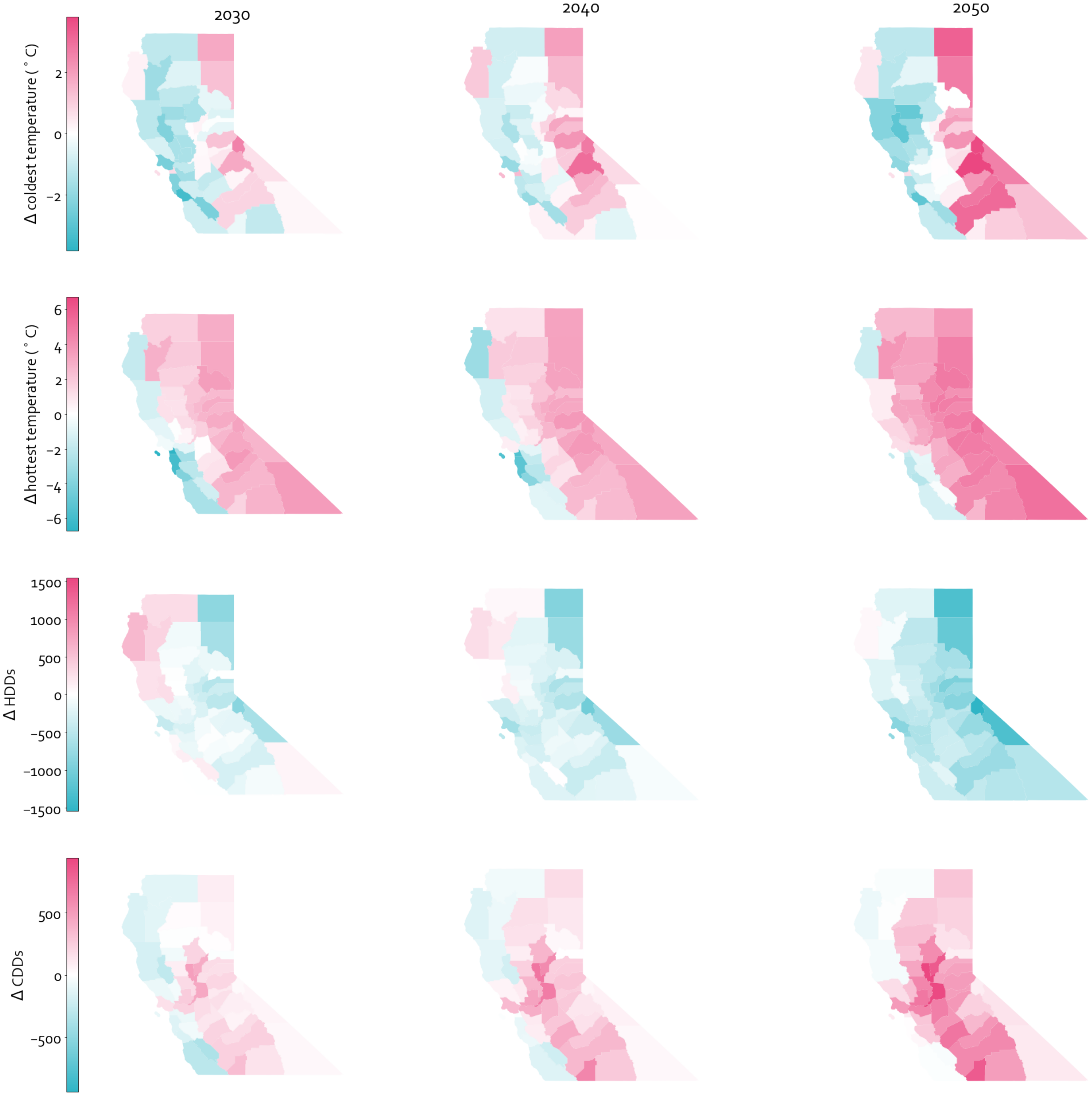

Figure 9 Annual change in (a) coldest temperature, (b) warmest temperature, (c) count of HDDs, and (d) count of CDDs per month between median GCM values assuming RCP8.5 for the years 2030, 2040, and 2050 and 2019 values per county in study area.

# Chapter 2 | Who heats and cools? Understanding access to residential heating and cooling in Northern California

## Introduction

Contemporary discussions about climate change mitigation in the US residential sector increasingly focus on residential heating electrification, or the deployment of electric heat pumps to reduce emissions from the residential sector, improve air quality within homes, and provide both heating and cooling. Increasingly, this discussion revolves around equitable electrification, or ensuring adoption of electric heat pumps across income levels, tenure, and race. In this paper, we argue that equitable electrification encompasses not only the ability of residents to purchase and install space conditioning equipment, but the ability of residents to use their equipment, or the ability of residents to access and benefit from heating and cooling. We explore the dimensions of access to heating and cooling by asking two questions: (1) what is the spatial and demographic distribution of access to space heating and cooling in Northern California? and (2) are the areas most in need of space heating and cooling in the future able to access heating and cooling? Our study focuses on the Pacific Gas & Electric (PG&E) service area in Northern California, where a dynamic climate and geography contributes to both heating and cooling needs that intersect with issues of energy affordability and cost of living that can limit access to heating and cooling.

In asking these questions, we engage with three important strands of energy research: work on energy poverty and fuel poverty that explores dimensions of heating (in)accessibility, more recent studies on household energy use for cooling in response to a warming climate and extreme heat events, and a related and emerging body of literature that uses household-level smart meter measurements to understand energy use for space conditioning. Building empirically and methodologically on these broader literatures, our study develops an understanding of both shared and diverging dimensions of access to heating and cooling in a study area with persistent heating needs and increasing cooling needs. In doing so, we can identify potential policy approaches and future research directions to ensure equitable access to critical space conditioning energy end-uses amidst an energy transition. In addition, we build on studies that use smart-meter data, but are largely focused on cooling, to extend our understanding of household space conditioning access to encompass both heating and cooling.

We answer these questions by combining household-level smart-meter gas and electricity data, climate and geographic data, socioeconomic indicators, and climate projections. Specifically, we use a segmented linear regression approach to identify homes with temperature-responsive energy usage, designating homes as heating and/or cooling. We pair our home-level heating and cooling designations with (1) a logistic regression model to understand the spatial and demographic distribution of heating and cooling use, and (2) a descriptive statistical approach to understand how heating and cooling use interact with future heating and cooling needs. We find that, while heating is much more prevalent in the study area, heating and cooling use demonstrate similar socioeconomic patterns, suggesting that shared approaches to energy and housing affordability can enable access to both heating and cooling. We also find that climate projections suggest persistent heating needs and increasing cooling needs in the study area, but that current usage of energy for heating and cooling is delineated by tract-level income and tenure.

# Relevant literature

## Conceptualizing access to residential heating and cooling

Access to residential heating and cooling is essential for thermal comfort, habitability, and the capacity of households to weather seasonal or extreme heat or cold events. A household with access to heating or cooling can consistently adjust their household temperature to achieve comfort, habitability, and resilience to heat or cold events. This access is socioeconomically, institutionally, and infrastructurally mediated: for households to access heating and cooling when needed, they require, among other things, working heating or cooling technology, access to networked fuel (in the case of natural gas or electric heating) or fuel markets (in the case of propane, wood, or heating oil), and affordable energy and maintenance services.

Historically, a significant body of research on household energy use has focused on heating access, advancing understandings of interrelated concepts like energy poverty and insecurity to understand heating access in a broader social, institutional, and infrastructural context (Bhattacharya et al. 2003; Harrison and Popke 2011; Hernández 2013; Hernández, Phillips, and Siegel 2016). Energy geography, environmental justice, and public health scholarship explores the lived experiences and spatial distributions of heating (in)accessibility. These studies are often directly or indirectly motivated by the links between heating and health. Harrison and Popke (2011) argue that energy poverty, or situations in which households "cannot afford to maintain the home's indoor temperature at a level that allows for a comfortable or healthy lifestyle", arises in North Carolina from an "assemblage" of socioeconomic conditions, material characteristics of housing, and landscapes of energy provision. Residents experiencing energy poverty or insecurity respond with a variety of coping mechanisms, which could range from not turning on the heat at all (Harrison and Popke 2011) or increasing expenditures, contributing to chronic household stress (Bhattacharya et al. 2003; Hernández et al. 2016). Studies exploring the spatial distribution of energy use intensity (EUI), a proxy for how thermally efficient a home is, establish inequities in the material condition of housing: studies from Michigan (Bednar, Reames, and Keoleian 2017) and Kansas (Reames 2016) establish inverse relationships between home efficiency, census area median income, and homeownership rates, as well as racial and ethnic disparities in home efficiencies.

In recent years, scholarship on household access to space conditioning has increasingly focused on cooling. As extreme heat intensifies due to climate change, the links between a healthy, habitable home and access to home cooling are increasingly salient (Isaac and Van Vuuren 2009). Empirical results show that affluence is linked to both higher levels of air conditioning adoption and higher levels of energy use for cooling (Chen, Ban-Weiss, and Sanders 2020; Ko and Radke 2014), and further suggest that residents of poorer regions begin using energy for cooling at higher temperatures than residents of wealthier regions (Cong et al. 2022). One study in Southern California additionally identifies vulnerable areas as regions with both low air conditioning (AC) penetration and a projected increase in extreme heat days (Chen et al. 2020). Thomson et al. (2019), studying responses to extreme heat throughout eastern Europe, characterize income – along with tenancy relations, the accessibility of cool spaces, and home size – as components of a household's "capacity to adapt" to indoor heat, which constitutes vulnerability alongside the risk of excessive indoor warmth (e.g., the amount of sunlight exposure in a building) and sensitivity to harmful consequences (e.g., the age or health status of residents).

In this paper, we study heating and cooling as interrelated household energy services for four reasons. First, climate mitigation programming and funding is increasingly oriented to the low-carbon provision of both heating and cooling: space heating electrification, or transitioning homes from combusting fuel for heat to using electric heat pumps, has the potential to offer both heating and cooling services to homes (Building Decarbonization Coalition n.d.). As policy programming, funding, and discourses increasingly focus on equitable access to electrified space heating, it is necessary to also examine the extent to which the services that these programs are meant to provide – space heating and cooling – are, themselves, inequitably accessed.

Second, while climate change is leading to increased heat and, in turn, increased cooling needs, heating needs are not necessarily less pertinent in a warming climate. As we show in this study (specifically in the section Future heating and cooling needs), mean future projections of heating degree days (HDDs) are comparable to 2019 levels in the study area. In parallel, mean projected cooling degree days (CDDs) are significantly greater than 2019 values. In our study area, as access to cooling becomes increasingly relevant to a larger population, access to heating remains no less relevant.

Third, heating and cooling both intersect and diverge in their forms of service provision. In our study area, most residents' heating and cooling needs are served by a single investor-owned, combined gas and electric utility, meaning that residents of the study area are dependent on a shared infrastructure network and institutional context – including the setting and regulation of energy rates, as well as the availability of bill assistance programs – to access heating and cooling. However, heating demonstrates significantly more fuel heterogeneity than cooling: even among customers accessing heating and cooling from the same utility, heating can be provided by gas, electricity, or a combination of the two, while cooling is generally provided by electricity. In our study area, as in many other places, heating can also be accessed through other fuels – like propane, wood, or heating oils – that are not part of a utility system. This is perhaps why literature on heating access has, in part, focused on heating provision as a "landscape" (e.g., (Harrison and Popke 2011)). The similarities and divergences in forms of heating and cooling provision also merit a study of heating and cooling in the same study area – while shared approaches may exist to address inequities in heating and cooling access, divergences in how heating and cooling are provisioned may also point us to areas where addressing inequities in heating and cooling require differing approaches.

Finally, to paraphrase Thomson et al. (2019)'s framework, heating and cooling share means through which households can adapt to indoor heat or cold as well as the dimensions of sensitivity to excess heat or cold. Similarly, the capacities of residents to adapt to as well as dimensions of sensitivity to inaccessible heating or cooling are intersecting: having higher incomes or greater access to capital, owning your home, and being embedded in supportive social networks can all allow residents to adapt to indoor heat or cold temperatures, while older residents, children, and people with respiratory conditions, for instance, may share a vulnerability to both hot and cold indoor temperatures. In other words, the accessibility of heating and cooling is undermined by what Bouzarovski & Petrova (2015) term "a common condition: the inability to attain a socially and materially necessitated level of domestic energy services."

Understanding access to residential heating and cooling is important in the context of shifting climate mitigation strategies, the increasing importance of cooling paired with the sustained importance of cooling, the intersecting and diverging forms of service provision for heating and cooling, and shared dimensions of capacities to adapt and sensitivities to indoor heat and cooling. In this paper, we explore how access to residential heating and cooling is distributed socioeconomically and in relation to future heating and cooling needs. The section below details how existing literature has statistically explored residential heating and cooling use.

## Statistical approaches to understanding residential heating and cooling energy use

Household energy use varies in space and time, due to variation in housing stock characteristics, behavioral patterns, and socioeconomic conditions (Chen, Ban-Weiss, and Sanders 2018). Because of this noted spatiotemporal variability, over a decade of literature in this research space calls for the use of micro, household-level energy usage data in studies of household energy use (Bartusch et al. 2012; Ewing and Rong 2008). In this section, we review (1) statistical methods through which existing engineering, urban planning, and economics scholarship designated households as heating or cooling, and (2) analytical approaches to relating household-level energy use or technology adoption to spatial, climate, and socioeconomic characteristics.

Most relevant to this paper are studies that use metered, household-level data to understand residential heating and cooling energy use, which relate energy usage to temperature using segmented or piecewise linear (Borgeson 2013; Chen et al. 2018, 2020; Sheikh 2017) or non-linear functions (Cong et al. 2022) as well as intensive margin estimations (Auffhammer 2022) or statistical comparisons of seasonal energy use (Ko and Radke 2014; Tong et al. 2021). Segmented regression approaches construct functions that relate residential energy consumption to ambient temperature, aggregated at the daily level, to determine two household-level characteristics: the stationary point or inflection temperature at which a household's energy use begins to show a temperature responsiveness (Chen et al. 2018, 2020; Cong et al. 2022), and the energy-temperature sensitivity of a household's energy usage after the SPT (Chen et al. 2018, 2020). Intensive margin estimations as used by Auffhammer (2022) derive the change in electricity consumption in response to changes in temperature, effectively determining a similar temperature responsiveness metric to Chen et al. (2018, 2020) but using binned, step-wise changes in temperature rather than a linear variable for daily temperature. Finally, comparisons of seasonal total energy use are used to quantify mean energy use over several-month winter or summer periods, considering additional energy use in winter and summer periods to represent temperature-sensitive heating or cooling use (Ko and Radke 2014; Tong et al. 2021). With one exception (Sheikh 2017), temperature-energy use studies tend to focus on electricity use rather than on gas or other fuel usage, and additionally tend to focus on cooling energy usage rather than heating energy usage.

Many studies that explore residential heating and cooling energy use, as well as studies that characterize adoption of energy technologies or material housing conditions relative to energy use, relate these classifications to spatial, climate, and socio-economic characteristics. Analytical methods to understand distributions of energy use or technologies include descriptive statistical approaches (Chen et al. 2020; Tong et al. 2021), bivariate tests of statistical significance (Cong et al. 2022; Tong et al. 2021), and linear and logistic regressions (Bednar et al. 2017; Edwards et al. 2023; Ko and Radke 2014; Reames 2016).

# Study area, data, and methods

## Study area

Our study is situated in the Pacific Gas and Electric (PG&E) service area in Northern California. PG&E is the largest investor-owned company delivering residential electricity in the US by number of customers (Energy Information Administration 2019) and the third-largest residential gas delivery company by volume of gas delivered (Energy Information Administration 2021). With dynamic, heterogenous climate conditions, many customers with both heating and cooling needs, uneven structural barriers to energy access, and intensifying decarbonization efforts, the PG&E service area is well suited to understand the spatial and socioeconomic dimensions of heating and cooling energy use.

The PG&E service area ranges from coastal regions with wet winters and cool summers, central Californian regions with moderate winters and hot and dry summers, and mountainous areas with large seasonal temperature ranges, including very cold winters and hot summers. Within many of these regions are smaller microclimates affected by ocean proximity and changing elevations (Pacific Energy Center 2006). As show in Figure 10, several building climate zones in the PG&E service area had both heating and cooling needs in 2019 (building climate zones represent distinct geographic areas with similar climates, primarily used to guide climate-specific building standards through the California Energy Code (California Energy Commission n.d.)).

Figure 11 indicates that much of the PG&E service area study area is temperature in climate – in 2019, winter average temperatures were centered around just below 10 °C, while summer average temperatures vary significantly across tracts, but are largely between 15 and 30 °C (though, as we note throughout the paper, summer temperatures are projected to steadily increase over time in the study area). The region also experiences notable extremes in temperature; in 2019, most tracts had a minimum temperature around 0 °C, with some seeing temperatures as low as -20 °C, and maximum temperatures ranged from about 35 to 45 °C. Inaccessibility of space heating and cooling has health implications even in a temperate climate. Epidemiological studies from similarly temperate climates in Australia (Singh et al. 2022) and New Zealand (Howden-Chapman et al. 2012) suggest that sustained indoor cold temperatures below the widely recommended indoor temperature of 18 °C are associated with respiratory, cardiovascular, and morbidity risks. Similarly, the associations between indoor heat and health risks is well established, with studies observing health outcomes as temperatures increase from baselines as low as 21 °C (Head et al. 2018). Respondents to a study focused on experiences of utility disconnections in the East Bay portion of PG&E's service area (which is just east of the San Francisco Bay), one of the most temperate parts of the study area, relayed health concerns about their homes being both too cold in the winter and too hot in the summer (Environmental / Justice Solutions 2021).

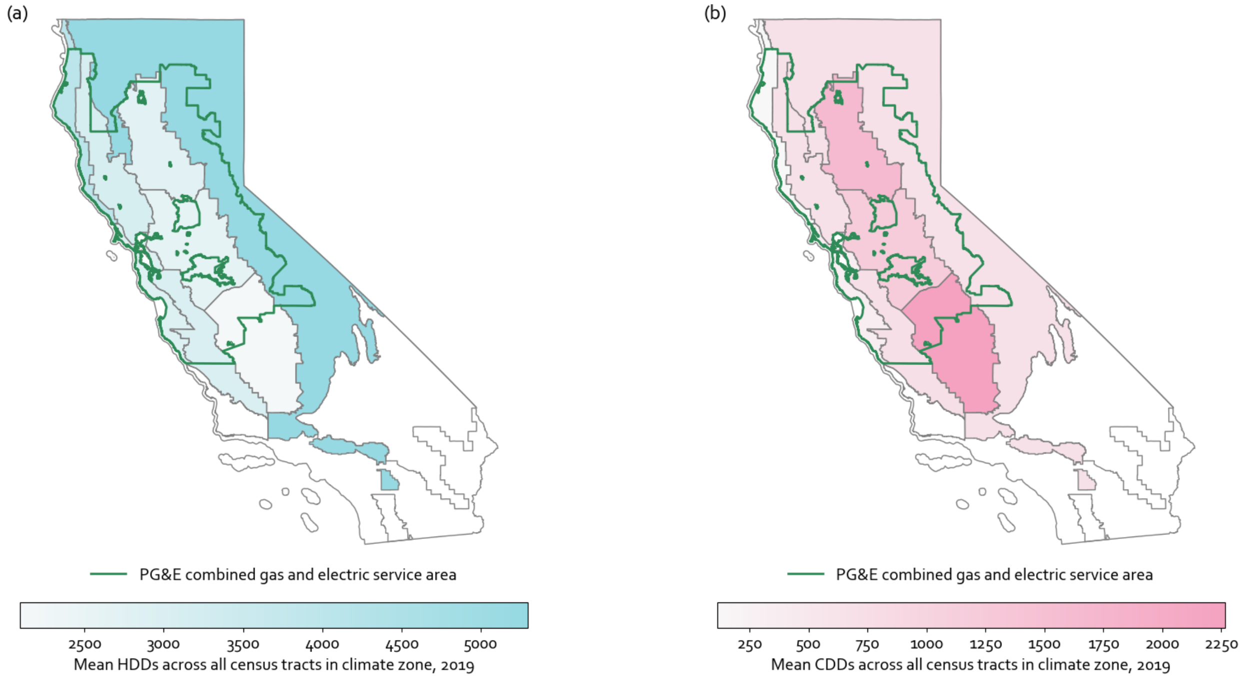

Figure 10 Map of California showing boundaries of PG&E combined gas and electric service area as well as boundaries of CEC building climate zones, with mean 2019 (a) heating degree days (HDDs) and (b) cooling degree days (CDDs) across all census tracts for each climate zone that overlaps with PG&E's combined service area

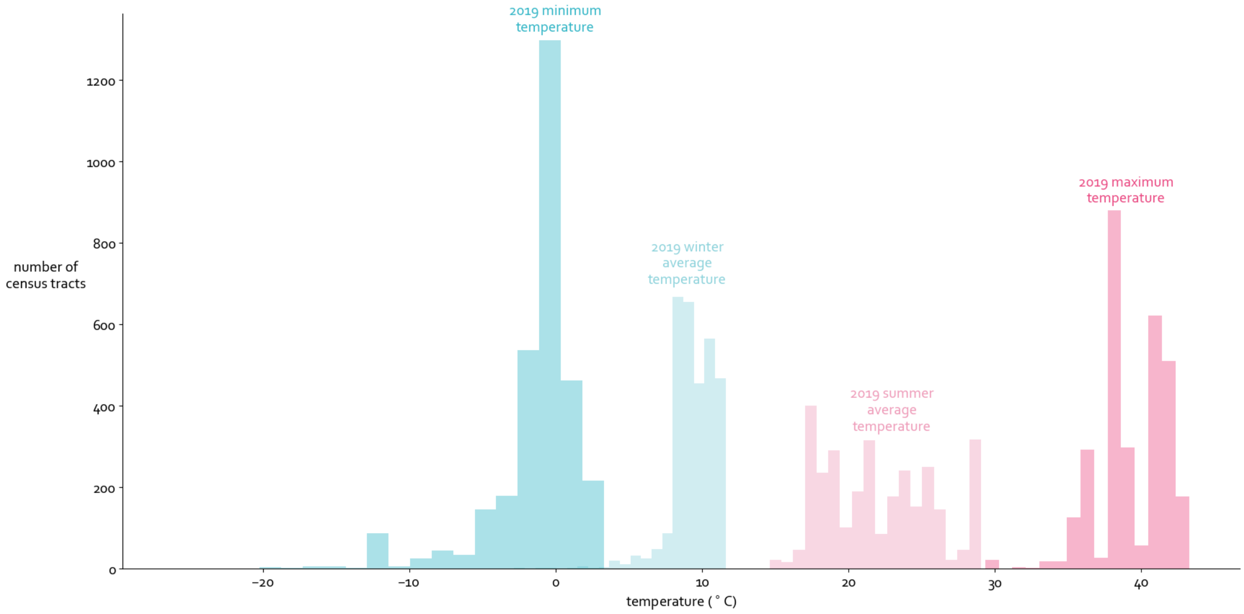

Figure 11 Distribution of 2019 minimum, maximum, winter (January, February, December), and summer (June, July, August) average temperatures across census tracts in the study area

Like other private utilities in California, PG&E charges some of the highest residential electricity rates in the US (Borenstein, Fowlie, and Sallee 2021). Through historically lower than electricity prices, residential natural gas rates charged by PG&E are growing as the utility charges more to recover costs from capital and operational investments (Gridworks 2020). At the same time, much of the PG&E service area is subject to a cost-of-living crisis that intersects with the high cost of energy. For instance, respondents to the East Bay-focused study above shared that compounding financial difficulties forced households to balance utility payments against other critical expenses, including steadily increasing rents, water bills, and food purchases (Environmental / Justice Solutions 2021). According to a state-wide survey conducted in 2019, just over 80% of renters in the PG&E combined gas and electric service area paid their own energy bill (as opposed to having the bill covered by a landlord) (DNV GL 2020).

PG&E also administers two state-wide income-qualified gas and electricity bill assistance programs, the California Alternate Rates for Energy Program (CARE) and the Family Electric Rate Assistance Program (FERA). CARE provides a monthly discount of at least 20% on both gas and electricity, while FERA provides a discount of 18% on electricity only for households of 3 or more (Pacific Gas & Electric n.d.-a). Notably, the East Bay-focused study above found that these programs were insufficient to cover costs for qualified households and had income thresholds that excluded many low-income households facing housing and energy cost burdens (Environmental / Justice Solutions 2021).

In parallel, the PG&E service area, along with California as a whole, is subject to intensifying climate change mitigation efforts, particularly for household electrification. In California, residential building electrification is managed at multiple levels. Recent federal and state funding commitments aim to incentivize the adoption of electric space heating technologies (Jenkins et al. n.d.). Individual utilities may offer rebates to homeowners who purchase electric space or water heating equipment, often facilitated by state-level funding allocated for efficient electric heating technologies (Borgeson n.d.). Increasingly, cities and counties facilitate electrification by passing gas bans, the most stringent of which require all new buildings to use electric space and water heating exclusively (Gough 2021). In California as a whole, electric heating is least common in single family households (80% of which use gas heating, and 14% of which use electric heating), and is most common in large multi-family buildings (where the penetration of both gas and electric heating is 40% each) (DNV GL 2020).

## Data

### Gas and electricity usage

Our study relies on data provided from household-level smart-meters, provided through a confidential data request program by the Northern California utility Pacific Gas & Electric (PG&E) (Pacific Gas & Electric n.d.-b), to identify fuel-specific residential heating and cooling. PG&E's smart-meter program, which collects electric and natural gas usage data from individual household meters, began in 2012. As the default metering option for all customers in the region, smart-meters are used for over 99% of customers (individual customers may choose to opt-out and install an analog meter instead) (Pacific Gas & Electric 2020a, n.d.-c).

Our raw study dataset contains data from about 74,400 households in 2019. The data is provided as daily usage with a 1-therm resolution (gas) and hourly usage with a 0.01-kWh resolution (electricity). We use kWh as our unit of energy throughout the study (i.e., gas usage is converted from therms to kWh). Beyond usage data, the dataset includes anonymized IDs representing customer accounts, physical smart-meters, and billing agreements, monthly billing data including rate schedules and bill amounts, indicators for single and multi-family households, and enrollment in bill assistance, solar net metering, and certain energy efficiency programs. The physical addresses of individual meters are not provided to preserve anonymity; instead, the census block group (CBG) of each household is linked to each anonymized smart-meter ID. Gas and electricity meters are sampled randomly within each CEC Climate Zone found in PG&E's service area.

We only consider the following records: (1) single meters[5] with an average daily electricity and gas usage above 2 kWh to filter out potentially unoccupied residences (retaining 94% of records from the raw dataset), (2) meters located in the combined electricity and gas PG&E service area[6] (retaining 89% of the records from the first filtering step), (3) meters that were not subscribed to a solar tariff at any point in 2019[7] (retaining 94% of records from the second filtering step), and (4) meters used only for electric vehicles (retaining 99% of records from the third filtering step). After filtering, we are left with about 58,300 households, or 78% of the data from our raw dataset. Of those 58,300 households, 75% have both electricity and gas connections and 25% have only electricity connections[8]. We aggregate all data at the daily level (all subsequent analyses and results are based on daily total gas and electricity usage in kWh).

A key limitation of our study is its focus on networked sources of energy for heating (gas and electricity). By relying on smart-meter data, we exclude non-networked sources of energy for heating in Northern California, including propane and wood. This exclusion is most prominent California Energy Commission (CEC) Climate Zones 16, where three-quarters of households use a non-utility primary heating fuel, as well as in climate zones 1 and 11, as shown in Table 5

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[5] We consider only single meters as opposed to master-metered records, where one meter tracks the energy usage of many units, because we cannot effectively disaggregate the energy usage of one household in these cases.

[6] PG&E's gas and electricity service area boundaries slightly differ; for this study, we take only households that fall within CBGs that are in the intersection of the two boundaries, which encompasses 89% of households in the raw dataset.

[7] The usage data for meters on a solar tariff provides total electricity usage minus solar generation, skewing our estimate of electricity usage for those households.

[8] Though our study area includes the combined gas and electric service area for PG&E, households that fall within the gas service area may not have gas connections, particularly if they rely on propane or wood for heating or if they are all-electric.

(Figure 12 below labels the location of each climate zone). Altogether, about 7% of respondents use a non-networked heating source.

Table 5 Distribution of reported primary heating fuels in the 2019 California Residential Appliance Saturation Survey by climate zone for climate zones that intersect with PG&E's combined electricity and gas service area (DNV GL 2020) (remaining % of households in each climate zone did not respond or selected "not applicable")

| Climate Zone | % of households using natural gas as primary heating fuel | % of households using electricity as primary heating fuel | % of households using non-networked sources (propane, wood, solar, or other) as primary heating fuel |
|---|---|---|---|
| 1 | 33.4 | 12.1 | 35.5 |
| 2 | 62.2 | 22.0 | 4.4 |
| 3 | 63.1 | 17.9 | 1.5 |
| 4 | 68.0 | 21.4 | 2.9 |
| 11 | 54.7 | 18.4 | 16.2 |
| 12 | 67.2 | 17.4 | 7.3 |
| 13 | 59.1 | 17.0 | 8.2 |
| 16 | 8.2 | 9.4 | 75.8 |

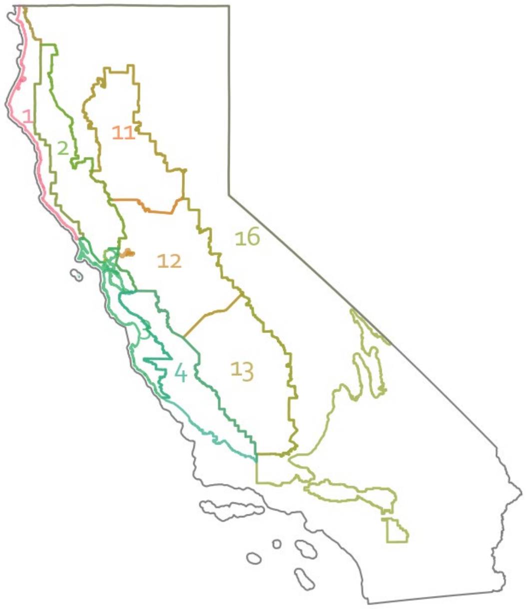

Figure 12 Labelled locations of each climate zone that intersects with PG&E's combined gas and electricity service area

### Air temperature

Our study relies on daily air temperature data to relate energy usage to temperature. We use data from the National Oceanic and Atmospheric Administration (NOAA) Global Historical Climatology Network daily (GHCNd) (Menne et al. 2012); in particular, we obtain average daily temperature observations from California temperature stations.

We first undergo a series of steps to ensure completeness of temperature data. Specifically, for any stations with missing data for average temperature, we use linear interpolation to impute missing average temperatures for up to 4 days of missing data (that is, if over 4 consecutive days of data are missing, we do not impute those values and retain them as missing data). We then eliminate any temperature stations where average temperature is missing after imputation for over 10% of days in 2019. We match each household in our dataset to a temperature station with complete data by Euclidean distance: for each household, we determine the centroid of that household's CBG and find the nearest temperature station with complete data. We are then able to link daily temperature and daily gas and electricity use observations to identify heating and cooling households (see section Identifying heating and cooling households below).

### Explanatory and control variables

To understand the spatial and demographic distribution of gas and electric heating as well as electric cooling while controlling for geographic and climatic variables that might impact heating and cooling use, we rely on four data sets. We primarily source indicators from the American Community Survey (ACS) as well as from the household-level metadata provided by the PG&E smart-meter data. We additional use data from the US Department of Housing and Urban Development (HUD), NOAA, and downscaled Localized Climate Analogues (LOCA) climate projection data. Table 6 summarizes the indicators, data sources, and aggregation levels for explanatory and control variables.

Table 6 Summary of spatial and demographic explanatory and control variables

| Indicator | Data source | Level of aggregation |
|---|---|---|
| Median household income | ACS 5-year estimates (2015-2019) | Census tract |
| Proportion of residents who are renters | ACS 5-year estimates (2015-2019) | Census tract |
| Median year built of housing | ACS 5-year estimates (2015-2019) | Census tract |
| Median number of rooms in home | ACS 5-year estimates (2015-2019) | Census tract |
| Proportion of residents who are racial minorities | ACS 5-year estimates (2015-2019) | Census tract |
| Proportion of residents who are Hispanic or Latino | ACS 5-year estimates (2015-2019) | Census tract |
| Proportion of residents who are elderly | ACS 5-year estimates (2015-2019) | Census tract |
| Proportion of residents who are children | ACS 5-year estimates (2015-2019) | Census tract |

| | | |
|---|---|---|
| Proportion of residents who are linguistically isolated | ACS 5-year estimates (2015-2019) | Census tract |
| Rural, urban, or suburban designation | HUD | Census tract |
| Presence of gas connection in household | PG&E smart-meter data | Household |
| Enrollment in CARE | PG&E smart-meter data | Household |
| Enrolment in FERA | PG&E smart-meter data | Household |
| Household type (multi vs. single family) | PG&E smart-meter data | Household |
| Building climate zone | PG&E smart-meter data | Household |
| 2019 summer average temperature | NOAA GHCN | Census tract |
| 2019 winter average temperature | NOAA GHCN | Census tract |
| Mean projected HDDs | LOCA climate projections | Census tract |
| Mean projected CDDs | LOCA climate projections | Census tract |

Data from the ACS as well as HUD are used to determine demographic and geographic characteristics of the census tracts in which individual meters are located. Based on a census of households, the ACS provides socioeconomic and housing data reported at various geographic levels. This project works with data at the census tract level, which are delineated by the Census Bureau to have relatively stable boundaries over time (Silva n.d.), and are a common unit of geographic analysis in comparable studies (e.g., Sunter, Castellanos, and Kammen 2019). We use the 5-year estimates (2015-2019) provided by the ACS which are most complete at the relatively small geographic unit of a census tract (Silva n.d.) and align with our gas and electricity usage data time period. We are specifically interested in the relationship between heating and cooling use and income levels, tenure, age of housing, size of housing (indicated by number of rooms), age of residents, race, and linguistic isolation using the indicators outlined in Table 6. We define elderly residents as residents who are 65 years or older, while children are under 18 years of age. The percent of linguistically isolated residents is defined as the percent of residents who report that all members of the household over 5 years of age speak English "less than 'very well'". We supplement ACS data with a measure of a household's census tract-level urbanicity, using the HUD's Urbanized Perception Small Area Index (UPSAI). The UPSAI classifies census tracts as rural, urban, or suburban based on a set of density and demographic indicators as well as how American Housing Survey respondents self-describe their neighborhood (Bucholtz, Molfino, and Kolko 2020).

We also draw on several household-level indicators from the PG&E smart-meter metadata. The presence of a gas connection in a household is determined by matching the account IDs provided by PG&E and identifying households where electricity accounts do or do not have a corresponding gas account; households without a corresponding gas account are assumed not to have a gas connection. Enrollment in CARE or FERA (which are bill assistance programs described in the section Study area above) is a binary indicator variable, determined based on a household's 2019 billing data: if a household was on a CARE or FERA rate plan at any point in 2019, they are considered to be enrolled. A multifamily vs. single family flag and a household's building climate zone are provided directly in the PG&E smart-meter metadata.

To understand a household's climatic conditions in 2019, the period during which they are flagged as heating or cooling, we consider a household's winter (defined as the months of January, February, and December 2019) and summer (June, July, and August 2019) average temperatures. We use NOAA's GHCNd data (Menne et al. 2012), calculating the average temperature in the summer and winter months as measured at the temperature stations nearest to each census tract.

Finally, we use LOCA data to understand projected future heating and cooling needs in the study area. LOCA data is hosted by Cal-Adapt, a data platform and repository that supports California's state- and local- level climate change assessment, mitigation, and adaptation efforts (Cal-Adapt 2023). Specifically, LOCA data consists of historical and projected (annual to 2100) maximum and minimum daily temperatures statistically downscaled for California to a 0.04-degree grid (each temperature projection represents a roughly 4 km x 4 km area) (Pierce, Kalansky, and Cayan 2018). While Cal-Adapt provides downscaled data for 32 individual General Circulation Models (GCMs) under two different greenhouse gas concentration scenarios, we consider 10 specific GCMs with greenhouse gas concentration scenario RCP 8.5 (the higher of the two modeled scenarios), as recommended for use by the California Public Utilities Commission (CPUC) for California energy utilities (Brockway and Dunn 2020).

For each of the 10 recommended GCMs, we obtain downscaled data for each year from 2035-2064, aligning with California's mid-century climate adaptation planning period (Cal-Adapt n.d.). Within the boundaries of each census tract, we calculate the average minimum and maximum daily temperature for each GCM and year, giving two observations (minimum and maximum projected daily temperature) for each day, census tract, and GCM. We then calculate the annual number of heating degree days (HDDs) and cooling degree days (CDDs) using a using a threshold of 18.3°C (65 F); HDDs and CDDs are indicators used in federal, state, and local energy planning to ascertain heating and cooling needs (U.S. Energy Information Administration (EIA) 2022). This calculation provides two observations (number of HDDs and number of CDDs) for each year, GCM, and census tract. Within each census tract, we calculate the mean of HDDs and CDDs as a measure of the magnitude of future heating and cooling needs among 300 projected values for each of 10 GCMs from 2035-2064. These indicators are also outlined in Table 6.

## Identifying heating and cooling households

For each individual gas or electric meter in our dataset, we use a segmented linear regression to identify households that heat with gas or electricity, cool with electricity, and households that have transitioned from using gas heating to using electric heating. A segmented linear regression, as used by Chen et al. (2018), allows us to identify whether households heat and/or cool by identifying the presence of statistically significant differing slopes before or after a temperature changepoint.

Specifically, for each individual gas or electric meter, we begin by considering only the daily total gas or electricity usage in 2019 alongside daily average temperatures. For each gas meter's 2019 data, we fit two models: a simple linear model in which there are no changepoints, and a segmented linear regression model with one changepoint. Because gas is a potential heating fuel, but not a cooling fuel, in the study area, we only consider the presence of up to one changepoint. For each electricity meter's 2019 data, we fit three models: a simple linear model in which there are no changepoints, a segmented linear regression model with one changepoint, and a segmented linear regression model with two changepoints. Electricity can be used as a heating or a cooling fuel in the study area, meaning that a household's electricity usage can plausibly change with two temperature changepoints. For each meter, we choose the model (0, 1, or 2 changepoints) with the lowest Bayesian Information Criterion (BIC). The BIC for a segmented linear regression subtracts a log-transformed mean squared error (MSE) from a penalty function that increases with the number of model parameters, in effect selecting a model that represents the underlying data without overfitting (Neath and Cavanaugh 2012).

We then apply a series of decision criteria to determine whether a household heats or cools. We first identify representative cases of gas or electricity usage as a function of temperature for gas (two in total) and electricity (four in total). These representative cases, along with the decision criteria used to identify whether households heat or cool, are described in more detail below.

For gas meters (Figure 13), we first consider all meters of case $A_g$ (1 changepoint). We consider households to be using gas heating if (1) the slope to the left of the temperature changepoint ($\alpha_{Ag,1}$) is negative within its 95% confidence interval (CI)[9], indicating decreasing gas usage with increasing temperature, and (2) $\alpha_{Ag,1}$ is greater in magnitude than the slope to the right of the changepoint ($\alpha_{Ag,2}$). The second condition, derived from Chen et al. (2018), accounts for temperature-sensitive loads other than heating, assuming that space heating is more temperature responsive (i.e. has a larger slope) than non-heating end uses or water heating. We then consider all meters that fall under case $B_g$ (0 changepoints). These meters might represent instances where gas is used primarily for space heating, in which case no changepoint is detected, or instances where gas is used primarily for non-heating end uses like cooking. We assume that case $B_g$ households are heating with gas if (1) the slope ($\alpha_{Bg,1}$) is negative within its 95% CI and (2) $\alpha_{B,1}$ is equal to no more than half the median of all $\alpha_{Ag,1}$ for case $A_g$ households that are designated as heating with gas. Condition (2) for case $B_g$ households allow us to classify 0-breakpoint households as heating when their temperature-responsive slopes are comparable

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[9] We use the term "all slopes within the 95% confidence interval (CI)" to refer to the best-fit slope plus or minus 1.96 standard errors from the mean.

to temperature-responsive slopes for 1-breakpoint households.

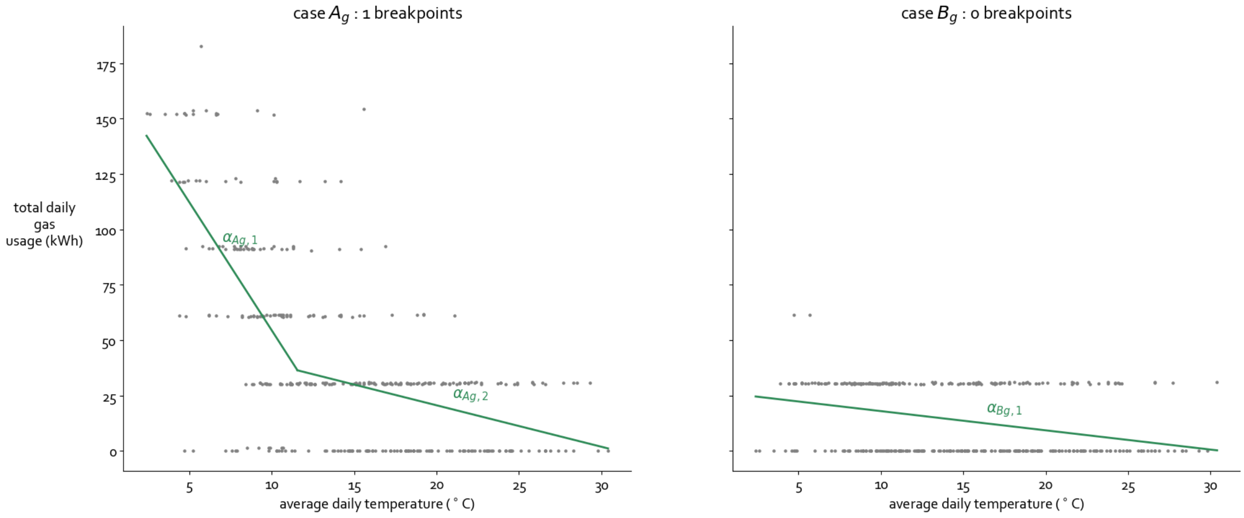

Figure 13 Examples of the two possible cases of gas usage-temperature piecewise regression results

For electricity meters (Figure 14), we first consider all meters of case $A_e$ and $B_e$. Case $A_e$ represents households with 1 changepoint, where one of the slopes (right or left) is equal to 0 within its 95% CI. Case $B_e$ represents all households with two changepoints. Similar to the criteria used for gas meters, for households that fall under one of these two cases, we consider households to be using electric heating if (1) the slope to the left of the left-most temperature changepoint ($\alpha_{Ae,1}$ and $\alpha_{Be,1}$ for cases $A_e$ and $B_e$, respectively) within the 95% CI are negative, indicating decreasing gas usage with increasing temperature, and (2) the slope to the left of the left-most changepoint is greater in magnitude than the slope to the right of the right-most changepoint within the 95% CI. For households that fall under one of these two cases, we consider households to be using electric cooling if (1) the slope to the right of the right-most temperature changepoint ($\alpha_{Ae,2}$ and $\alpha_{Be,3}$ for cases $A_e$ and $B_e$, respectively) within the 95% CI is positive, indicating increasing gas usage with increasing temperature, and (2) the slope to the right of the right-most changepoint within the 95% CI is greater in magnitude than the slope to the left of the left-most changepoint within the 95% CI.

We then consider all meters that fall under case $C_e$, which demonstrate a "V" shape, with one changepoint but neither slope equal to 0 within the 95% CI. These meters might represent cases where electricity is used for both heating and cooling with few days when electricity is used for neither heating nor cooling, or they may represent cases where electricity is used for temperature-responsive non-space conditioning end uses. We consider case $C_e$ households alongside case $D_e$ households, where no changepoint is detected – which, again, might represent the use of electricity for space conditioning or the use of electricity for other temperature-responsive end uses. We assume that case $C_e$ and $D_e$ households are heating with electricity if (1) the left-most slope (case $C_e$) or the single slope (case $D_e$) is negative within the 95% CI and (2) the magnitude of the left-most slope (case $C_e$) or the single slope (case $D_e$) is less than half the median magnitude of the left-most slopes for case $A_e$ and $B_e$ households that are designated as heating with electricity. We assume that case $C_e$ and $D_e$ households are cooling with electricity if (1) the rightmost slope (case $C_e$) or the single slope (case $D_e$) is positive within the 95% CI and (2) the magnitude of the right-most slope (case $C_e$) or the single slope (case $D_e$) is less than half the median magnitude of the right-most slopes for case $A_e$ and $B_e$ households that are designated as cooling with electricity.

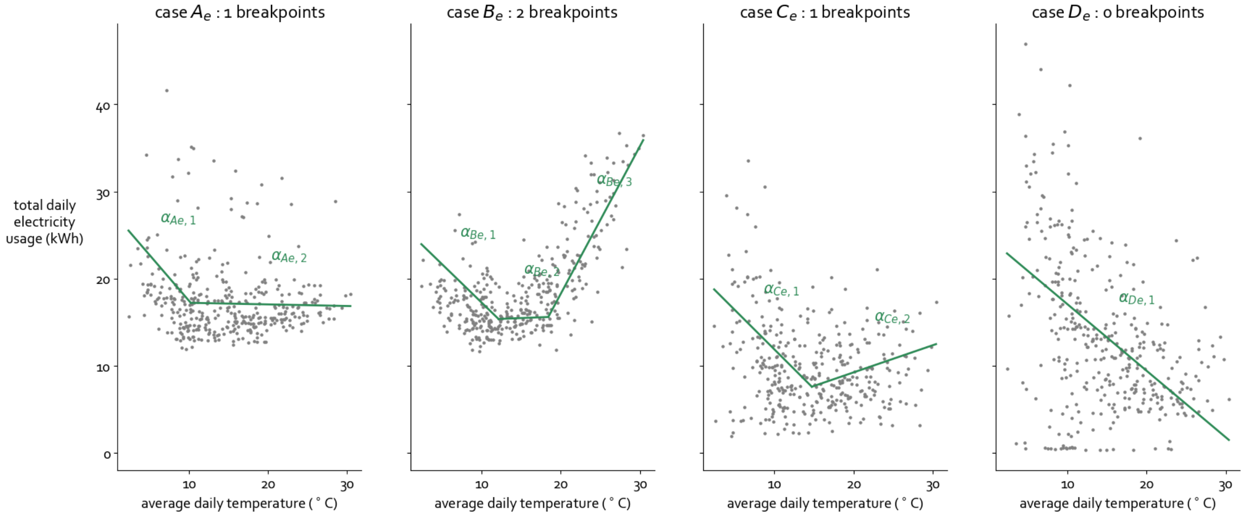

Figure 14 Examples of the four possible cases of electricity usage-temperature piecewise regression results

We compare our estimates to aggregated estimates from publicly-available state (the CA Residential Appliance Saturation Survey (RASS)) and federal (ACS) sources to ensure that our estimates of heating and cooling use align with survey and census estimates; this process is described in more detail in the appendix (Comparing heating and cooling identification to public datasets). In short, we find that our estimate of gas heating and electric cooling usage are generally lower than survey questions, which asks about the presence of heating and cooling equipment, potentially indicating that the presence of heating and cooling equipment does not necessarily mean that that equipment is used consistently. We find that our estimate of electric cooling exceeds surveyed results in some climate zones, which might point to the use of electric heating as a secondary heating source (e.g., through the use of room space heaters).

## Analytical approach

Our analytical approach encompasses (1) a logistic regression model to understand the spatial and demographic distribution of heating and cooling use, and (2) a descriptive statistical approach to understand how current heating and cooling use interact with future heating and cooling needs.

To understand the spatial and demographic distribution of heating and cooling use, we utilize a series of logistic regression (logit) models that relate the log-odds of a household utilizing their heating or cooling with a series of demographic and spatial indicators and control variables.

Logit models are used in several household energy technology adoption studies to model binary or categorical variables including heating fuel use (Kapsalyamova et al. 2021; Karaaslan, Algül, and Karaaslan 2022) and heat pump adoption (Edwards et al. 2023). A multinomial logistic regression takes the general form in equation (1), where $y$ is a binary response variable, $x_1 \ldots x_n$ are independent variables, and $b_1 \ldots b_n$ are the coefficients that maximize the likelihood function, a measure of how likely a set of coefficients are to produce the observed response (Kleinbaum and Klein 2010). A logit model is particularly suited to our context, where we are looking for the correlations between a set of demographic and spatial indicators and a binary response variable (heating use or cooling use).

$$P(y) = \frac{1}{1 + e^{-(a + b_1x_1 + b_2x_2 + \cdots + b_nx_n)}}$$

(1)

Specifically, we estimate a model that relates the probability of detecting heating (whether gas or electric) or the probability of detecting cooling to the normalized census-tract level median household income, proportion of residents living in poverty, proportion of residents who are renters, normalized median year built of housing, proportion of residents who racial minorities, proportion of residents who are Hispanic or Latino, proportion of elderly residents and children, proportion of linguistically isolated residents, enrollment in CARE or FERA, household type, and the urbanicity of a household. These variables encompass social and economic dimensions of access to space conditioning. We additionally control for local climate conditions through normalized average seasonal temperature (winter for heating, and summer for cooling), as well as a household's building climate zone. Finally, when predicting the probability of detecting heating, we add a control variable that indicates whether a household has a gas connection to control for households that might use a non-networked source of heat like propane or wood.

To understand how heating and cooling use interact with future heating use, we conduct a descriptive statistical analysis, adapting Tong et al. (2021)'s quadrant analysis approach and Chen et al. (2020)'s vulnerability analysis approach. Specifically, we define four quadrants that characterize future (1) heating and cooling needs as measured by the projected future tract-level HDDs and CDDs, respectively, from 10 climate models over a 30-year climate adaptation period as discussed in the Data section above and (2) heating and cooling use, calculated as the percent of households in each tract determined to be heating (using gas or electricity) or cooling. These quadrants are delineated by the mean projected HDDs/CDDs and heating and cooling use to define areas of higher and lower need for heating and cooling along with higher and lower usage of heating and cooling. Within each of these four quadrants, we determine the distribution of two tract-level variables: median household income and percent of renters. These variables are chosen because they are proxies for two critical dimensions of access to heating and cooling: whether households have the capital for household improvements, appliance installations and maintenance, or bill payments, and whether households have sufficient control and ownership over their home and material conditions.

# Results

Using the heating and cooling identification approach described above, we detect heating use (either gas or electric) in about 68% of households in our dataset. We detect gas heating in 74% of gas-connected households in our dataset (53% of all households), electric heating in 27% of households in the dataset, and neither gas nor electric heating in 32% of households. We detect the use of both gas and electricity for heating in about 12% of households in our dataset, indicating households that might, for instance, have a central gas heating system but supplement their gas heating with electric room space heaters. We detect electric cooling use in about 40% of households in our sample. The sections that follow explore how detected heating use and cooling use relates to climatic, geographic, and socioeconomic indicators, as well as to future heating and cooling needs.

## Logistic regression results

The results of the logistic regression model (described in the Analytical approach section) are shown in Figure 15.

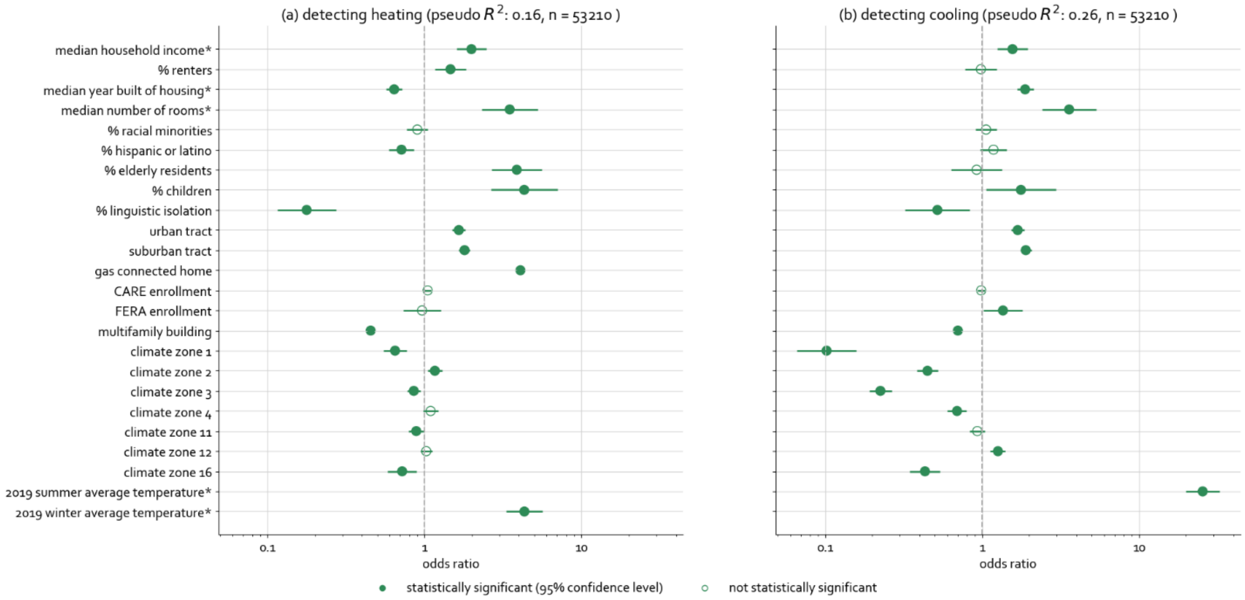

Figure 15 Logistic regression results relating socioeconomic and climate indicators to (a) the probability of detecting cooling and (b) the probability of detecting heating. Variables with asterisks (*) are normalized to values between 0 and 1. For climate zones, the omitted variable climate zone 13; for urban, suburban, and rural tract designations, the omitted variable is rural tracts.

### Geographic and climatic trends

With regards to our geographic and climatic control variables – seasonal temperature, climate zone, and reported use of networked heating sources – we observe some intuitive and some surprising results.

For cooling, the geographic and climate trend results are consistent with what one would expect. The probability of detecting cooling increases in tracts with warmer summer temperatures. We observe a decreased probability of detecting cooling in nearly all climate zones compared to the omitted category of climate zone 13, which is the warmest climate zone in the study area by number of 2019 HDDs and CDDs (see  Figure 10 and Figure 12). These probabilities generally correlate to the CDDs in each climate zone, with the smallest odds of detecting cooling appearing in cooler, coastal climate zones.

For heating, the geographic and climate trend results have some results that line up with expectations, and others that require additional analysis. We find that the probability of detecting heat increases for households with gas connections, which is intuitive, as households without gas connections may use alternate heating sources like propane or wood (along with, potentially, electricity). However, we also find the surprising result that the probability of detecting heating increases for tracts with higher winter temperatures – that is, it increases where winters are warmer. Similarly, where coefficients are statistically significant, we find that colder climate zones show a lower likelihood of heating than the warmer reference climate zone 13.

How can we understand the seemingly counter-intuitive relationship between temperature and heating use? First, we'll note that heating and cooling differ in the study area in one key respect: nearly all parts of the study area have heating needs, while only some parts of the study area have cooling needs. As  Figure 10 shows, even the warmest climate zone in the study area experienced over 2000 HDDs in 2019 (compared to the coolest climate zone, which experienced around 200 CDDs). Because this study operationalizes heating use as a binary variable (rather than, e.g., the quantity of energy used for heating), and heating needs are distributed throughout the study area, we don't necessarily expect to see a negative relationship between temperature and heating use in the same way that we expect to see a positive relationship between temperature and cooling use. That is, residents of even relatively warm areas in the study area still need home heating.

However, the fact that the relationship between temperature and heating use is strongly positive – rather than being, for instance, not statistically significant – deserves further examination. We examine this relationship in more detail in the appendix (Exploring the relationship between temperature and heating use). We find that the statistically significant positive effect between winter temperatures and heating use is largely attributable to the fact that the coldest parts of our study area tend to be areas where residents may be more reliant on non-networked sources of heat (e.g., propane or wood), and thus we cannot observe heating use in those areas. However, we find that there is still a statistically significant positive relationship between winter temperature and heating use for households with gas connections (though it is smaller in magnitude than the coefficient shown in Figure 15(a)). For households with gas connections, we find that this positive relationship is primarily present within households in suburban tracts, which could reflect expectations of thermal comfort in warmer suburban areas. The robustness checks that shape this understanding of the relationship between winter temperature and heating use can be found in the appendix (Exploring the relationship between temperature and heating use). The results discussed below on socioeconomic characteristics of heating use are robust to these alternate model specifications.

### Built environment and socioeconomic characteristics

We find significant correlations between socioeconomic variables and heating and cooling use. Outside of the geographic and climatic variables discussed above (climate zone, winter temperature, and gas connectivity), the tract- and household-level characteristics with the strongest correlations with heating are tract-level median household income, percent of elderly residents and children, percent of linguistically isolated households, and whether a household is multifamily.

Specifically, for heating, we find that as the median income or percent of elderly residents or children in a tract increases, households in that tract are more likely to heat. Conversely, as the percent of linguistically isolated households increases in a household's tract, or if a household is multifamily, it is less likely to heat.

For cooling, outside of summer temperatures and climate zone, the tract- and household-level characteristics with the strongest correlations with cooling are tract-level median household income, percent of children, percent of renters, percent of linguistically isolated households, and whether a household is multifamily. As with heating, we find that median tract household income and the percentage of children in a tract is associated with a higher likelihood of cooling, while areas with higher proportions of linguistic isolation and multifamily households show a lower likelihood of cooling. Additionally, areas with more renters are less likely to cool. Households in urban and suburban tracts are both more likely to heat and cool than households in rural tracts, while the likelihood of both heating and cooling increases where houses have more rooms.

Finally, we find that only FERA enrollment is significantly related to cooling use through a small but statistically significant coefficient. Enrollment in CARE is not statistically significantly linked to heating nor cooling, and FERA enrollment is not significantly related to heating use[10].

## Future heating and cooling needs

We explore the relationship between current heating and cooling use and future heating and cooling needs in Figure 16 and Figure 17, which show the distribution of tracts within heating/cooling need-use quadrants and the distribution of tract-level income and proportion of

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[10] We considered that correlations between median census tract-level household income and CARE/FERA enrollment might be contributing to the mostly non-significant coefficients for CARE/FERA-enrolled households. We tried an additional specification that eliminated the median census tract-level household income variable but found that the coefficients for CARE/FERA enrollment remained the same (non-statistically significant except for a small positive coefficient correlating FERA enrollment and electric cooling usage).

renters per quadrant, respectively. We divide the quadrant analysis for heating use between gas-connected and non-gas connected households because households without gas connections in the study area are more likely to use other, non-networked sources of heating, requiring a separate interpretation than households with gas connections that are less likely to use non-networked heating sources.

Figure 16 shows that heating and cooling needs will persist (and, in the case of cooling, will increase) in 2035-2064. Comparing Figure 16 to  Figure 10, for instance, shows that the range of projected HDDs across all tracts in Figure 16 actually stays relatively close to the range of 2019 HDDs across climate zones shown in  Figure 10, and that the range of projected CDDs increase: the hottest climate zone in 2019 had about 2250 HDDs on average, while some census tracts are projected to see HDDs of 3000 or more based on the 30-year average projection in Figure 16. Observing how the quadrants in Figure 16(a) are geographically distributed shows that high need-high usage tracts and high need-low usage tracts are often neighboring tracts in similar geographic areas. For heating among households with gas connections (Figure 16(a)(i) and (b)(i)), non-coastal tracts around the San Francisco Bay demonstrate the highest projected need, along with variation in current usage. For cooling (Figure 16(a)(iii) and (b)(iii)), the central parts of the study area demonstrate the highest projected need, with high current usage in most tracts. The results for households without gas connections (Figure 16(a)(ii) and (b)(ii)) are more challenging to interpret, as many of these households might access heating through fuels other than gas and electricity. As expected, we see a greater projected need for heat among non-gas connected homes in cooler coastal and mountains areas. While we see a mix of low and high current usage in these high projected need areas, our understanding is also limited by a lack of information on how households in these areas might use propane, wood, or other fuels for heating.

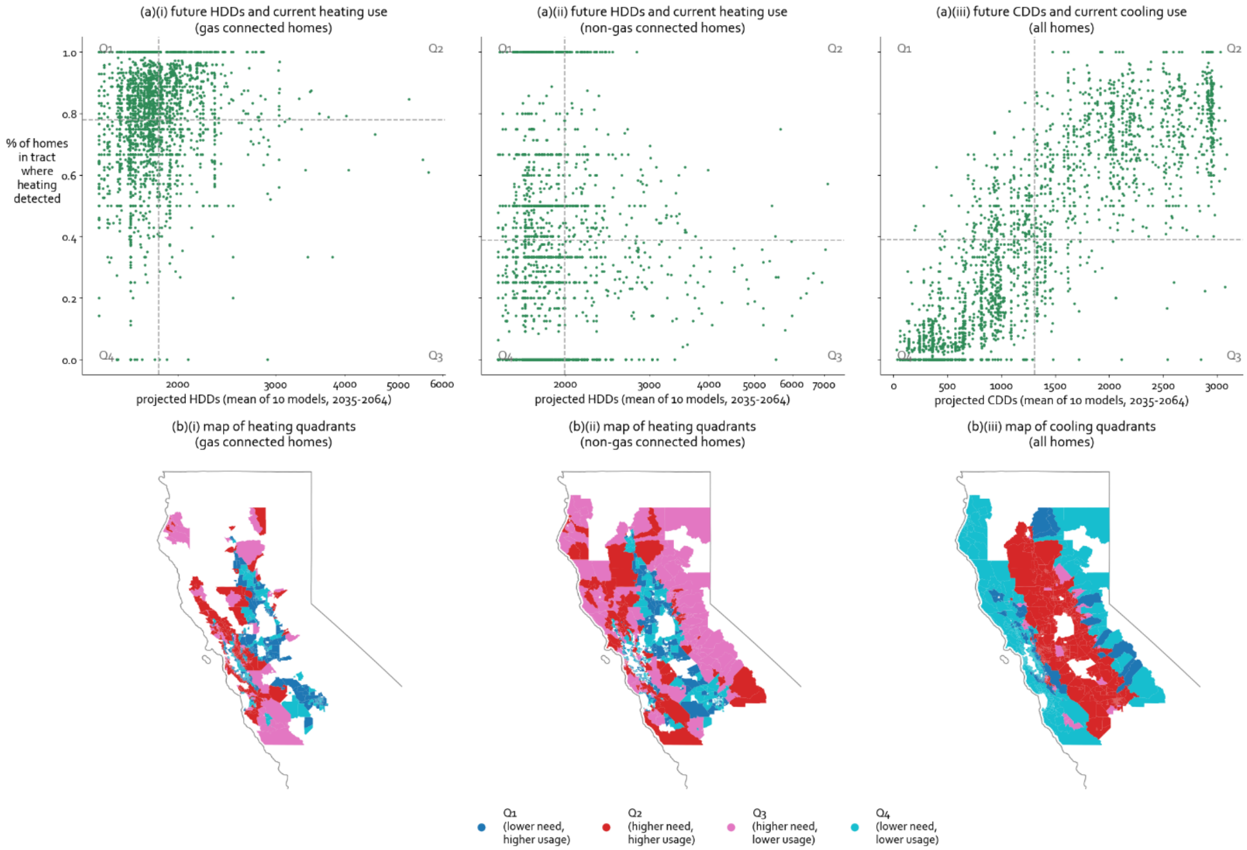

Figure 16 (a) projected heating/cooling needs and current heating/cooling usage with labeled quadrants and (b) map of quadrants for (i) heating use in gas-connected households, (ii) heating use in non-gas connected households, and (iii) cooling use in all households (note that figures (a)(i) and (a)(ii) use a log scale for the x-axis)

Figure 17 shows two notable patterns in the distribution of income and tenure among tracts falling within different heating and cooling quadrants. First, we find that tracts with high projected heating needs but lower current usage have median incomes that skew lower and a proportion of renters that skew higher than tracts with higher projected heating needs and high current usage for gas-connected households, indicating that low-income communities or tenants may have less access to warm households even in a warming climate. Second, we find that tracts with higher cooling needs but lower current usage have a similar income distribution and proportion of tenants to higher need-higher usage tracts, but a lower income and higher proportion of tenants than lower need-higher usage tracts, indicating that low-income communities and tenants in the study area who are most in need of cooling under future climate conditions might have less access than higher-income communities and owners who have a relatively lower need for cooling.

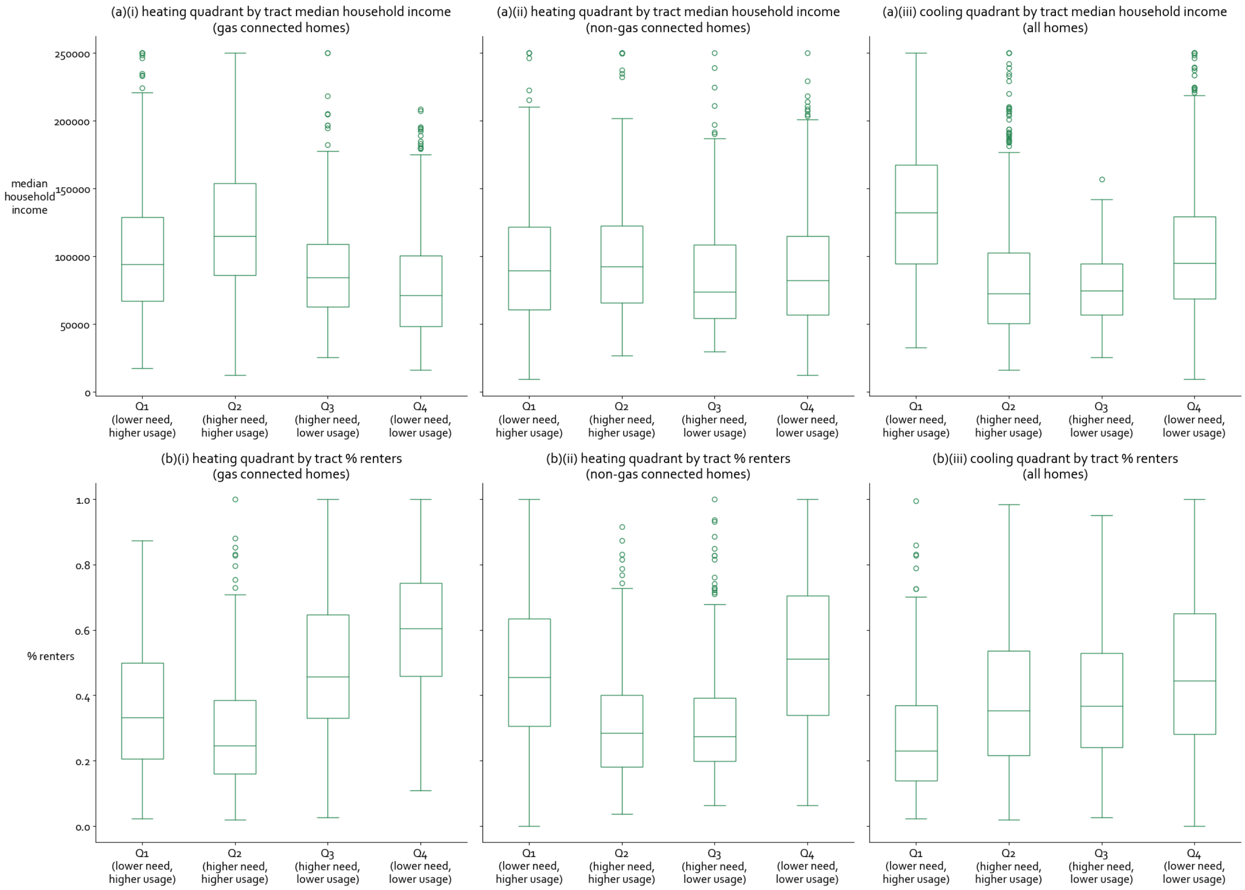

Figure 17 (a) distribution of tract-level median household income within quadrants and (b) distribution of proportion of renters within quadrants for (i) heating use in gas-connected households, (ii) heating use in non-gas connected households, and (iii) cooling use in all households. Lines indicate median values; boxes indicate first and third quartiles of data; whiskers indicate 1.5x the inter-quartile range; points indicate outliers past the inter-quartile range.

# Discussion and conclusion

This paper explores two questions: (1) what is the spatial and demographic distribution of space heating and cooling in Northern California? and (2) are the areas most in need of space heating and cooling in the future currently able to access heating and cooling? We answer these questions using a piecewise regression on energy usage and temperature data, extending existing methods that identify cooling energy use in households to also identify heating use in an area where both heating and cooling needs are prevalent. We combine the piecewise regression designation with a logistic regression and with descriptive spatial and socioeconomic analysis.

We build on existing studies that observe household-level energy usage for space heating and cooling in both methodological and empirical ways. We extend existing piecewise regression methods (as used by (Chen et al. 2018, 2020; Cong et al. 2022)), typically used to detect electric cooling usage in warmer climates, to detect both heating and cooling, including both gas heating and electric heating. To do so, we build on existing approaches to introduce additional decision-making criteria in a region where residents have both heating and cooling needs. We additionally can more precisely measure certain variables – like whether a home is multi-or single-family, or whether a household is enrolled in a bill assistance program – by drawing on utility records rather than census aggregations. We additionally compare estimates from piecewise regressions to estimates from publicly available state and federal survey sources. We generally find that the piecewise regression approach, based on household energy usage, estimates that fewer homes heat with gas and cool with electricity than surveys do, potentially indicating that the surveyed presence of heating and cooling equipment does not necessarily mean that that equipment is used consistently. We also find that our estimate of electric cooling exceeds surveyed results in some climate zones, which might point to the use of electric room space heaters as a secondary heating source.

We also offer empirical insights into the dimensions of heating and cooling use. We discuss those insights below, alongside limitations of our study as well as implications for policy and research.

## Shared indicators of heating and cooling use and need

We find that heating use and cooling use demonstrate similar socioeconomic patterns: wealthier tracts tend to both heat and cool more, while linguistically isolated tracts and multifamily households both heat and cool less. These results hold when controlling for various climatic and geographic factors, including connectivity to utility fuels in the case of heating. These results mirror the findings of similar studies exploring how energy usage for cooling interacts with socioeconomic factors, including studies based in Southern California (Chen et al. 2020) and Arizona (Cong et al. 2022). These results also extend our understanding of access to space conditioning by introducing evidence of widespread inequitable access to heating that is mediated by similar factors to cooling – particularly income.

We also find that as the proportion of children increases in a tract, households are more likely to both heat and cool, and as the proportion of elderly residents increase in a tract, households are more likely to heat, but not more likely to cool. This result suggests that families with children or households with elderly residents may heat their households more. One focus group report from the study area shared accounts from participants of, for instance, turning on the heat when their elderly parents are home to ensure they don’t get sick, or keeping their home warm to avoid triggering their child’s asthma (Environmental / Justice Solutions 2021); the correlations we observe between the proportion of children and elderly residents and heating and cooling use suggest that residents heat and cool more as a protective practice for vulnerable household members.

We find no positive or negative correlation between enrollment in bill assistance program CARE and heating and cooling use, nor do we see a correlation between FERA and heating access. However, we do see a small positive and statistically significant correlation between FERA and cooling use. Because FERA only assists with electric bills, and only serves households of 3 or more, the small positive correlation between FERA enrollment and electric cooling makes sense: unlike heating, cooling is fueled by electricity and thus its cost can be offset by FERA. By contrast, the lack of correlations between CARE and heating and cooling use suggests that CARE, which is the only bill assistance program that covers both gas and electricity usage, is more of a stopgap than a program that enables energy usage for space conditioning.

We also find geographic and socioeconomic patterns at the intersection of future heating and cooling needs and heating and cooling usage. We identify tracts that will continue to have high heating needs even in a warming climate, but currently have lower rates of heating use, and we find that these tracts tend to be lower income with more tenants than tracts that have high needs but currently high rates of heating use. We also identify tracts that will have high cooling needs, increasing in a warming climate, but currently have low cooling usage, and find that, though they are comparable in income and tenure to high need-high usage tracts, they tend to have a lower income and more tenants that tracts with low need and high usage. Similar to existing analyses (e.g., (Chen et al. 2020)), we identify tracts that are vulnerable to a warming climate but a lack of cooling access. We also establish that future heating needs will remain relatively similar to current needs in this study area, but lower-income areas with more renters generally do not access heat despite a continuing need for home heating.

## Limitations

Our study is subject to 4 key limitations: (1) our inability to observe heating use in households that use a non-networked source of energy for heating, (2) data omitted in the creation of an analytic dataset from the raw data, (3) our use of an unsupervised method of detecting heating and cooling use, and (4) an operationalization of heating and cooling access that relies on quantitative methods and household-level data. We discuss each of those limitations below.

Because our study relies on utility data, we are unable to fully observe heating use in households that might use a non-networked source of energy for heating, like propane or wood. Our study can only speak to electric heat usage in these households, which may not have gas connections, and we address these households by controlling for the presence of a gas connection in a home. Critically, regions in the study area that tend to use more non-networked sources of energy are also among the coldest parts of the study area, making them important sites to understand the intersection of heating needs and heating access. Sources of heating like propane or wood are subject to their own questions of affordability and access that might be distinct from networked, utility sources of heat like gas or electricity. Understanding access to non-networked heat – which isn’t as centrally provisioned as networked electricity and gas, and thus does not have one institutional source of data – requires survey and interview methods beyond the smart-meter data analysis approach taken in this paper.

Additionally, we retained only about 78% of the data from our raw dataset. The most notable omissions in data are meters outside of the combined gas & electricity service area and meters that were subscribed to a solar tariff at any time in 2019. Filtering on the combined gas &

electricity service area eliminated some observations in the southern-most part of the PG&E service area, where heating needs might be most pressing. Obtaining a full idea of heating and cooling usage in these households would require data requests from multiple utilities to piece together the landscape of gas utilities in that part of California. Filtering on meters subscribed to a solar tariff may have led to an underestimate of households heating or cooling with electricity as households with solar might be able to more economically space condition with electricity.

Critically, our method of detecting heating and cooling is unsupervised: we do not have a labelled dataset that tells us if or when homes are heating and cooling with which to verify our identification approach. In this respect, our approach is similar to prior studies that also use smart meter data and attempt to understand physical characteristics and occupant behavior from a distance. Taking an unsupervised approach may have led to over- or under-estimates of heating and cooling use; validating smart meter-based identification strategies is an important area for future research, as we discuss in the next section.

Finally, our study focuses on access to heating and cooling at the household level, understanding heating and cooling access using quantitative methods. This approach is useful in identifying systematic inequities in heating and cooling use, but it is also necessarily limited; the results from this study should be interpreted alongside broader literature and future research that takes a broad view of heating and cooling access using a range of methods. For one, the household-level focus cannot account for the different ways outside of the home that heat and cold are encountered – for example, in schools or workplaces – or the different ways that thermal comfort is accessed – for example, in public spaces like cooling centers.

Additionally, taking a quantitative approach based in part on census data is inherently limiting. These limitations emerge in part because of the level of aggregation of ACS data: some variables that may impact energy use for space heating or cooling, like the physical condition or efficiency of a home, are unobservable with our data, and while we could observe some variables at the household level, like multi- or single-family status or enrollment in bill assistance programs, other important variables like income or the presence of children or elderly residents were geographically aggregated, allowing for less precise characterizations of households. Furthermore, the meaning and stakes of heating and cooling access differ across households in ways that are not observable or measurable quantitatively. For instance, two households in our data set might both be designated as heating households, but one household might have to reduce spending on other essential expenses to heat their household. These dynamics are not observable using our methods.

## Implications

The limitations above point to several avenues for future research. First, with smart meter-based studies that use unsupervised methods to deduce energy use characteristics (such as this study) becoming increasingly prevalent, studies that validate common smart meter data analysis methodologies like piecewise regressions against actual occupant behavior could be incredibly valuable in guiding future smart meter-based research. Second, we suggest that research on access to home heating remains relevant in a warming climate as research on access to home cooling becomes increasingly important. The shared institutional and infrastructural contexts under which heating and cooling are delivered suggests that continued research on home heating access can complement the rich and emerging qualitative and quantitative literature on planning for and vulnerability to extreme heat (e.g., see (Keith, Meerow, and Wagner 2019)). Third, and relatedly, the limitations of our study point to the importance of understanding access to non-networked forms of heat, which in our study area are prevalent in the coldest regions.

Our results also point to two main implications. First, we contextualize our results on heating and cooling access in discussions of climate mitigation through residential electrification retrofits to suggest that our understanding equitable electrification should encompass more than access to individual technologies like heat pumps. Our results suggest that access to the services that heat pumps are meant to deliver – residential heating and cooling – are, themselves, uneven: we find that income, tenure, and linguistic isolation, among other factors, can explain whether households consistently heat or cool.

Though our study does not identify causal factors for household access to heating or cooling, existing research in the study area points to persistently and increasingly high residential energy rates and a broader a cost-of-living crisis as factors that might limit access to energy services (Borenstein et al. 2021; Environmental / Justice Solutions 2021; Gridworks 2020), and research on household energy use more broadly establishes how material home conditions, access to capital, and access to social networks can shape households' ability to heat and cool (Bednar et al. 2017; Harrison and Popke 2011). A more comprehensive approach to equitable electrification, then, should consider the factors that constitute access to the heating and cooling services electrification is meant to provide: the unaffordability of energy rates, limited or inadequate bill assistance programs, and rising rental rates and costs of living.

Second, though heating and cooling access are constituted by similar factors, they also differ in their provision: in our study area, where households do use their heat, they heat with gas, while households only cool with electricity. To the extent that policy conversations in the study area have encompassed these constitutive factors, they have focused most persistently on equitably reforming electricity rates to encourage decarbonization (Ashford and Chhabra 2023). We argue in this study that heating remains an important and necessary end-use in the study area, but that it is unevenly accessed. Ensuring access to heating while meeting climate mitigation goals might, on the one hand, necessitate similar strategies as ensuring access to cooling. But even optimistic projections of heating electrification project that millions of households in California will stay connected to gas in the coming decades (Mahone et al. 2019), suggesting that, in the absence of careful planning for gas rates and a gas transition, inequities in access to heat might be exacerbated.

# Appendices

## Comparing heating and cooling identification to public datasets

Our approach to identifying homes that use gas and electricity for heating and cooling is based on established (e.g., (Chen et al. 2018, 2020; Cong et al. 2022)) relationships between electricity and gas usage and air temperature. However, this approach is also unsupervised: we do not have a labeled, household-level usage dataset with which to validate our identification approach. To increase confidence in our estimates, we compare our estimates of heating and cooling energy use with information in two publicly available survey and census datasets. These data sources, and the indicators accessed in each, are summarized in Table 7[11].

We use the state-level CEC Residential Appliance Saturation Survey (RASS) 2019 microdata, which includes data from about 39,000 households in California, to compare our estimates of gas and electricity heating and cooling use to reported primary heating fuels and reported air conditioning type. RASS asks: "what type of heating system do you use to heat this home?" and "what type of central air conditioning/cooling system(s) do you have in your home?". RASS constructs their sample by stratifying homes by electric utility, CEC Climate Zone, and a series of other income, home age, and meter type proxies (DNV GL 2020). Publicly available RASS data is geographically aggregated, so we cannot select responses from the specific census tracts that we have data from in this study. To obtain a sample from RASS that is as close as possible to our sample, we consider only responses where PG&E is listed as the electric utility. We do not additionally filter on the gas utility because RASS indicates the gas utility based on survey responses rather than geographic location – in other words, filtering on the gas utility would exclude any households within the PG&E gas service area that are not connected to utility gas, while our dataset retains households in the PG&E gas service area that are not connected to utility gas. As Figure 18 shows, the PG&E gas and electric service areas primarily differ in the southern portions of climate zones 4 and 13, which are served by PG&E electricity but not gas. In interpreting the divergences between our and RASS's estimates for those climate zones, we keep in mind that our samples are not identical. Finally, because RASS is not a random sample, we use the RASS-provided sample weights to construct aggregate estimates of primary heating fuel and AC usage within each Climate Zone in the study area.

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[11] Though the federal Energy Information Administration (EIA)'s Residential Energy Consumption Survey (RECS) 2020 microdata asks about both heating and cooling, we do not include it as a comparison dataset because of its relatively small sample size in California (about 1,152 households) as well as its geographic coarseness which limits comparability with our smart-meter dataset (because the public-use microdata does not provide geographic information beyond the state level, using RECS would leave us with records from much warmer Southern California homes).

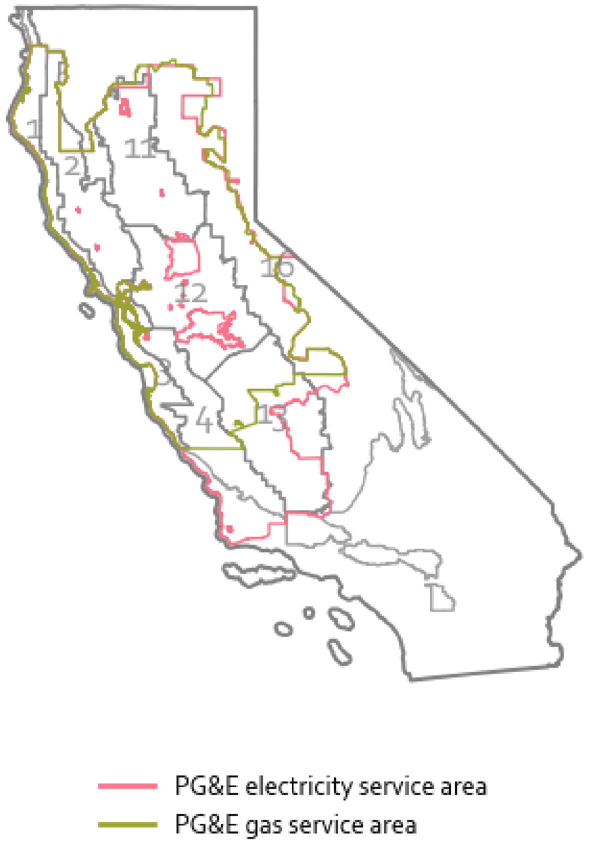

Figure 18 Map of CEC climate zones, PG&E electricity service area, and PG&E gas service area

We use the Census Bureau's American Community Survey (ACS) 2015-2019 five-year estimate to compare our estimates of gas and electricity heating to reported heating fuel on the ACS; here, the census asks: "which fuel is used most for heating this house, apartment, or mobile home?". Unlike RASS, the ACS does not ask questions about air conditioning or cooling. We aggregate ACS primary heating fuel data at the climate zone level using Census Bureau-provided population weights. To obtain a sample from the ACS that is as close as possible to our sample, we only consider data from census tracts that fall in the combined PG&E gas and electric service area.

Both RASS and ACS ask questions that are slightly different from ours. Our approach seeks to detect consistent, increasing energy usage at higher temperatures (for cooling) and lower temperatures (for heating). While RASS and ACS's heating questions ask about heating usage, they do not provide an indication of the consistency with which respondents use their heat. RASS's cooling question simply asks about the presence of a cooling system (rather than cooling use). Still, these survey questions offer valuable information about the presence of heating and cooling systems in households.

Table 7 Summary of consistency check datasets and indicators

| Data source | Indicator(s) | Description | Year of data and spatial aggregation level |
|---|---|---|---|
| RASS | Main heating fuel; type of air conditioning (AC) | Main heating fuel includes twelve options for primary heating fuel (including several central and portable electric and gas equipment options); type of air conditioning includes four AC types and one option for no AC | 2019 aggregated at the climate zone level |
| ACS | Heating fuel used most often | Includes nine options (among them networked gas, electricity, and no fuel used) | 2015-2019 five-year estimate aggregated at the climate zone level |

In Figure 19 we compare our estimates to each data source above. For gas heating, our estimates are lower than both RASS and ACS estimates in all climate zones except for climate zone 1 (where our estimate is greater than RASS, but less than ACS) and 13 (where our estimate is slightly greater than both RASS and ACS). In total, we estimate that just over 50% of all households in our sample are heating with gas, while both RASS and ACS estimate that closer to 60% of all households are using gas as their primary fuel. For electric heating, our estimate exceeds RASS's estimate in all climate zones, and exceeds ACS's estimates in some climate zones (1, 2, 3, and 16) but is lower than ACS's estimate in others (4, 12, 13, and, by a very small margin, 11). In total, our estimate is quite close to ACS's estimate but greater than RASS's estimate. For electric cooling, our estimate is lower than RASS's estimate in every climate zone, as well as in total.

Our results for gas heating and electric cooling support the notion that the presence of heating and cooling equipment – as indicated by RASS and ACS's questions – does not necessarily mean that that equipment is being used consistently enough to meet the heating and cooling decision criteria outlined in this study. The divergent result for electric heating – where we detect more electric heating households than RASS, and in some cases than ACS – might reflect the fact that electric heating can be more easily "stacked" on other heating types as a secondary source of heat. That is, a household can have central gas heating but also use room space heaters.

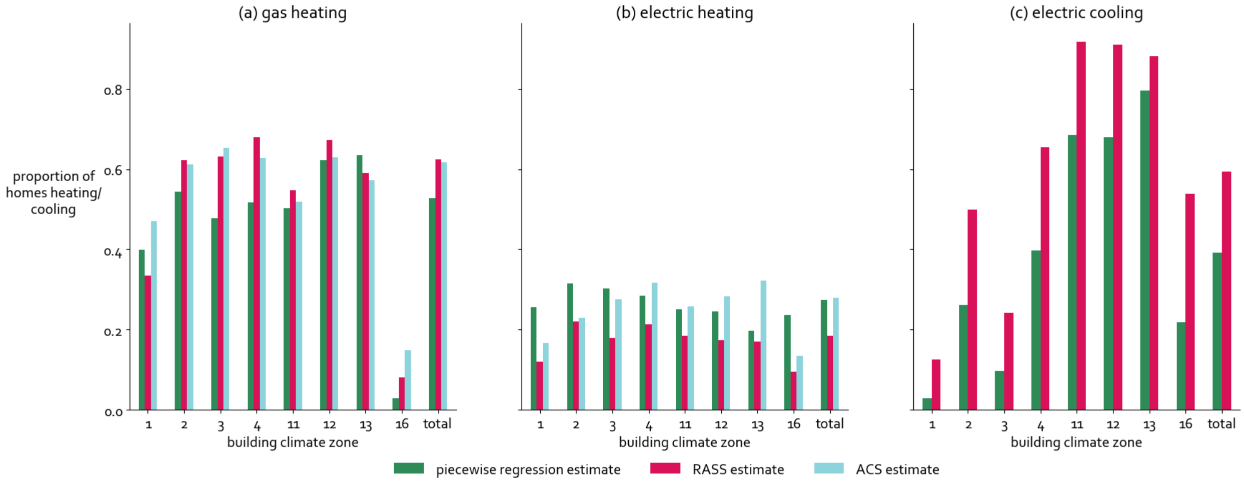

Figure 19 Comparison of piecewise regression, RASS, and ACS estimates at the climate-zone level and in total

## Exploring the relationship between temperature and heating use

We introduce a range of alternative logistic model specifications to determine whether the positive relationship between temperature and heating use is robust, making the following changes to the base model:

> (a) we include additional census tract-level climate variables (relative humidity, precipitation, and wind speed) from NOAA's Local Climatological Data (LCD) (NOAA 2022)[12] to test if other climatic variables can explain the positive relationship between temperature and heating usage (e.g., if areas with warmer winters are actually more humid, increasing heating demand),
> (b) we run the logistic regression only for homes that are gas connected, which eliminates many homes that likely use propane or wood for heating and may also be in colder climates,
> (c) we include additional interaction terms that interact the gas connection status of a home with winter temperature, since gas-connected and non-gas connected homes are distinctly geographically distributed, to see if the temperature-heating use relationship is only observed among homes that are or are not gas connected,
> (d) we replace the climate zone variables with an interaction term that interacts climate zone with temperature to see if the positive temperature-heating use relationship is observed only in specific climate zones,
> (e) we include additional interaction terms that interact home type (single vs. multifamily) with temperature to see if the positive temperature-heating use relationship is driven by a particular home type, and
> (f) we include additional interaction terms that interact tract type (urban, rural, or suburban) with temperature to see if the positive temperature-heating use relationship is driven by a particular type of tract

The results from these tests are shown in Figure 20. There are three notable results in Figure 20: (1) Figure 20(b) indicates that the positive effect of temperature on heating is smaller in magnitude when only gas-connected homes are considered, (2) Figure 20(c) indicates that within gas connected homes, temperature has a non-statistically significant effect on heating use compared to a significant positive effect within non-gas connected homes, and (3) Figure 20(f) indicates that a positive temperature effect is observed within rural and suburban tracts, but no effect is observed within urban tracts. Otherwise, Figure 20(a) suggests that the inclusion of other climate variables, though they are statistically significant, does not change the effect of temperature on heating use, Figure 20(d) suggests that the positive relationship between

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[12] To assemble tract-level relative humidity, precipitation, and wind speed values, we first filtered LCD stations to keep only those with any winter (January, February, December) data for the three variables of interest. Of those LCD stations, the station nearest to each census tract with was identified, and the winter relative humidity, precipitation, and wind speed was calculated as the average of each variable of interest for the LCD station nearest to each tract.

temperature and heating use is present within all climate zones, and in Figure 20(e) we find a positive correlation between temperature and heating use of a similar magnitude for both multifamily and single family building observations.

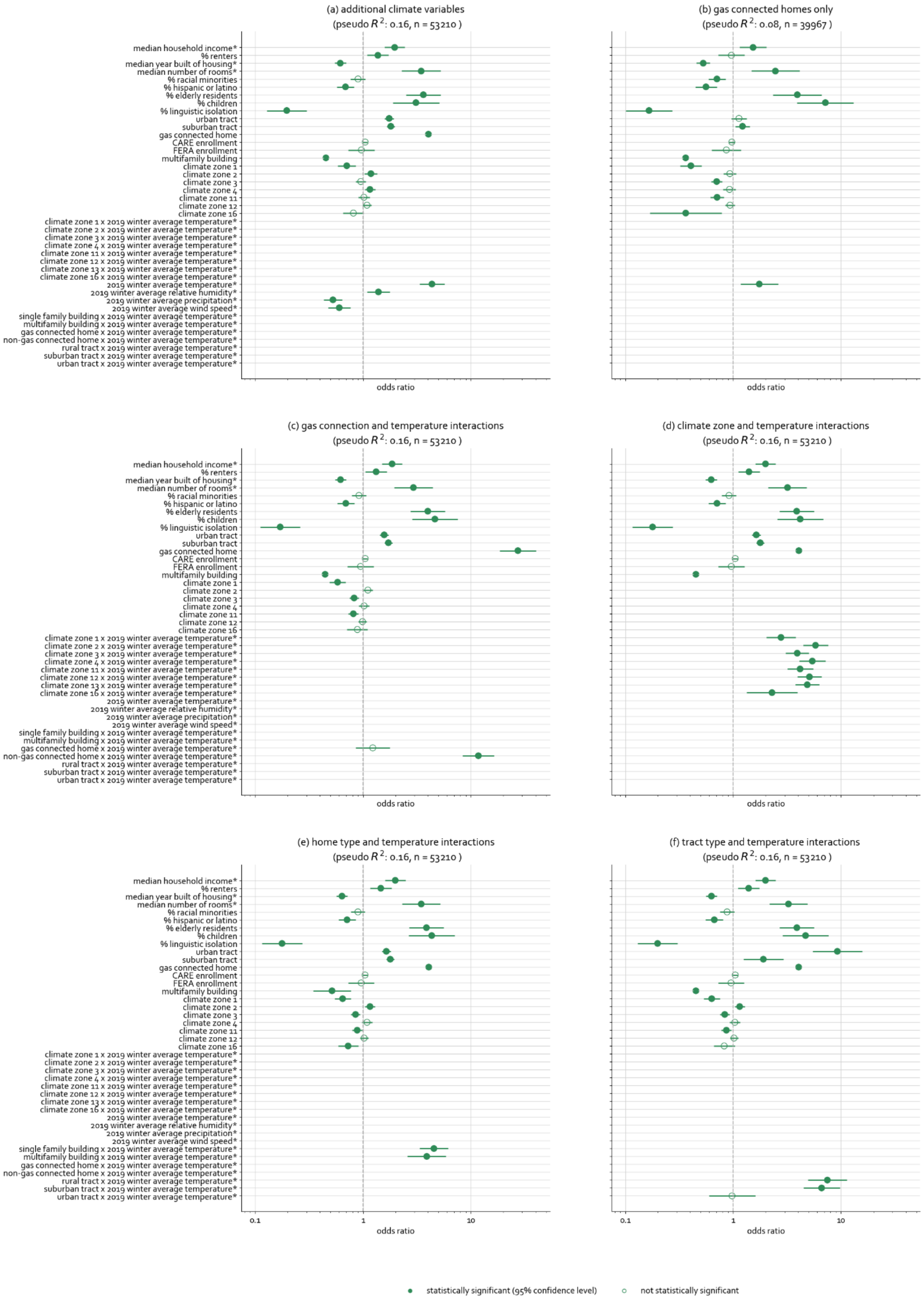
(a) additional climate variables
(pseudo $R^2$: 0.16, n = 53210 )
(b) gas connected homes only
(pseudo $R^2$: 0.08, n = 39967 )
(c) gas connection and temperature interactions
(pseudo $R^2$: 0.16, n = 53210 )
(d) climate zone and temperature interactions
(pseudo $R^2$: 0.16, n = 53210 )
(e) home type and temperature interactions
(pseudo $R^2$: 0.16, n = 53210 )
(f) tract type and temperature interactions
(pseudo $R^2$: 0.16, n = 53210 )
median household income*
% renters
median year built of housing*
median number of rooms*
% racial minorities
% hispanic or latino
% elderly residents
% children
% linguistic isolation
urban tract
suburban tract
gas connected home
CARE enrollment
FERA enrollment
multifamily building
climate zone 1
climate zone 2
climate zone 3
climate zone 4
climate zone 11
climate zone 12
climate zone 16
climate zone 1 x 2019 winter average temperature*
climate zone 2 x 2019 winter average temperature*
climate zone 3 x 2019 winter average temperature*
climate zone 4 x 2019 winter average temperature*
climate zone 11 x 2019 winter average temperature*
climate zone 12 x 2019 winter average temperature*
climate zone 13 x 2019 winter average temperature*
climate zone 16 x 2019 winter average temperature*
2019 winter average temperature*
2019 winter average relative humidity*
2019 winter average precipitation*
2019 winter average wind speed*
single family building x 2019 winter average temperature*
multifamily building x 2019 winter average temperature*
gas connected home x 2019 winter average temperature*
non-gas connected home x 2019 winter average temperature*
rural tract x 2019 winter average temperature*
suburban tract x 2019 winter average temperature*
urban tract x 2019 winter average temperature*
0.1
1
10
odds ratio
● statistically significant (95% confidence level)
○ not statistically significant

Figure 20 Logistic regression results for temperature-heating use robustness checks, relating the probability of detecting heating to (a) base model indicators and additional climate variables, (b) base model indicators for only the subset of homes that are gas connected, (c) base model indicators, with the temperature variable replaced by a gas connection and temperature interaction term, (d) base model indicators, with the temperature and climate zone variables replaced by a climate zone and temperature interaction term, (e) base model indicators, with the temperature variable replaced by a home type and temperature interaction term, and (f) base model indicators, with the temperature variable replaced by a tract type and temperature interaction term. Variables with asterisks (*) are normalized to values between 0 and 1. For climate zones in all figures other than (d), the omitted variable is climate zone 13; for urban, suburban, and rural tract designations in all figures, the omitted variable is rural tracts.

The results suggest that that the strongly positive relationship between winter temperatures and heat use is driven in part by (a lack of) data in the coldest parts of the state, which may be served by propane or wood heat rather than gas heat. As Figure 21 shows, the coldest temperatures in the study area are mostly concentrated among homes that are not connected to gas lines. Still, we observe a statistically significant positive relationship between temperature and the probability of heating use when considering only those homes that are connected to gas (Figure 20(b)). When inspecting homes that are connected to gas, we find that these homes skew strongly suburban, as shown in Figure 22; we also find that urban and suburban homes tend to be located in areas with warmer winters than rural homes (Figure 23). If we interact the tract type – urban, suburban, or rural – with temperature for only those homes that are connected to gas, we only observe a positive relationship between temperature and heating use in rural and suburban tracts. If we further limit our sample to homes in tracts where at least 90% of residents in the 2015-2019 ACS are estimated to have utility gas or electricity for heat (as an additional filter to ensure we are largely including homes that are not accessing propane or wood for heat), we find that a positive relationship between temperature and heating use persists among suburban homes. These results are shown in Figure 24.

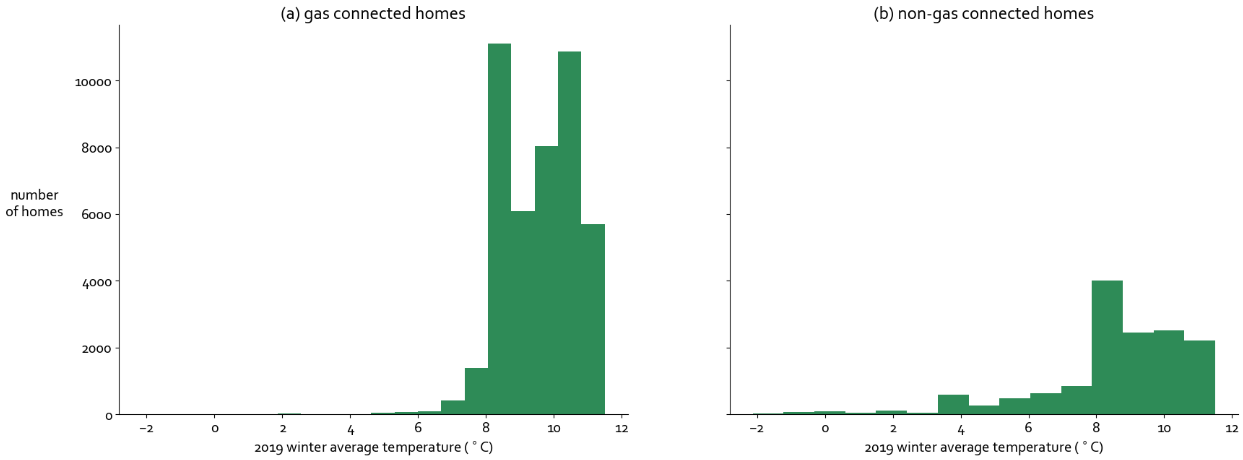

Figure 21 Histogram showing number of homes by 2019 winter average temperature for (a) gas connected homes and (b) non-gas connected homes

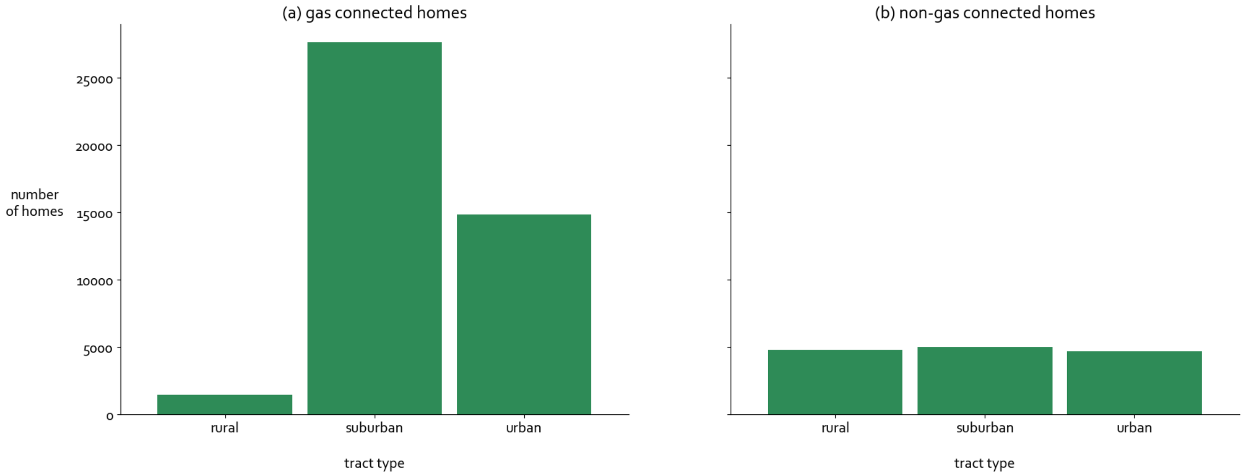

Figure 22 Bar plot showing number of homes by tract rural, suburban, or urban designation for (a) gas connected homes and (b) non-gas connected homes

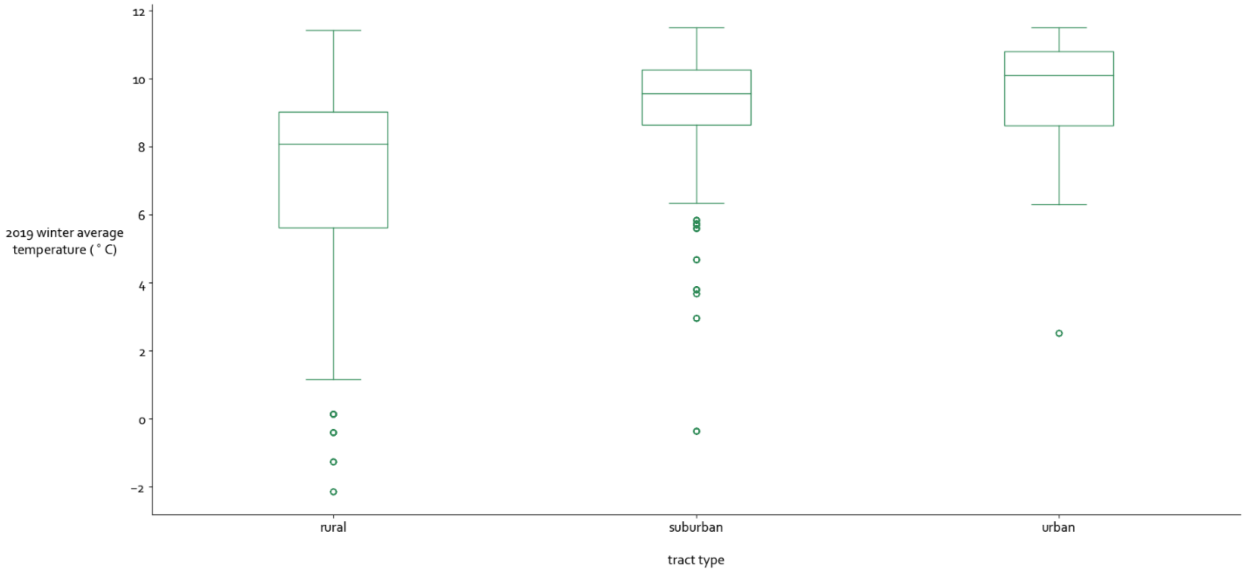

Figure 23 Distribution of 2019 winter average temperatures by rural, suburban, or urban designations for all homes

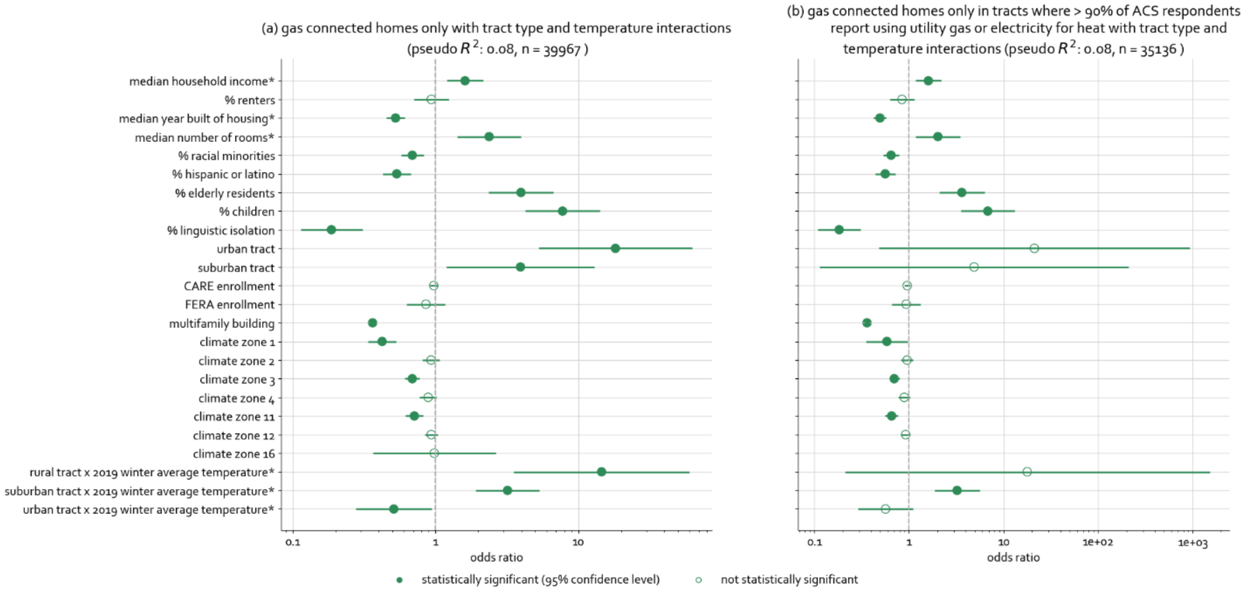

Figure 24 Logistic regression results for temperature-heating use robustness checks that using the base model but replacing the temperature term in the base model with a tract type and temperature interaction term for (a) gas connected homes only and (b) homes that are both gas connected and located in census tracts where over 90% of residents report using utility gas or electricity for heat. Variables with asterisks (*) are normalized to values between 0 and 1. For climate zones in both figures, the omitted variable is climate zone 13; for urban, suburban, and rural tract designations in both figures, the omitted variable is rural tracts.

# Chapter 3 | Constructing equity: planning relationships and the emergence of climate mitigation imperatives

## Introduction

In recent years, city climate action plans have increasingly centered equity or justice as a goal of climate mitigation or adaptation in what has been termed an “equity turn” in climate planning (Angelo et al. 2022). For instance, the number of municipal climate action plans that include justice as an aspiration or area of planning have steadily increased in the past 15 years (Diezmartínez and Short Gianotti 2022). The equity turn reflects a growing recognition of climate mitigation and adaptation as a question of social justice, encompassing both the “common but differentiated responsibility” of responding to climate change, as well as how climate change impacts people “differently, unevenly, and disproportionately” (Sultana 2022). Despite the increasing inclusion of equity in climate discussions, and the critical stakes of an equitable transition, equity remains an amorphous concept. As established by broader discussions on the sustainable city, ambiguous but essential ideals of environmental planning can contain underlying tensions and contradictions, and be mobilized differently by corporate, policy, and grassroots actors (Greenberg 2013).

Many of those climate action plans discuss equity in relation to climate mitigation and decarbonization, and specifically energy interventions, where social justice considerations have historically been sidelined for more techno-economic framings (Miller, Iles, and Jones 2013; Wachsmuth and Angelo 2018) and where equity programming is often initiated by community groups rather than by policy-makers (Carley and Konisky 2020). This paper investigates how equity emerges as a planning ideal, tracing cities’ initial articulation of equity as a climate mitigation goal to the incorporation of equity into planning for residential heating electrification - the process of transitioning homes from using fossil fuels to using electricity for space and water heating - which is increasingly foregrounded in climate change mitigation policy, particularly in the urban US (Gough 2021; Mahone et al. 2019; Rocky Mountain Institute 2020).

Residential heating electrification and building energy interventions more broadly are often characterized as an opportunity for urban climate policy, with local governments in many US states having the authority to set building codes that are more stringent than state law (C40 Cities 2022). But as cities reorient climate mitigation and decarbonization around questions of social justice, mitigation policies become not just opportunities for urban climate action but questions of how structures within and outside a city’s jurisdiction can result in distributional inequities (Neij and Heiskanen 2021). For residential heating electrification, for instance, the risk of displacement due to home retrofits and poor tenant protections, questions of state and federal funding availability, and the affordability of energy bills for gas or electric customers -

among other concerns - are at the root of equitable electrification planning (Emerald Cities Collaborative 2020; Greenlining Institute 2019).

Through detailed case studies of two equitable residential heating electrification planning processes, this paper investigates how cities arrive at equity aspirations as well as how municipal climate governance constructs ideas about equity. In particular, I contextualize this process of constructing equity in the legacy of technocratic planning in the energy and decarbonization realm as well as in the multi-scalar issues at the heart of (in)equitable residential heating electrification. I focus on the Northern California cities of Oakland and San Jose, which have made early, public commitments to equitable residential heating electrification (City of Oakland 2020a; City of San José n.d.-b). This paper demonstrates that our understanding of "equity" is not predetermined but is dynamically shaped by relations between planning actors. In particular, this work establishes how consultants are central to this relational understanding of equity as actors that can advocate for or gatekeep equity aspirations and can position themselves as both technical and procedural experts.

## The politics of equity in local environmental planning

As both climate planning and research orient towards equity, scholars have increasingly explored diverse and divergent understandings of equity and how, in practice, equity is incorporated into climate planning. While this paper focuses on equity as a climate and environmental planning ideal, mirroring the language used in the municipal climate planning processes around which this paper is centered, the broader discussion about equity is inseparable from discussions of both climate justice and sustainability.

Ikeme (2003) clarifies that, in environmental contexts, equity typically attends to procedural elements and distributional outcomes, but justice itself is a broader, overarching term that includes and expands beyond procedural and distributional justice. Normative concepts and critical assessments of climate and environmental justice efforts, then, are closely linked to climate equity. Like "equity", "sustainability" is an open-ended concept that can guide local environmental planning as a common-sense imperative, even when linked to multiple and sometimes conflicting discourses and uses (Redclift 2005). Equity is often by definition a component of sustainability through the "three Es" sustainability framework of environment, economy, and equity (Giddings, Hopwood, and O'Brien 2002; Redclift 2005), though, in practice, equity can be sidelined in sustainability planning (Zapata and Bates 2017). Turning to the literature on sustainability alongside scholarship on climate justice and equity planning can help us understand how ambiguous terms are used by local governments.

As broad and contested terms, climate equity and climate justice might belie multiple and sometimes conflicting understandings. As Newell et al. (2021) identify in a review of scholarship and research on climate justice, diverging understandings of climate justice reveal differences in scale, silos between climate mitigation and adaptation, and an integration - or separation - of climate justice and other justice claims. Diverging understandings of environmental planning ideals can also emerge temporally. In Campbell (2016)'s reflection on the evolution of sustainability as a planning ideal, sustainability is a dynamic concept, "reflexive [and] iteratively pulled by other ideas and social forces." While this flexibility can make sustainability an empty signifier or a co-opted concept, it can also serve as a unifying concept or retain a "big-tent organizing function" (Agyeman 2008; Campbell 2016).

Equity, too, can become a signifier divorced from the contexts and legacies that it is meant to confront. Angelo et al. (2022), who investigate the integration of equity in Climate Action Plans (CAPs) in California, find that equity goals are infrequently integrated with policy even where CAPs name equity as a goal. Instead, CAPs maintain a technical, carbon emission-reduction orientation, without proposing policies that confront racial or economic inequality. Likewise, comprehensive plans in California, even when assessing and incorporating environmental justice principles, infrequently address race or racism (Brinkley and Wagner 2022). Similarly, sociologists and geographers studying how "sustainability" is used and conceptualized in the city find that the term can be instrumentalized by both local governments and corporate actors as a branding device or asset to attract further investment (Béal 2015; Greenberg 2013, 2015; Knuth 2016, 2019). Still, Greenberg (2013) argues, "non-market" conceptions of sustainability continue to exist and resonate with a broad cross-section of grassroots environmental actors: "to keep alive and advance towards dreams of a sustainable future, it is first necessary to grapple with underlying tensions and contradictions of the term" (Greenberg 2013:4).

What tensions and contradictions must we grapple with to advance towards equitable climate policy? Though climate equity is a relatively nascent imperative, equitable planning, more broadly, is associated with the framework and practices of equity planning, in which planners are political actors working within and beyond municipal governance structures to advance redistributive policies (Krumholz and Forester 1990; Metzger 1996; Zapata and Bates 2015). Here, planners are widely conceptualized: a planner is not just a professional planner in a municipal department, but also, for example, a member of a community-based organization or a regional or state agency staff member. Critically, equity planning is relationship based: it requires both oppositional and collaborative approaches, and long-term relationship-building across sectors and scales (Zapata and Bates 2015). Integrating climate change and environmental justice considerations requires the engagement of a broad set of civil society actors, whose agendas and expertise can differentially influence the development of local environmental plans (Mendez 2015). It is in these relationships, and the participation structures and deliberative processes that facilitate the inclusion of different actors, that tensions and contradictions can arise in how equity is understood.

## Unpacking participation and planning relationships in (equitable) climate planning

Equitable or just climate planning processes are realized in part through procedures, structures, and resources that facilitate relationships between planning actors, which might include frontline community members or members of community-based organizations (CBOs), city, state, or regional agency staff, or consultants. These resources and procedures, including workshops, engagement sessions, webinars, and opportunities for public comment, are often characterized as elements of participation or community engagement, blanket terms for the different ways that local governments ostensibly share information or seek feedback and direction on policy development. In reality, there are many different purposes and interpretations of participation, and participation doesn't always succeed at - or even intend to - facilitate the inclusion of diverse communities or communities impacted by the policies at hand. Participation can be instrumental, deployed as a means to secure support for a development, or principled, incorporated in planning as a fundamental right that aims to mobilize collective action and empowerment (Pretty 1995).

Planning scholars exploring the possibilities of participation in the context of local climate mitigation and adaptation initiatives point to long-term relationship building and capacity building as well as shifting the balance of power in environmental governance as elements of non-instrumental participation in service of equitable climate policy. Fitzgerald (2022), investigating Climate Action Plans (CAPs) in five US cities (Austin, Baltimore, Cleveland, Portland, and Providence), finds that equity planning and pledges require concerted trust-building, particularly between planners and the communities for which they aim to deliver equitable outcomes. Critically, the interests of communities meant to be served by equitable climate action can be in opposition to more established or well-resourced actors. Schrock et al. (2015), comparing the approaches of three US cities (Boston, Philadelphia, and Portland) prioritizing equity in their climate action planning, argue that equitable planning requires capacity on the part of both public officials and community organizers to both advocate for and analyze equity goals and also to counter or reframe the interests of larger coalitions, including mainstream environmentalists, businesses, and corporations.

Such an increase in capacity and agency can be viewed as part of a broader restructuring of decision-making to ensure that affected communities share power in governance. As MacIver et al. (2022) identify in an assessment of a collaborative air quality management process in Oakland, a shift in the distribution of power in environmental governance requires environmental agencies to take on a different role, from implementing top-down plans to providing technical training to residents that supports community members' informed participation. Conversely, an instrumental or limited approach to participation can actively disempower community members. Sociologists and urban studies scholars studying sustainability and water resource planning in New York and California find consistent patterns of environmental justice being de-linked from technical questions, where environmental justice is understood as a "special interest" that is tangential, or even a distraction, to environmental goals (Checker 2011; London, Sze, and Lievanos 2008; Sze, Gambirazzio, et al. 2009; Sze, London, et al. 2009).

If environmental and climate justice is to be integrated with technical decision-making to facilitate shared power in governance among communities affected by environmental or climate injustice, then equity planners need to pay particular attention to the forms of knowledge that are valued and incorporated at different stages of climate planning. The de-linking of participation or community engagement and decision-making can reflect the persistence of technocratic planning approaches, which give preeminence to policy making approaches that favor quantitative measures, like cost-benefit or risk analyses, define urban problems through narrow models or codifications, and sideline deliberative processes (Raco and Savini 2019). As sociologists and planning scholars identify, climate plans, even those that purport to be equitable or just, often reflect underlying technocratic planning by maintaining an exclusively carbon emission-reduction orientation or failing to acknowledge the links between climate mitigation and adaptation and historical legacies of injustice (Angelo et al. 2022; Anguelovski et al. 2016). An alternative to technocratic approaches is the incorporation of local knowledge, particularly through deliberative processes in which the knowledge of residents affected by an environmental issue is valued alongside professionalized knowledge. Planning and public health scholars argue that this incorporation can help avoid reductive understandings of urban environmental problems, raising previously unacknowledged concerns and identifying effective, context-specific analysis and implementation options (Corburn 2003; Smith et al. 2022).

## Situating consultants in equitable climate planning

The existing planning literature on local climate equity advances our understanding of how participation structures, approaches, and resources shape planning relationships, largely focused on the relationships between cities and community-based organizations (CBOs) and sometimes also positioning larger environmental organizations, professional or government scientists, and corporate coalitions in that relationship. However, the broader planning and public administration literature on local environmental planning shows that consultants are another key actor in configuring participation and policy visions. This section explores how consultants can be understood in the context of climate and environmental equity and justice scholarship.

Beveridge (2012), who traces historical scholarship on consultants in public policy, describes consultants as a “shadow government” whose influence is justified by a changing articulation of the role of the state from rational planners to cost-cutters to partners with the private sector. At the local level in particular, the predominance of consultants is attributed to leaner budgets combined with larger and more complex scopes of planning (Loh and Norton 2015). Critically, the planning and public administration literature largely focuses on multinational firms and management consultants, though scholars have acknowledged the diversity of consultants and think tanks active in public policy (Head and Crowley 2015) .

Consultant-driven planning is closely related to the different manifestations and purposes of participation for three reasons. First, as Scott and Carter (2019) identify in their study on the influence of private consultants on a collaborative water management process in the state of Georgia, the business model of consultancies cause consultants to be more reliant on prior experience than the specific context at hand to assemble policy. This reliance can manifest in the form of prescriptive recommendations (Scott and Carter 2019), the blanket promotion of specific organizational practices (Kipping and Wright 2012), and the circulation of dominant urban design paradigms among varied cities (Loh and Norton 2015). If equitable climate planning requires the integration of local, specific experiences and knowledge (Corburn 2003; Mendez 2015), a reliance on consultancies risks undermining this integration by prioritizing policy approaches that are potentially divorced from local contexts. As Beveridge (2012) argues, the predominance of consultants in and of itself reflects a valuing of private-sector knowledge and expertise as superior to, more "efficient", and more specialized than that of public administrators or residents.

Second, as Keele (2019) argues in an investigation of how consultants shape climate adaptation policy in Australia, the embeddedness of consultants - particularly consultants who prescribe particular policy approaches or organizational form - remakes governance in a "neoliberal image" of efficiency, accountability, and entrepreneurialism, positioning climate policy as a site in need of constant management, and, in turn, constant consulting. If equitable climate planning requires long-term relationship and capacity building (Fitzgerald 2022; Schrock et al. 2015) but, simultaneously, the need for consulting is constantly reproduced, then consultants might become the actors at the center of that long-term approach, dictating the trajectory of trust and resource allocation between cities and community-based organizations.

Finally, as Beveridge (2012) argues, consultants can also capitalize on the perception of consulting firms as neutral communicators through a process of "depoliticization", where actors emphasize their expertise and de-emphasize their political role. Depoliticization can give way to "arena shifting", where decision-making, now framed as apolitical, moves away from formal institutions to arenas where there is less scrutiny, and where roles and responsibilities of individual actors are more unclear. A depoliticization of climate planning can sideline the explicitly political measures needed to realize non-instrumental participation, including capacity building, shifting the balance of power and decision-making, and intentionally valuing non-professionalized knowledge.

The interdisciplinary literature on consultants in environmental planning establishes consultants as agential actors that emerge in a context of shrinking budgets and changing and expanding articulations of the role of the state in environmental governance. The themes that emerge in this literature interact closely with the broader social science literature on realizing equitable or just climate action, motivating a closer examination of how consultants, cities, and CBOs interact in equitable climate planning processes.

## Methods, study area, and timeline

How do cities arrive at equity aspirations? How does municipal climate governance construct ideas about equity? To answer these questions, I take as case studies the cities of Oakland and San Jose, which have made early, public commitments to equitable electrification (City of Oakland 2020a; City of San José n.d.-b). Oakland and San Jose were chosen for this research as two cities in a transitional space between committing to equitable residential heating electrification and drafting roadmaps to achieve those commitments. These two cities are not necessarily positioned as comparisons, but as two cases of municipal commitments to equity that, together, allow us to form a clearer and more robust idea of how equity is conceived in cities, allowing for the development of a richer theoretical argument through cross-case conclusions (Yin 2014:46–48).

## Methods

I approach this question using semi-structured interviews, participant observation at primarily virtual city workshops and meetings, and document analysis. Semi-structured interviews (about 40 in total) occurred with staff at city staff, housing, energy, labor and environmental justice advocacy organization staff and volunteers, and utility and community choice aggregator staff. Interviews were conducted both online and in-person, and typically lasted 1 to 1.5 hours. I initially identified interview participants through a systematic review of planning documents and city council minutes relevant to electrification interventions. I additionally reached out to local housing, energy, labor, and environmental justice organizations that may not have been officially consulted in city planning processes to understand if or how they approach electrification discussions. Because environmental and energy justice advocacy in the Bay Area is interconnected across cities and geographies, I additionally interviewed energy justice coalition members who work primarily in proximal cities including Richmond and San Francisco but work closely or in coalition with advocates in Oakland and San Jose. This qualitative data collection occurred over 1.5 years, from summer 2021 through the end of 2022.

Interviews and documents were coded inductively and iteratively and analyzed alongside reflections from participant and workshop observation using a constant comparative method aided by memo writing (Boeije 2002; Thornberg and Charmaz 2017). Specifically, interview and document excerpts were assigned an initial set of descriptive codes as they were read and re-read (that is, without a predetermined set of codes), largely identifying actors (e.g., "consultant", "city staff"), processes (e.g., "modeling for climate action plan"), and sentiments and experiences (e.g., "urgency", "hesitation"). Writing memos about and around excerpts enabled a comparison between and within interviews, documents, and observations, making way for an evolved set of codes that were more generalized and analytical (e.g., "challenging technocratic planning"). This iterative process of coding, re-coding, and comparison allowed for themes to emerge from the data and enabled a richer understanding of conceptions and operationalization of equity in Oakland and San Jose's climate mitigation planning.

## Study area and timeline

Figure 25 indicates key planning events in relation to equitable electrification in Oakland and San Jose, allowing us to situate both cities' equity pledges and discourse in the wider context of climate planning and electrification efforts municipally and at the state and federal level.

### Oakland

The City of Oakland's climate change planning began in 2012, with the publication of the Oakland Energy & Climate Action Plan, a collection of 175 climate change-mitigation oriented city actions to achieve a 36% reduction in GHGs by 2020 (City of Oakland 2012). The Energy & Climate Action Plan was authored by city staff along with representatives from regional agencies and several contracted consulting agencies. Building electrification was not mentioned in the 2012 plan, which framed building emissions mitigation largely in terms of weatherization and energy efficiency improvements.

In 2018, the City of Oakland revisited their climate action planning with the Equitable Climate Action Plan (City of Oakland 2020a), a collection of about 40 actions with the goal of "identify[ing] an equitable path toward cost-effectively reducing Oakland's local climate emissions a minimum of 56%, transitioning away from fossil fuel dependence, and ensuring that all of Oakland's communities are resilient to the foreseeable impacts of climate change, by 2030." In mission, then, the 2018 Equitable Climate Action Plan differed, and was more expansive, than the 2012 Energy & Climate Action Plan: it explicitly aimed for equity and offered climate resiliency along with mitigation as an objective (though the 2012 Energy & Climate Action Plan included actions around climate resiliency, its stated objective was the reduction of Oakland's GHG emissions and energy usage). In process, too, the 2018 Equitable Climate Action Plan diverged from the 2012 Energy & Climate Action Plan-writing process: along with city staff from a range of departments, chiefly the Environmental Services Division but including housing, public works, workforce development, and other departments, regional agencies, and contracted consultants, the ECAP involved a community advisory committee, a neighborhood leadership cohort, and several community-based organizations.

For residential buildings, the ECAP laid out two primary actions: eliminating natural gas in new buildings, and developing a plan for all existing buildings to be efficient and all-electric by 2040 (City of Oakland 2020a), framed in terms of metrics for success (for instance, the number of building electrification retrofits) and city advocacy actions (for instance, securing additional funding to eliminate natural gas in disadvantaged neighborhoods). The Oakland City Council delivered on the first action by the end of 2020, passing a Building Electrification Ordinance that required all newly-constructed buildings to be all-electric (City of Oakland 2020b), while the existing buildings plan, originally meant for release in 2022, remains under development. The existing building plan under development is constructed by both city staff and other local consultants, though not the same ones involved in the creation of the ECAP.

### San Jose

San Jose's early documented municipal climate action begins with the 2007 adoption of San Jose Green Vision, an early municipal sustainability plan with goals of clean tech job creation, energy use reduction, and renewable energy adoption (City of San José 2007); Green Vision was not referenced in interviews. More recently, in 2018, the San Jose city council adopted Climate Smart San Jose, a municipal climate action plan that aimed to meet the goals of the Paris Agreement after the US withdrew from the agreement. The climate plan was authored by city staff and contracted consultants from several multinational management consulting firms.

Climate Smart San Jose outlined nine key strategies, each with several associated actions; among these strategies was to make homes fully electric (City of San José 2018). Climate Smart San Jose sparsely used the language of climate equity or justice, referencing equity only in passing in the context of aligning Climate Smart with the city's General Plan, which does hold social equity as a goal.

In 2019, San Jose became one of 25 cities participating in the first American Cities Climate Challenge (ACCC), an initiative of Bloomberg Philanthropies. The ACCC functioned by placing one climate advisor – a full-time staff member who would work for the city for the duration of the challenge – in each participating city's environmental services division. Beyond the climate advisor, cities were able to access consulting services from a set of partners, largely national environmental organizations, consultancies, and thinktanks, including the Natural Resources Defense Council (NRDC) and the Institute for Market Transformation. The ACCC focused particularly on climate policy for transportation and buildings, citing these two sources of GHG emissions as areas where mayors had "significant authority" (National Association of City Transportation Officials 2019). Additionally, the staff supporting the ACCC helped with political and campaign work – sending speakers in support of a particular climate policy to a council meeting, for instance, or meeting with council members or their chiefs of staff.

In late 2020, following the initial wave of 2020 municipal gas bans across California, the San Jose City Council approved a set of two natural gas ban ordinance that prohibited gas in new residential buildings, and many commercial ones (Wipf 2020)[13]. These ordinances were attributed to both the work of the ACCC staff along with campaigning and advocacy from several local chapters of national environmental organizations, including the Sierra Club and Mothers Out Front. By 2022, San Jose had published a framework for electrifying existing buildings (City of San Jose Department of Environmental Services 2022). In language, it differed notably from prior planning documents: the framework was "centered on community priorities", and posited "to reduce GHG emissions from existing buildings…while bringing to the forefront the concerns and priorities of historically marginalized communities."

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[13] San Jose's gas ban in new buildings passed with notable controversy: Bloom Energy, a fuel cell manufacturer with close ties to the mayor, successfully lobbied for an eleventh-hour exemption that would include their company's facilities (Nguyen and Herrera 2021), a change that "significantly weakened" the potential climate benefits of the ordinance in the view of one of the staff members linked to the ACCC, and remains a subject of advocacy for local environmental activists.

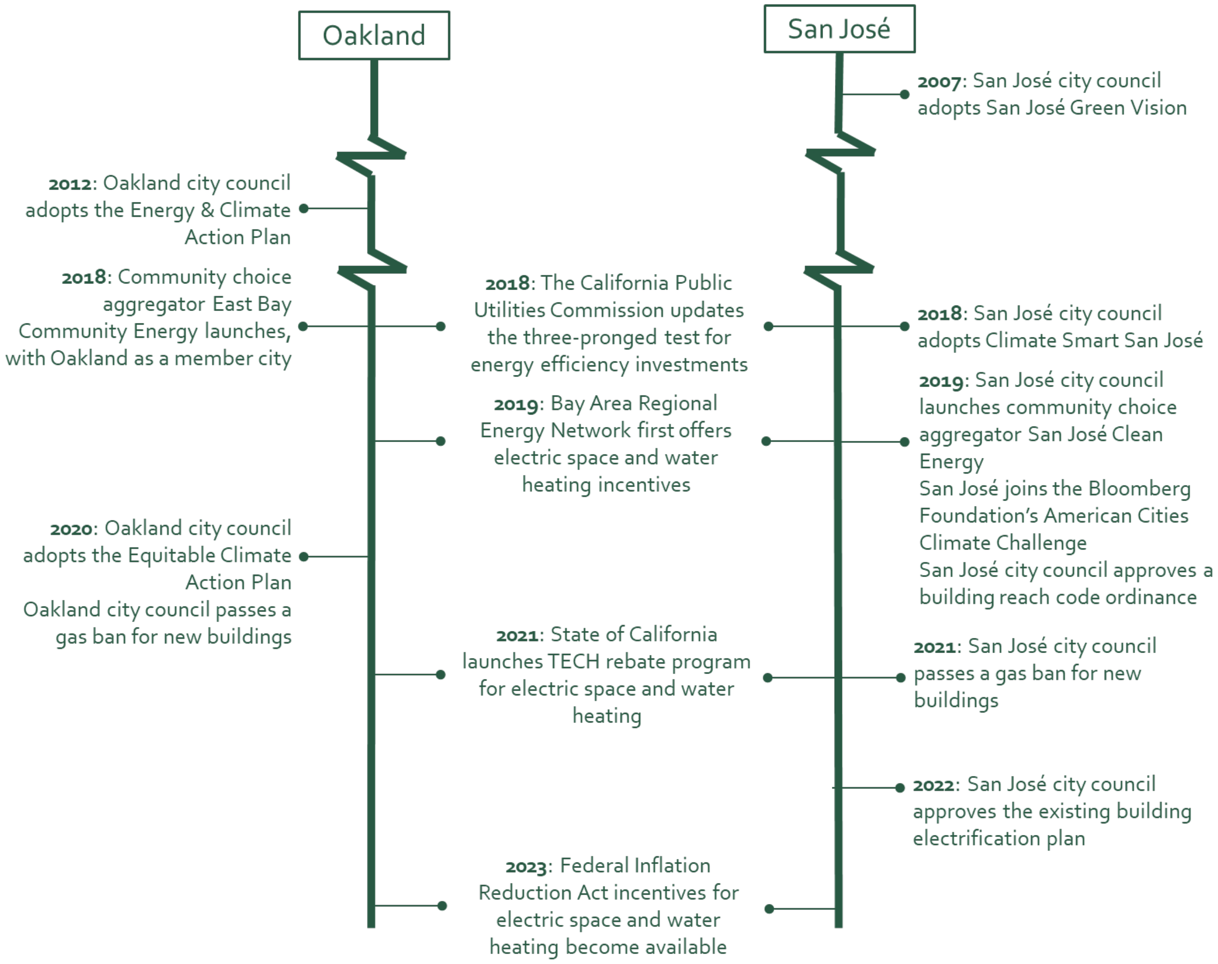

Figure 25 Timeline of key building electrification events in Oakland and San Jose, with key state and federal events in the center

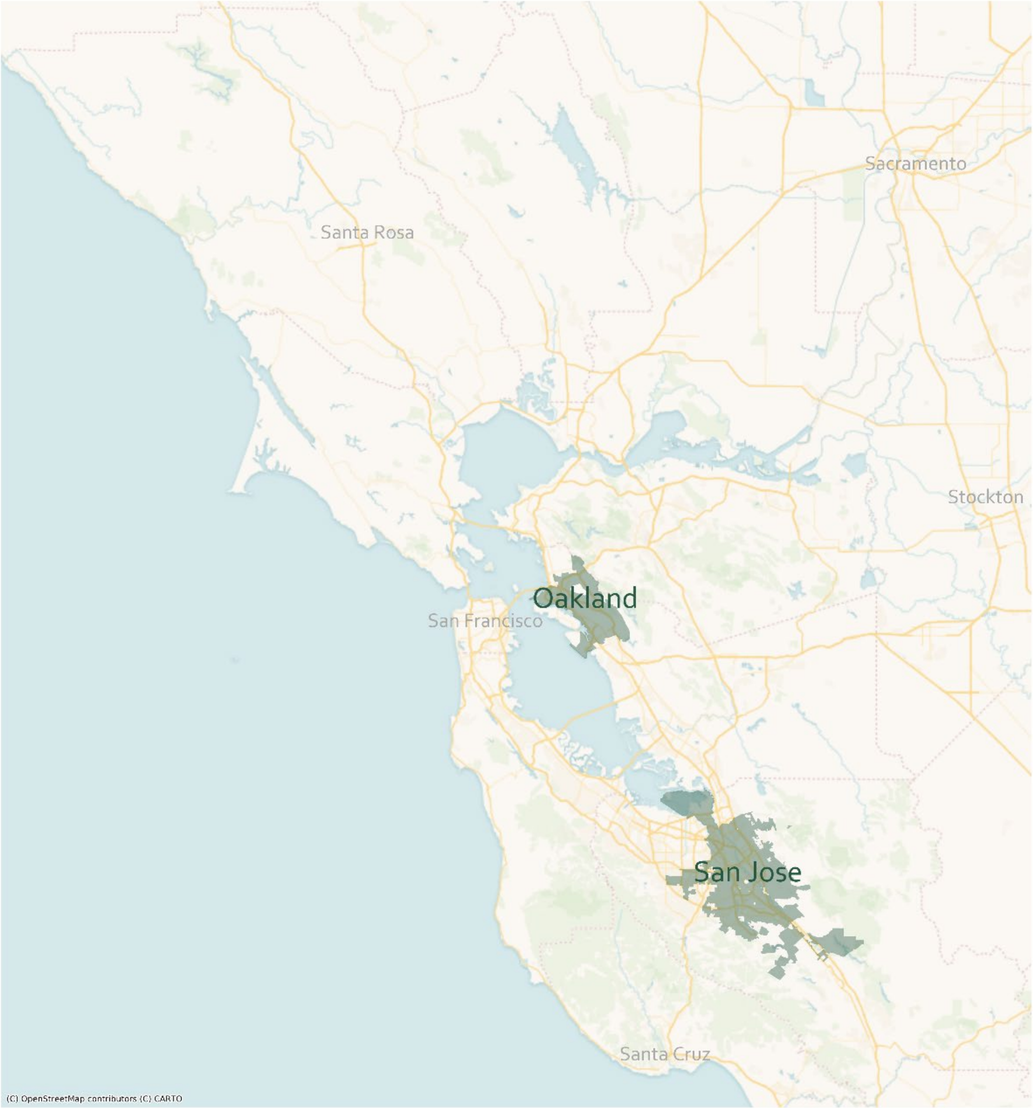

Figure 26 Oakland and San Jose, the two case study cities, in the broader San Francisco Bay Area

# A relational understanding of the equity turn

As demonstrated above, Oakland and San Jose did not always articulate equity as a goal of climate planning; rather, these goals emerged over the course of a decade or more of municipal climate planning. In the sections below, I argue that equity as an aspirational municipal goal is constructed through relations between three primary actors: contracted consultants, community-based organizations (CBOs), and city staff. Rather than conceiving of these relations as a cycle of dialogue between equivalently resourced and positioned actors, I argue that consultants, as intermediaries between CBOs and cities, are the key mediators of equity aspirations within a city.

Investigating Oakland and San Jose side-by-side demonstrates the heterogeneity of how consultants position their expertise, while investigating the trajectory of both cities shows how the equity turn has given way to both new forms of consulting and expertise. Specifically, I find that in San Jose, where national or multi-national consultants dominate climate planning, these consultants can act as gatekeepers of new planning concepts, in a sense allowing equity planning to happen and recreating themselves as procedural experts in the process. Conversely, in Oakland, we can see a transition from national consultancies to more locally embedded consultants through the equity turn; here, consultants act more as advocates, coming into conflict with and reshaping the city's established modes of climate planning.

## The advocates and gatekeepers of equity aspirations

In both Oakland and San Jose, consultants – and their funders – played critical but diverging role in the articulation of equity as an aspiration. In Oakland, local consultants advocated for equity, in the process coming into conflict with established modes of planning and the practices of larger, national consultancies. In San Jose, philanthropic funding channeled through consultants gatekept equity, allowing non-city nor CBO actors to decide if and how equity was incorporated into climate and electrification planning.

The conflicting roles of local versus national consultants in Oakland is evident in the challenges that emerged throughout the process of moving from a largely technocratic 2012 Energy & Climate Action Plan to a more bottom-up Equitable Climate Action Plan (ECAP). The analytical inputs for the ECAP proceeded in two phases. One was an internal modeling effort, led by analysts at Bloomberg Associates (BA), the consulting arm of Bloomberg Philanthropies, an organization that encompasses the philanthropic activities of former New York City mayor and stock trader Michael Bloomberg. This internal effort was followed by an external community engagement effort, led by three "equity facilitators" – a climate action coalition of several Bay Area-based grassroots organizations, one California-based environmental justice consultancy, and one design and planning consultancy that provided technical analysis services. The first phase – which modeled how different technology interventions would reduce carbon emissions in Oakland – was characterized as a "mini Climate Action Planning process" ahead of the broader ECAP update by a former staff member at BA who worked on the Oakland contract. Modeling emission trajectories in Oakland required input from city staff across a range of departments in pursuit of granular data on Oakland's built environment but remained largely confined to city and BA staff.

As Oakland moved into the external part of the ECAP formation, tensions arose between the modeling and engagement efforts, as articulated by one member of the environmental justice consultancy:

> "On the city's part, they say they want to do equity. But they don't really know what that means. One of the key principles of equity is that the people need to speak for themselves and say what they need and want. And another key principle is that the way we've been doing things so far hasn't been working. So if you tell us, well, this is how it's been done in the past, we're not going to be swayed by that argument. For example, business as usual, and then emissions reductions forecasting, right? That's a central component of climate action planning. Now, it sounds as though it's neutral, but what you include in the baseline of business as usual matters and what you forecast based on that matters. Equity was never embedded into that framework before – what would it look like to have equity embedded in that framework?"

As this interviewee put it, community engagement alone was not sufficient to advance the climate action planning process meaningfully towards equity; to do so required a questioning of many of the established practices of climate action planning, among them how emissions reductions are even calculated. Tensions and questioning in the calculative devices used in climate action planning – greenhouse gas inventories and GHG reduction modeling, for instance – were also alluded to by a technical analyst from the design and planning consultancy, who shared that many of the issues that emerged throughout the community engagement sessions were difficult to tie to actual greenhouse gas reductions through the BA model.

The City of Oakland's use of multiple consultancies, both local and national, thus led to local consultancies taking the explicitly political role of advocates in Oakland's climate action planning process. The critical role undertaken by local consultants can be understood in the context of how these consultancies emerged. For the two smaller consultancies contracted to work on Oakland's 2018 ECAP, their origins were fundamentally tied to equitable environmental policy; the technical and design consultancy began their work with Obama-era Sustainable Communities Regional Planning efforts largely on reservations, while the environmental justice consultancy was borne of local environmental justice lawyers and activists looking to bridge their advocacy and policy work. These consultancies framed their work as explicitly political, a framing that carried into Oakland's Climate Action Planning.

In San Jose, consultants shaped two framings of climate action: first, in 2018, the Climate Smart San Jose plan, whose implementation led to San Jose's involvement in the ACCC and the ensuing climate action and electrification framework. These two framings, only 4 years apart, were markedly different. Climate Smart cast climate action and sustainability as a set of personal actions that would lead to a "high quality of life" through an overarching framing called "Good Life 2.0".; in effect, climate action was framed as a private good that could be achieved by the San Jose resident, someone with the capital and means to achieve the "Good Life 2.0". Underlying this framing of climate action was an imaginary of San Jose as a pool of high-income customers ready to adopt low-emission technology, as shared by an analyst from the consulting firm that led the creation of Climate Smart:

> "The variable is behavioral economics, the rate at which you can adopt green and low carbon goods and services to cause meaningful reduction in $CO_2$ emissions. And that is what San Jose's secret sauce is. They have a pool of early adopters, essentially because they are Silicon Valley. They are willing to take risks. They have low- and middle-income populations as well, but they also have lots of high-income workers. So some of that capital can be directed to things which may not be commercially viable in another neighborhood, like rooftop solar or buying a battery electric car."

Notably, and unsurprisingly, this 2018 imaginary of San Jose as a pool of high-income risk-takers and early adopters directly contrasted with how other actors viewed the city. Two staff members at a local housing organization, for instance, shared this:

> "We [in San Jose] think of ourselves as poor, I think we think of ourselves as struggling to respond to housing needs, even as we build a fair amount."
>
> "People see the South Bay as wealthier folks buying solar panels because they can afford it, mostly in single family areas, or folks buying Teslas or electric vehicles. But that's not something you see from most of the populace in San Jose… I think the city slogan is We're The Heart of Silicon Valley, and we try to appear like we're so technologically forward, but I don't really see it."

2019 brought a new set of actors to San Jose's climate planning as they became one of the 25 cities of the Bloomberg ACCC, and in 2022 San Jose began using the language and promises of equity directly, particularly in their ACCC-funded building electrification planning. Here, both San Jose and the nature of climate action were framed differently: San Jose was a city where "many families are struggling to make ends meet", and addressing climate change meant "minimiz[ing] the burdens and maximiz[ing] the benefits of the transition to all-electric buildings for historically marginalized communities" (City of San Jose Department of Environmental Services 2022). However, the ACCC did not always frame climate action as a question of social equity; rather, this framing was the result of concerted efforts by staff at the organizations and consultancies contracted by the ACCC to change the framing of the challenge. One ACCC staff member recounted this shift:

> "When we started out, the whole project was really laser focused on carbon emissions. But I'd say in 2020, along with the nation, the Climate Challenge experienced a reckoning around race and equity and, I would say, the staff sort of committed to this and tried to bring the institutions around, if you know what I mean. But I think we have been able to really show the funder the importance of this, basically shifting from having climate as the single goal to having climate and equity as shared goals."

These requests existed internally in the Climate Challenge before the summer of 2020, but were met with disinterest from Bloomberg Philanthropies until the summer of 2020. Another staff member of a contracted organization shared that part of the difficulty of incorporating equity was Bloomberg Philanthropies' – and by extension, Michael Bloomberg's – fixation with metrics: "[Michael Bloomberg] is a living donor whose sole focus, whose claim to riches was all around data". After the summer of 2020, when the consultants contracted to work on the ACCC had authorization to reframe the Climate Challenge as a climate-and-equity project, the work of the Climate Challenge consultants shifted from technical assistance work to stakeholder engagement work. New consultancies were brought in, some specifically focused on "equity consulting", and a set of local CBOs were invited to shape and provide input on the plan.

San Jose's shifting climate framings – from private climate action for wealthy early adopters to the carbon emission-centered of the early ACCC to the equity focus of the later ACCC – demonstrates how both consultants and philanthropy can gatekeep planning concepts, recasting the nature of both individual cities and climate action according to internal priorities. In San Jose, equity aspirations were the result of a tension between consultancies and contracted organizations and their funders. Local actors – the city itself, as well as its CBOs – were relatively removed from the struggle to articulate equity as an aspiration and were re-inserted once Bloomberg Philanthropies authorized a new frame of climate action.

## Tensions and reproductions in equity planning

The articulation of equitable climate action and equitable electrification in Oakland and San Jose reveals not only the key role of consultants in relationally constructing equity, but also how an equity focus introduces tensions as well as contributes to the reproduction of consultant-driven planning practices. Specifically, recasting climate mitigation actions like electrification as questions of equity challenges the technocratic approaches that underpin both climate action and climate consultants' work, while also allowing consultants to remake themselves as procedural experts and, in the process, reproduce the need for consulting in local climate governance.

### Challenges to technocratic planning approaches

In both Oakland and San Jose, a framing of climate mitigation and electrification as a question of equity challenged consultant-mediated technocratic planning practices. In particular, models and metrics – and the specific ways in which they are operationalized by consultants and philanthropists – were contested as both Oakland and San Jose progressed through their own "equity turns".

In Oakland, conflicts over technocratic planning were evident in how models were used and contested in the move towards an equitable climate action plan. The consultancy Bloomberg Associates (BA) was primarily in charge of modeling the emissions reduction potential of various climate actions, using the CURB (**C**limate Action for **Urb**an Sustainability) model, a model first developed by BA and now under the purview of the World Bank (World Bank 2016). For BA, models like CURB did not necessarily or exclusively serve a purpose for their client. Using the CURB tool in Oakland was a way to deliver insights on the cost and emissions reduction potential of different technology options, but it was also a way to pilot the tool, to figure out what it can or can’t be used for. In the broader perspective of the consultancy, Oakland was an early part of the US market for their work. Thus, the consultancy designed CURB to be a “plug and play” model that could intentionally be used in any city. It was hardly ever this simple – in Oakland, for instance, BA consultants had to concertedly engage city staff to acquire a significant amount of local data and assumptions on Oakland’s built environment to make the model work.

Despite this collection of local data, the actual material interventions modeled by CURB were static, set ahead of time by the model designers at BA and designed to be transported to any participating city or client. For members of Oakland’s equity facilitator team – a climate action coalition, an environmental justice consultancy, and a design and planning consultancy – these preset actions defined climate action too narrowly. As one interviewee from the equity facilitation team suggested by way of examples, the model was not able to consider the cost or emissions impact of building affordable housing near transit developments and avoiding emissions from personal vehicles, or the inclusion of measures that don’t inherently lower carbon emissions but are nonetheless critical to equitable climate action, like climate resilience projects.

A result of the conflicts apparent in Oakland’s Equitable Climate Action Plan was the creation of a Racial Equity Impact Assessment and Implementation Guide (Environmental / Justice Solutions 2020). The guide was not part of the original scope of the ECAP, but resulted from the work done by the equity facilitation team to counter what that team saw as technical planning frameworks that were ill-prepared to consider policy solutions that were both equitable and enabled effective GHG emission reductions. This guide provided both qualitative and quantitative ways to assess the impacts of potential climate mitigation and adaptation actions, providing a deeply context-specific alternative to climate planning that contrasted with the plug-and-play nature of the CURB model.

In San Jose, the use and performativity of a data- and metrics-driven approach shaped the internal tensions to incorporate equity in climate mitigation and particularly in electrification planning. The narrative of the ACCC is that it emerged after then-President Donald Trump pulled out of the Paris Climate Accord to show that climate mitigation was still relevant and actionable. In particular, the ACCC aimed to prove the feasibility of *near-term* carbon emission reductions. With a near-term emissions reduction focus came a portable program design, including a standardized list of climate policies for cities to pursue. This portable, standardized approach to climate policy making resulted from a modeling effort where over 200 policies were modeled for participating cities based on how much emissions they would reduce in a two-year period, but, as one interviewee shared,

> “…there were so many assumptions baked into that model that it also was kind of like, is this really a data centric program? Like, if you look at the assumptions...anyways.”

In this way, the models and resultant targets and metrics were performative: the actual conditions in a city and actual emissions reductions were less relevant than the projection of being a data-driven program. This near-term focus both undermined a focus on longer-term emission reductions as well as on the types of structural change and coalition building that would take longer than the 2 years of the challenge to build up. In the words of a former staff member that supported the climate challenge:

> "…something I really believe in is cross sectoral and coalition building, and power building on the ground to get more ambitious policy in place. But that takes time. So even if you build a strong coalition, and campaign plan, that itself could take two years, and then the program is over."

While the need to prove near-term emissions in the ACCC precluded longer-term political strategies, it also undermined more basic aspects of equitable policymaking, like community engagement. Though the later-era equity-focused ACCC involved more stakeholder engagement, consultants who were brought on specifically for community engagement still found that there wasn't sufficient time, infrastructure, money, or structure in the challenge for genuine community co-creation processes.

In both Oakland and San Jose, then, dominant consultant-driven climate planning processes made use of not only technical tools, but standardized, universalized technical tools that could serve a consultancy or philanthropy's broader goals. For BA, this meant a model that was transferable across cities, while for Bloomberg Philanthropies, this meant a policy approach that appeared data driven and served short-term goals. Conflicts over equitable policymaking challenged and contested the use of these technical tools.

### Remaking expertise and reproducing consultants

A focus on equitable electrification not only challenged technocratic modes of policymaking, but also remade consultants as procedural experts and reproduced the need for consulting. To understand this remaking and reproduction, we look particularly to San Jose, where the recognition that many of the measures that enable equitable electrification – preventing displacement and eviction due to home retrofits, maintaining affordable electric bills, or creating local, high-road jobs – cannot be designed or assessed through emission reduction models necessitated new forms of expertise. In San Jose, this new form of expertise was the facilitation of community and stakeholder engagement.

Unlike the technical expertise transferred by consultancies to cities, procedural expertise as a product necessitates a different type of consultant involvement in cities. Consultants have always been faced with concerns – from city staff, or the public, or CBOs – that just don't fit neatly in climate planning. Before the equity turn in San Jose, the consultancy that led Climate Smart managed and deflected these concerns by filtering them through their model: if local environmental groups called for more tree cover or green space, the model was used to show that tree cover or green space wouldn't sufficiently reduce carbon emissions in line with the Paris Agreement.

As San Jose moved into the equity era of the ACCC, and began more concertedly engaging CBOs and the communities they served, the consultancies leading the building electrification framework were faced with both concerns that didn't fit into what they had been contracted to do – questions about abandoned cars or neighborhood safety – and concerns surrounding electrification that they couldn't fully address – like how to avoid displacement or utility bill increases with electric heat retrofits. As the ACCC transitioned from being a source of technical assistance to a source of procedural expertise, these concerns could no longer be filtered through a model or technical tools. In some cases, the consultancies redirected participants to another city agency. In others, where the concerns raised were incontrovertibly tied to electrification, consultants had to devote additional resources. For the consultants leading the framework, questions of tenant and renter protections was a recurring issue that demanded their attention in plan writing. While the existing buildings framework repeatedly named the risk of displacement and the importance of tenant protection (City of San Jose Department of Environmental Services 2022), it provided little in terms of pathways for the city to pursue adequate tenant protections. For a staff member at a CBO involved in the framework's community engagement process, on the topic of displacement,

> "…the consultants were remarkably not reassuring. Every kind of reasonable question is like, we'll have to see, we're not even at that stage yet…So that's the experience, is that there's this kind of outreach, but it creates a fair amount of anxiety."

This staff member's experience demonstrates the limits of the procedural expertise through which consultants have remade their work: their involvement is both short-term, meaning that some questions can be dismissed as a problem for later, and limited to discrete engagement sessions, when addressing issues like tenant protections may require concerted and long-term organizing. These sessions still served an important purpose for CBOs; one staff member at another CBO noticed an increased awareness among the community members they serve around electrification, and felt that some components – job creation, for instance – were thoughtfully included in the final plan, even if others, like tenant protections, were not.

In remaking themselves as procedural experts, consultants also – intentionally or not – recreate the need for consultants in (equitable) climate policymaking. This process occurs in two ways. For one, consultancies package planning processes like "co-creation" as a product, piloted in one city and ready for use in others. Consultancies - some fully devoted to building electrification planning in cities - position themselves as both technical and procedural experts on electrification, billing "co-creation" as their approach for helping cities transition from gas to electric buildings. For the consultancy that led the co-creation approach for San Jose's existing building electrification framework, San Jose was the first city where this approach was piloted (they had previously primarily helped cities with technical assistance). Since then, it's become something that this consultancy has sought to do with other cities – co-creation has become, in effect, "another offering in [consultancy]'s toolbox". Procedural expertise, then, becomes another consultant-delivered product.

Beyond that, turnover and understaffing in a city can cause consultancies to take a larger, more involved role, one that ultimately builds a dependency on consultancies to create climate policy. In San Jose, while the intention was for the city's small environmental services division to serve as an intermediary, translating technical concepts to CBOs, the two consultancies leading this effort ended up doing much of the translating work themselves, becoming the only liaison between CBOs and electrification knowledge.

# Discussion and conclusion

Cities are increasingly centering equity in climate planning, a critical imperative in the context of uneven experiences of climate change. This paper investigates how this imperative is constructed in climate mitigation and decarbonization planning. I explore both climate mitigation planning more broadly and the specific case of residential heating electrification, an effort embedded in both technocratic decision-making and broader structural inequities, focusing specifically on two cities with equitable building electrification pledges: Oakland and San Jose. In investigating these cases, this paper demonstrates that our understanding of equity is not predetermined, but constructed through existing and evolving relations within cities, with consultants at the center of this construction of equity.

Specifically, through these two cases I find that consultants can serve as equity advocates, as in Oakland, where locally embedded consultants with explicitly political origins contended with established planning processes, or as equity gatekeepers, as in San Jose, where tensions over equity were mediated between consultants and their philanthropic funder, removing cities and CBOs from the process of defining an equity aspiration. The equity turn both challenges consultant-mediated forms of knowledge production, contesting how models and metrics are used, and gives way to new forms of consultant expertise through community and stakeholder engagement.

While the broader planning literature has long considered the technical and apolitical nature of climate and environmental planning approaches (Angelo et al. 2022; Anguelovski et al. 2016), this paper argues that knowledge production in climate mitigation policy-making is distinctively and importantly consultant-led. To understand the implications and evolution of consultant-driven equity planning, we can return to Raco and Savini (2019)'s overview of technocratic planning as approaches that give preeminence to policy making approaches that favor quantitative measures, like cost-benefit or risk analyses, define urban problems through narrow models or codifications, and sideline deliberative processes (Raco and Savini 2019).

Technocratic planning appears in equity planning through tools that are not just quantitative but are also transferable: consultants, particularly national or multinational consultancies, conduct work that is inherently short-lived and is sustained through the creation of knowledge that is marketable across clients and geographies. As Scott and Carter (2019) argue, consultants are often more reliant on prior experience than the specific context at hand to assemble policy. The equity turn challenges the utility of transferrable models and metric development and gives way to new forms of knowledge creation. In Oakland, this contestation led to the creation of more qualitative, context-specific policy assessments, while in San Jose it created the possibility for new or evolved consulting practices that emphasized the procedural expertise of consultants. These evolving consulting practices, while valuable in their deeper engagement with local organizations, are still limited in their short-term approach that treats engagement or participation as an alternative to longer-term political strategies. As cities change with the equity turn, so too do consultancies; future appraisals of how consulting work changes throughout the equity turn might reveal changing understandings of engagement and participation.

This paper also points to the importance of understanding consultants as heterogeneous, with different origins and motivations. Investigating in detail just two cities' electrification planning processes above shows that "consultants" can be a catch-all term, ranging from the consulting arm of one multi-billionaire's New York-based philanthropy to Bay Area-based, employee-owned operations. Scale, ownership, and implicit or explicit theories of change can vary dramatically among organizations under the "consultant" banner, and these characteristics of consultants can shape their approach to conceiving of and approaching the question of equitable electrification or climate mitigation policymaking.

Relatedly, this paper also points to the necessity for future work on philanthropy-city and philanthropy-consultant relations in climate policy. While a significant literature considers the climate and environmental planning approach of Michael Bloomberg as mayor of New York City – an approach described as "largely technocratic and managerial", focusing on the articulation of quantitative benchmarks and measures of success (Solecki 2012), as well as "market oriented" (Checker 2011; DuPuis and Greenberg 2019) – fewer research efforts considers the broader influence of Bloomberg Philanthropies on climate planning in cities across the US. These questions exist beyond Bloomberg Philanthropies and questions of climate mitigation, with the emergence of, for example, the Bezos Earth Fund or climate resilience initiatives through the Rockefeller Foundation.

The undue impact that Bloomberg Philanthropies had over climate planning in these two cases – both by setting the material terms of climate mitigation in Oakland through the Bloomberg Associates' model, and by both delaying and initiating equity discourse in San Jose – points to the broader issues facing cities designing and implementing climate policy. Both Oakland and San Jose have small environmental services divisions. For most of the data collection period, both cities had only 2 staff members and occasional interns tasked with a large scope of climate action. Sustaining equitable climate action in cities requires context-specific knowledge and expertise, which might involve sustaining and funding long-term, local climate policy professionals through state or federal resources. In the absence of sustained local production of knowledge, cities may turn to outside consultants and challenges to shape equitable climate policy.

Ultimately, this paper does not seek to argue that consultancies are inherently bad (or good) for climate equity. Consultancies can provide valuable, specialized knowledge to cities, particularly on emergent technical topics, and can share learnings across geographies. In some cases, as in

Oakland, consultancies can serve as political advocates. Rather, the role of consultants in a city should be assessed relative to their actual contribution to building capacity in a city, rather than recreating the need for consulting, and for their interactions with and contributions to local power and coalition building. As the case of building electrification demonstrates, the structural inequities that contribute to risks of inequitable electrification – a lack of tenant protection, increasing electricity bills, fragmented or inadequate funding – require longer term political strategies and coordination with ongoing coalitions and efforts. In fact, coalition building has been an emergent response to California's electrification discussions – a statewide coalition of environmental justice CBOs has formed to facilitate convenings throughout the state, trying to chart a path and intervention for the state's billion-dollar budget for building decarbonization.

Getting equity "right" in climate mitigation is critically important, and municipal equity pledges represent an increasingly common-sense recognition of the links between climate and social equity. This recognition extends beyond municipal contexts; at federal and state levels, millions of dollars are increasingly allocated to equitable climate action (Newburger 2022). To sustain aspirations of equitable climate action, and to realize the best and most transformative version of these pledges and funds, it is necessary to investigate how visions of equity come about, and how they shape or reinforce planning practices. This paper serves to highlight the critical role of consultant-centered planning relationships in defining, delaying, or determining equity aspirations.

# Chapter 4 | Circumscribing equity: local commitments and institutional uncertainty in residential heating electrification

## Introduction

> "The biggest challenge [in my work] is definitely trying not to hurt people. It's the thing that is most top of mind for the work, is first do no harm and then try to make things better." *Emily[14], city buildings & energy strategist*

In recent years, climate mitigation policy in California – as in other US states and other countries – has focused on heating electrification, or the transition from combusting gas to using electricity for space heating (Mahone et al. 2019). For many local actors, from city-contracted consultants to city and regional staff, environmental justice organizations, and local branches of national environmental non-profits, heating electrification has coincided with an increasing recognition of climate mitigation and adaptation as a question of social justice. This increasing recognition, or the "equity turn" in local climate planning (Angelo et al. 2022) , is reflected in institutionalized documents like city climate action plans (City of Oakland 2020a; Diezmartínez and Short Gianotti 2022), and in the work of local tenants' rights and environmental justice organizations (Emerald Cities Collaborative 2020; Greenlining Institute 2019; SAJE 2021), consultancies (Building Electrification Institute 2023), and industry associations (Building Decarbonization Coalition 2019).

But for local actors like Emily[14], "doing equity" is loaded with hesitation or fears that ostensibly equitable policies might not reach who they are meant to reach, or, even worse, might harm low-income or tenant recipients of those policies. This paper investigates two sources of hesitation, and how they impact local work on heating electrification: the uncertainty of future energy affordability produced by corporate and opaque utilities, and the uncertainty of how heating electrification will be financed due to fragmented, austere funding.

The risk of displacement after home retrofits, questions of funding availability particularly for low-income homeowners and tenants, the affordability of energy bills for gas or electric customers, the resilience of the electrical grid, and the distribution of electric heating and its associated benefits in terms of improving local air quality and resilience to extreme heat - among other concerns - are at the root of equitable electrification planning (Emerald Cities

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[14] All names are changed to preserve anonymity.

Collaborative 2020; Greenlining Institute 2019). These concerns are determined by structures and processes beyond the local level, including electricity and gas utility regulation that determines affordability, (a lack of) tenant protection, and state and federal home retrofit funding. These structures and processes constitute in part what Swyngedouw and Heynen (2003) describe as "the networked socioecological metabolisms and their associated power relations through which things become constituted and organized". If the *thing* is the local trajectory and effects of heating electrification – who gets electrified heat, when, and with what consequences - then the power relations embedded in utility regulation, home retrofit funding, tenant protections, and more will shape that trajectory.

This paper first contextualizes heating electrification in the broader literature on scale and uncertainty in local climate planning. Then, after introducing the case of electrification planning the Bay Area in Northern California, I discuss how different local actors relate to different possible trajectories of heating electrification – from transformational to market-oriented approaches – and explore how scale and uncertainty interact and are produced through utility regulation and funding fragmentation. I argue that the production of uncertainty at different scales can both limit local impulses and visions of equity, and also enable broader shared understandings of the possibilities of home energy transitions.

# Who are local actors?

Though climate governance literature has stressed the role of local institutions in climate adaptation (Agrawal 2008), broader sustainability (Zeemering 2012), and energy democracy campaigns (Becker, Angel, and Naumann 2020; Becker, Beveridge, and Naumann 2015), to name a few, definitions of local institutions or actors are sparse in these contexts. This is perhaps because, as food systems scholar note, the term local is inherently idiosyncratic and non-universal; what is local is socially constructed within given contexts (Eriksen 2013), and can't be defined purely by geographic boundaries but also by relationships, or by the connections maintained between participants in a local system (Eriksen 2013; Trivette 2015). This section explores what local might mean in the context of residential energy transitions and in the equity turn, motivating the focus on "local actors" in this paper.

If local institutions or systems maintain connections and relationships between participants, then dominant conceptions of the energy system – which extend to its governance and planning and to how energy is abstracted in research and policy (Miller et al. 2013) – tends to be non-local. Lennon (2017) distinguishes between "Big-E" and "little-e" conceptualizations of energy: in a Big-E conceptualization, energy is alienating, an immutable commodity that can be accumulated and deployed anywhere; in a little-e conceptualization, energy is relational, a capacity that results from the ties between people and biospheric forms rather than a product that one can have and grow. How we conceptualize energy is not an inherent property of a physical system: the dominant form of electricity provision, for instance, where geographically dispersed generators transform thermal or mechanical energy to electricity that is transmitted to far-away users, can be conceptualized to either obscure or emphasize how parts of that system are connected to people, places, and ecology.

Building on a relational understanding of local institutions and systems (Eriksen 2013; Trivette 2015) and an exploration of both alienating and relational lenses on energy (Lennon 2017), we can think of local actors as actors that work to further physical configurations, institutional arrangements, or conceptual understandings of the energy system that emphasize the social and ecological relations embedded in that system. This understanding of local actors is intentionally broad, because the local actors active in equitable heating electrification – and broader climate equity and justice campaigns (Fitzgerald 2022; Giugni and Grasso 2015) – are heterogeneous in their political strategies, approaches, and frameworks. In some contexts, as in scholarship that focuses on energy democracy and re-municipalization campaigns in western Europe, the relational work of local actors develops specific and targeted claims to re-make state and non-state institutions and urban space (Angel 2017; Becker et al. 2020). By contrast, "equity" as a term can be more amorphous and less connected to specific political claims, with divergent understandings and operationalizations among local actors (Angelo et al. 2022; Zapata and Bates 2015).

In exploring the work of local actors in the climate equity turn, then, it is important not to homogenize those actors. Méndez (2020:17), writing on climate movements in California, emphasizes "contentious politics of scale, values, markets, and race in relation to climate change", but adds that these "worldviews can change over time" – they are not unchanging or absolute. The local actors that feature in this paper include long-time energy democracy or environmental justice advocates, local branches of national environmental organizations, consultants working for municipalities, city or regional agencies, and community choice aggregators[15]. They are diverse in their origins, institutional contexts, and understandings of climate change and climate policy, but share a discursive commitment to equity and a broad practice of understanding, or beginning to understand, energy as a relational rather than alienating system. This paper's investigation of how the local equity turn interacts with scale mirrors and extends Méndez (2020)'s observation, identifying where tensions exist in the politics of local equity commitments but also where worldviews are shifting.

# Scale and uncertainty in local climate equity

Local actors recognize their interdependence with other levels of governance. A public administration study of US city sustainability and climate plans, for instance, finds that these documents regularly document forms of interdependence with state, federal, and international governance institutions, particularly as a source of information and resources but also as a site of advocacy (Zeemering 2012). This section reviews scholarship on how scale interacts with

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[15] See the section Electricity and gas delivery in the study area for a more detailed explanation of community choice aggregators; in short, they are subscription-based entities that procure energy for local customers, often with the goal of procuring a greater share of renewable energy than the local utility.

local political demands around climate and energy around two aspects of scalar politics: Christopher Brown and Purcell (2005)'s discussion of scale as both fixed and fluid, and Goh (2020)'s call for planners to reframe their climate planning practice in part around "political relationships based on a broader notion of public participation and democratized decision making".

Christopher Brown and Purcell (2005), drawing from foundational literature in geography, characterize scale as "fluid and fixed". They suggest "scalar arrangements" are socially produced through ongoing political processes, making them fluid and changing, but are also routinized and institutionalized, fixing certain arrangements in place for long periods of time. In the context of local political claims over energy, these fixed and fluid scalar arrangements can be viewed through the lens of infrastructures, and particularly networked infrastructure (Monstadt 2009). The electric grid is a key infrastructure through which urban studies and science and technology studies (STS) scholars understand power relations between actors. Blanchet (2015), studying grassroots energy transition initiatives in Berlin, argues that the electric grid shapes the balance of power in energy transitions, increasing the power of certain financial and regulatory actors and undermining the influence of local actors. But this fixing in place or concretizing of a certain political arrangement is also not taken for granted in Blanchet's case, where actors use the issue of energy transition to acquire or change ownership or control over electric distribution. More broadly, urban climate initiatives can reflect attempts to rescale or reorganize environmental governance at the local level. As Bulkeley (2005) argues, urban climate programs may seek "to reframe an issue which is usually considered in global terms within practices and institutions which are circumscribed as local". These local practices are not necessarily territorially limited or bounded but can be networked and multi-scalar.

This paper focuses not only on understanding the scalar arrangements that shape local climate equity work, but specifically on how these scalar arrangements produce uncertainty and with what effects. Because urban climate interventions reframe issues as local, there is uncertainty inherent in this rescaling. Bulkeley and Castán-Broto (2013; 2013) characterize these uncertain interventions as "experiments" that create new forms of political space within cities and blur levels of authority. But different manifestations of uncertainty exist beyond the context of urban climate interventions. In Stokes' (2020) multi-state investigation of how interest groups actively sustain or oppose clean energy policy, she introduces the idea of the "fog of enactment", or the period of uncertainty between policy pledges and actual implementation exacerbated in part when policy areas have overlapping jurisdiction. While geography and political science scholarship on climate politics explore uncertainty as temporal (Broto and Bulkeley 2013; Bulkeley and Broto 2013; Stokes 2020)– exacerbated or highlighted through transitions and interventions – uncertainty can also be understood as inherent to institutions. STS and sociology scholarship, for instance, has explored the production and consequences of the ignorance or "non-knowledge" underpinning uncertainty characterizing ignorance as a normal institutional feature, one that can maintain power relations or be a source of possibility as uncertainty is acknowledged (McGoey 2012; Paul, Vanderslott, and Gross 2022). In this way, uncertainty can be constitutive of "fluid and fixed" scalar arrangements (Christopher Brown and Purcell 2005).

In the case of urban climate interventions like residential electrification, what fixed and fluid scalar arrangements exist, and how do they interact with political relationships and democratized decision-making (Goh 2020)? This paper focuses on two arrangements: the regulation of private energy utilities and the funding of home retrofits[16]. The following section establishes how these two scalar arrangements operate in the study area, drawing on existing geography, environmental justice, and legal studies literature to understand the politics of these scalar arrangements.

## Methods and study area

This paper explores the work of local actors in the nine-county Bay Area, a region in Northern California surrounding the San Francisco Bay. As a region with discursive, public commitments to equitable electrification (and equitable climate action more broadly) at multiple local and regional levels – including within individual cities, community choice aggregators (electric power procurement institutions which are defined and described in the following section), and local branches of national environmental organizations – the Bay Area is well-suited as a case study to understand how local actors purporting to commit to equitable climate policies navigate larger institutional structures. Of particular relevance to this paper is that these local actors share a common context of electricity and gas delivery and utility regulation as well as home retrofit funding, described in more detail in subsequent sections. A case study research approach is particularly well suited for tracing complex processes and relationships, and for phenomena that cannot be neatly distinguished from the contexts in which they occur (Yin 2014).

Data for this paper is largely qualitative. I draw on semi-structured interviews, participant observation at primarily virtual city workshops and meetings, and document analysis. Semi-structured interviews (about 40 in total) occurred with city staff, housing, energy, labor and environmental justice advocacy organization staff and volunteers, and utility and community choice aggregator staff. Interviews were conducted both online and in-person, and typically lasted 1 to 1.5 hours. I initially identified interview participants through a systematic review of planning documents and city council minutes relevant to electrification interventions. I additionally reached out to local housing, energy, labor, and environmental justice organizations that may not have been officially consulted in institutionalized electrification planning processes to understand if or how they approach electrification discussions. Documents analyzed included public comments for city and state proceedings, webinar records

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[16] While this paper focuses on wider institutional scales, local climate and heating electrification planning also interacts with the household scale, which Crowther et al. (2023), in their investigation of local heating electrification plans in the UK, highlight as an implementation “disjuncture”: the success of local heating electrification schemes depends on the “collective participation” of residents accessing and using these technologies, but divergent expectations of heating systems can undermine this collective participation.

for city, state, and federal outreach efforts, and utility reports and filings. This qualitative data collection occurred over 1.5 years, from summer 2021 through the end of 2022.

Interviews and documents were coded inductively and iteratively and analyzed alongside reflections from participant and workshop observation using a constant comparative method aided by memo writing (Boeije 2002; Thornberg and Charmaz 2017). Specifically, interview and document excerpts were assigned an initial set of descriptive codes as they were read and re-read (that is, without a predetermined set of codes), largely identifying actors (e.g. "city staff", "state energy commission"), processes (e.g. "stacking funding for home retrofits"), and sentiments and experiences (e.g. "urgency", "hesitation"). Writing memos about and around excerpts enabled a comparison between and within interviews, documents, and observations, making way for an evolved set of codes that were more generalized and analytical (e.g., "impenetrable governance structures"). This iterative process of coding, re-coding, and comparison allowed for themes to emerge from the data and enabled a richer understanding of how equity pledges interacted with scalar arrangements in the Bay Area.

## Electricity and gas delivery in the study area

In the nine-county Bay Area, electricity is delivered through a dual institutional arrangement. The investor-owned utility (IOU) Pacific Gas & Electric (PG&E) maintains physical distribution infrastructure, bills customers, and addresses outages, while local Community Choice Aggregators (CCAs) procure energy on behalf of subscribed local customers, often ostensibly to purchase a greater share of renewable energy than the local IOU (Hsu 2022; O'Shaughnessy et al. 2019). PG&E is the sole provider of natural gas in the area.

Similar to many regimes of electricity and gas delivery throughout the US, PG&E is a regulated monopoly; it is the only company legally authorized to deliver electricity and gas in much of Northern California, and in exchange PG&E can recover its capital costs – often through customer rates – and additionally make a shareholder profit (Kibbey 2021). Of the 168 IOUs delivering electricity in the US (as opposed to cooperatives or publicly-owned utilities), PG&E is the largest by number of customers (Energy Information Administration 2019); of the over 1000 residential gas delivery companies in the US, PG&E is the third-largest by volume of residential gas delivered (Energy Information Administration 2021). IOUs are typically regulated by a state utility or public service commission; in California, PG&E and other IOUs are regulated by the California Public Utilities Commission (CPUC).

In the United States, private or investor-owned utilities (IOU) for gas and electricity service provision are typically regulated by a state utility or public service commission. Increasingly, public utility commissions (PUCs) and rate-setting have been examined as political processes imbricated with power dynamics by geographers and legal scholars as well as environmental justice advocates. The literature on PUCs points to rate-making as one of the key ways that commissions shape energy landscapes: rates determine the extent to which capital investment will be recovered and thus shape what energy infrastructure serves public goals (Howell 2011). Luke (2021), writing on utility regulation in Georgia, argues that rate setting – along with PUCguided disconnect policies or late-payment fees – makes the commodification of electricity possible, sustaining accumulation for private companies without protecting residential customers. Similarly, legal and environmental justice scholars investigating a rate case in New York state argue that communities affected by utility-driven fossil fuel infrastructure expansion are disempowered from challenging the IOU in PUC settings due to information and resource asymmetries, in part because IOUs can withhold information that does not align with their financial interests (Nagra, Bergman, and Graham 2022). Given the increasing recognition of the centrality of PUCs to (un)just energy policies, a growing environmental justice advocacy literature focuses on the measures needed to democratize PUCs, identifies sources of regulatory capture through revolving doors between utilities and commissioner appointments, and argues for knowledge and capacity-building to allow broader engagement in PUC proceedings (Farley et al. 2021; Patterson and Hua 2022; Triedman et al. 2021).

By contrast, CCAs often purport to be more democratic than IOUs. Two of the larger CCAs in the study area, for instance, are governed by boards or city councils as well as community advisory committees, with meetings open to the public in either case (East Bay Community Energy n.d.; San Jose Clean Energy n.d.). Still, because CCA services are essentially layered on top of IOU infrastructure and rates, IOU and PUC issues become CCA issues. For instance, emerging CCAs face a barrier to formation and operation through the "exit fee" that CCAs are required to pay PG&E, the calculation of which has raised concerns among California CCAs around the transparency of PG&E's assumptions and the validity of the calculation methodology (Jung 2017). Even with a dual institutional framework that attempts to make energy provision cleaner and more equitable, the landscape of electricity and gas delivery in Northern California is shaped by opaque regulatory and corporate proceedings. By design, CCAs remain imbricated with IOUs like PG&E in several ways: they both depend on PG&E's maintenance of infrastructure necessary for electricity delivery and rely on PG&E's rate design to bill residents.

## Funding home retrofits in the study area

Funding for building electrification is administered on federal, state, and local levels. Most recently, and most prominently, state and federal governments have allocated electrification-specific rebates and tax credits through the federal Inflation Reduction Act (IRA) and the California TECH rebate program (TECH Clean California 2023; US Department of Energy 2022). Some cities, like San Jose, have created specific rebate programs for electrification (City of San José n.d.-a), along with regional agencies, whose existing rebate programs now extend to building electrification (BayREN 2023). In practice, though, electrification – particularly for low-income households – is funded by several sources, not all of which are bespoke incentives or rebates for heating electrification. A household or building in California might access the Low-Income Weatherization Program (LIWP), a state program administered by the Department of Community Services & Development funded by proceeds from the state cap-and-trade program (California Department of Community Services & Development 2021), and individuals can use

Medicare funds[17] to offset the cost of heat pump installation. Federally, maintenance and retrofits in low-income units are incentivized through the Low-Income Housing Tax Credit (LIHTC), where state housing agencies award credits to private developers for low-income housing construction, acquisition, or rehabilitation (Scally, Gold, Hedman, et al. 2018; Tax Policy Center 2020). Though home electrification has generally not qualified as an expense for the two most prominent federal energy assistance programs – the Low-Income Home Energy Assistance Program (LIHEAP) and the Weatherization Assistance Program (WAP), administered by the US Department of Health & Human Services (HHS) – recent federal pilot programs make funding available to local agencies administering WAP to pay for electrification retrofits (Kujawski and Tidwell 2022).

Looking at the full stack of potential funding for residential electrification shows that funding for (equitable) home electrification is part of fragmented and concurrent political projects. The one-time (but potentially renewable) funding allocations from bespoke rebate programs, like the ones funded through IRA, TECH, regional agencies, or individual cities, exist in part as "market transformation" or "market development" programs. TECH articulates the "market transformation" theory of change most directly: the goal of TECH, as articulated in stakeholder meetings and presentations, is to make electric heating equipment – like air-source heat pumps or heat pump water heaters – competitive and in-demand, an approach that is meant to drive "economies of scale" and increase the share of heat pumps in the home heating and cooling market (Energy Solutions 2021). The 10-year IRA rebates are framed through many terms, among them the goal of "[spurring] durable market demand…by demonstrating the value of energy upgrades" (U.S. Department of Energy 2022). The structure of these various programs – as one-time funding commitments, sometimes with declining incentives over time – suggests that they are not meant to exist in the future and that the market will take over where the incentives end, mirroring the strategies taken by other energy sectors. TECH, for example, refers specifically to California's declining, now-retired solar incentive as a blueprint for residential electrification (Energy Solutions 2021).

On the other hand, many routinely funded (yet underfunded) programs like WAP, LIWP, the LIHTC, or Medicare exist at least in part as redistributive initiatives. Knuth (2019) describes WAP, for instance, "both as an energy conservation program and a form of government economic redistribution". WAP emerged from the 1970s energy crisis as a form of energy conservation, but is targeted specifically at low-income residents and aims to weatherize homes and improve health and energy expenditure outcomes (Bednar and Reames 2020). LIWP can be understood through a similar conservation-and-redistribution lens: the program aims to reduce greenhouse gas (GHG) emissions, but specifically delivers no-cost energy upgrades for low-

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[17] As of 2021, certain Medicare recipients can receive rebates for air conditioners (Hammond 2021; KFF Health News 2019; Worstell 2023). Interview participants for this study who were involved in implementing low-income electrification confirmed that Medicare was one of several sources of funding used to install heat pumps with cooling capabilities for qualifying residents, though little data exists on how systematically this rebate is used to install heat pumps.

income single-family and multi-family affordable housing developments (California Department of Community Services & Development 2021). The LIHTC and Medicare were not established through the same environmental frames as programs like LIWP and WAP, but were still created with redistributive aims, with LIHTC designed to spur private rehabilitation of low-income housing units (Will and Baker 2013), and Medicare intended to cover medical bills for retirees not served by employer-sponsored coverage (Blumenthal, Davis, and Guterman 2015). Underpinning these programs is some degree of recognition of how income and age can indicate access to (in)adequate or habitable housing due to systematic barriers to homeownership and home maintenance (Bednar et al. 2017; Harrison and Popke 2011). But these programs are also subject to precarious support: WAP funding allocations have been constantly limited, and the program has at times faced the threat of full defunding (Bednar and Reames 2020; Knuth 2019), Medicare has similarly faced existential threats to spending (Cohen 2022), LIWP's funding allocations are not guaranteed from one year to the next (Hens and Lamon 2021), and the availability of credits through the LIHTC is vulnerable to tax code changes and levels of private interest in investment (Scally, Gold, and DuBois 2018).

# Contingent uncertainty and (in)equitable electrification

The rest of this paper takes a local view of the two scalar arrangements described above, exploring how local equitable electrification pledges and efforts interact with utility regulation and retrofit funding. Specifically, the subsequent sections establish how utility regulation and retrofit funding create uncertainty at the local level with the effect of both limiting and circumscribing local impulses and visions of equity, and also inspiring a shared reframing of electrification as a tool for collective and community health.

## Contingent uncertainty and the corporate utility

> "If you have an all-electric home, you have the ability to have backup power and protection against increasing natural gas rates…we know that natural gas rates are increasing much faster than electric rates." *City of Oakland Equitable Electrification webinar presentation*

> "In some of the studies, we can't say that [heating electrification] will necessarily save you money on your monthly bill – that's an equity issue, do we want to promote this to people? Even if we give it to them for free, is it costing them over the long run? I think that's obviously a larger question in terms of electric versus gas rates, so that's why we're a little hesitant on just promoting it to everyone. There are certain pockets, especially those who have solar, that it makes a whole lot of sense for." *Interview with staff member at a regional energy program administration agency*

> "And then we're living in this time of PG&E power shut offs, right? So let's say we have another crazy fire, and they shut off power. I just switched to all-electric, I have no access to hot water. I can't cook my food that's thawing out of the refrigerator because the power's been out for a day or two." *Interview with a Bay Area-based energy democracy organizer*

The claims, promises, and anxieties that surround residential heating electrification are inseparable from questions of household finances and electric reliability. Depending on who you ask, and the forum in which they are speaking, residential electrification provides a source of backup power, or it makes you more vulnerable to blackouts; it leads to long-term bill savings, or you end up with a higher energy bill than when you started.

The quotes above are more contingent than they are contradictory. The perils of an unplanned electrification transition are sometimes framed as a question of natural gas rates: a concern about electrification scenarios where wealthier homeowners electrify first is that fewer people will remain connected to the gas system, raising the fixed costs paid by remaining gas customers (Greenlining Institute 2019). But electric rates bring their own sources of uncertainty. For instance, CA-based studies find electrified homes may end up paying more to heat their homes and face higher lifecycle costs when installing a heat pump, particularly in the PG&E service area (Borenstein, Fowlie, and Sallee 2022; Mahone et al. 2019). Still, the household economics of heating electrification become more favorable under certain conditions: where homes already have air conditioning, were built post-1990 or were recently renovated with larger capacity electrical panels (Mahone et al. 2019), or, as the regional agency staff member above noted, where homes have solar panels. Air conditioner access, living in newer housing, or adopting solar panels are all socio-economically mediated conditions, facilitated by both homeownership and access to capital (e.g. Chen, Ban-Weiss, and Sanders 2020; Sunter, Castellanos, and Kammen 2019).

Similarly, protection against electric unreliability is uneven: an all-electric home equipped with a reliable, capacious back-up battery can avoid the worst consequences of a power outage, while an all-electric home without back-up power might be the most acutely exposed to that outage. Those consequences themselves, too, are uneven – having an essential medical device that relies on electricity or being isolated from networks of support, for instance, can exacerbate the severity of an outage (Asian Pacific Environmental Network et al. 2020).

The benefits of electrification are enabled, then, by socio-economically mediated technological arrangements that are partially realized when individuals can reduce their reliance on the utility – for example, by generating their own power or having their own energy storage. Because equitable electrification purports to be for the many Bay Area residents – particularly renters and low-income households – whose rates and electric reliability are most intertwined with the utility, it is also circumscribed by the uncertainty produced by utility governance. As one staff member at a CCA observed, "[we can't] really call it accessible electrification if we're electrifying low-income homes and people can't afford their bills." The uncertainty of electricity and gas rates and electric reliability, which undermines the universalist aspirations of equitable electrification planning, are produced at the scale of the corporate utility largely through the impenetrability of utility governance. Equitable electrification planning becomes a question of navigating this institutionally and socially produced uncertainty, with local actors seeking alternative spaces for intervention and taking on the burden of infrastructure and rate development themselves.

### Navigating uncertainty through and around utility governance

Local actors recognize and reformulate their work around the uncertainty produced by rates and reliability, but often do so by circumventing direct utility decision-making. Though rates are set in General Rate Cases (GRCs), which are utility-specific proceedings that occur every 3 years (California Public Utilities Commission 2021), staff at regional agencies, local non-profits, or local consulting firms approach these cases cautiously, if at all. In some cases, agencies are prohibited from engaging in advocacy as part of their mandate; in others, staff find the cost of engaging in these processes, to which utilities bring their own resources and lobbyists, prohibitive. GRCs were described by personnel at regional agencies as "intense and very labor-intensive" where proceedings "take on a life of their own", by staff at a well-resourced national environmental non-governmental organization as a space where "it's pretty hard to engage without spending your life doing it", and by members of a Bay Area-based consulting firm focused on energy issues as "extraordinarily complicated and enormously costly to participate in." Instead, local environmental actors seek out alternative regulatory spaces that are broader and aim to provide a policy framework or direction to rates, rather than spaces in which the rates themselves are set.

These spaces include regulatory commission En Bancs – hearings where regulatory commissioners and staff solicit public and expert comments on specific issues (California Public Utilities Commission 2022) – or webinars, white papers and reports hosted by local environmental actors (e.g. Building Decarbonization Coalition 2022). These spaces, which often exist to share information and resources among local actors, are removed from GRCs but sometimes aim to facilitate the entry of local decarbonization actors into GRCs. Their content reinforces the impenetrability of rate-setting. One webinar, for instance, suggests that decarbonization advocates can approach GRCs by creating coalitions of industry associations because involvement in a GRC requires dedicated lawyers, modelers, and private resources.

Despite the intractability of change in utilities, then, local actors seek out more accessible and less technical regulatory spaces. Still, these spaces and structures are unevenly accessible and trusted. For one Bay Area-based energy democracy organizer, working within the CPUC structure is necessary but inadequate, and the legitimacy of the CPUC is undermined by its regulatory support of fossil fuel expansion in other proceedings (e.g. see Earl and Lewis 2021). Further, the engagement of local environmental organizations in GRCs – something that decarbonization advocates increasingly push for – depends on the ability of those organizations to create coalitions and associations with sufficient legal, technical, and capital resources to fully participate in GRCs, which, in the absence of intentional coalition-building, can lead to the exclusion of more local or under-resourced organizations. For one Bay Area based organization, for instance, involvement in GRCs was a question of finding trusted national organizations to partner with, whose resources and modeling they could rely on.

In parallel, actors navigated the absence of pathways to intervention in the utility by taking on the burden of addressing electric (un)reliability themselves. The City of Oakland, for instance, includes actions in their climate action plan to establish Resilience Hubs, or city and community facilities that can provide electricity, food, and other necessities in the case of a power outage or other disaster. The City's efforts occur not in partnership with the utility, but with the local CCA (City of Oakland 2020a). For advocacy organizations, including a volunteer-based group in the San Jose area and a non-profit coalition, the local work that they do in convincing decision-makers to pursue electrification involves collecting resources and experts that can attest to the dependability of solar with battery backup as a suitable technical configuration to enable electrification.

Analyzing utility regulation in the study area through the lens of institutionally created uncertainty also points to the incompleteness of emerging, "place-based" approaches to the problems posed by gas utility infrastructure. Specifically, 'neighborhood-level' or 'strategic' decommissioning of natural gas infrastructure is a prospective approach to electrification in which geographically bounded portions of the natural gas system that need upgrading or repair are taken offline and connected households are fully electrified. Strategic decommissioning is presented by CCAs, regulators, thinktanks, and gas utilities alike to reduce the costs of operating the gas system, sparing ratepayers the cost of stranded assets, and to convert homes to all-electric with more economic efficiency. For some, targeted electrification enables an equitable transition by potentially reducing the costs of operating the gas system for customers that remain connected to gas, or by targeting areas with both older infrastructure and the state designation of a "disadvantaged communities" (DiChristopher 2022; East Bay Community Energy 2022; Gridworks 2021; Southern California Gas Company et al. 2022).

In one sense, strategic gas decommissioning is presented as a way to manage the contingent uncertainty produced by utilities: if it works as expected, strategic gas decommissioning can reduce the costs of operating the gas system, in turn avoiding the risk of rapidly increasing gas bills for communities that stay connected to gas. The turn to strategic decommissioning represents a departure from previous home energy transition strategies as they were promoted by large environmental organizations, utilities, and regulators. Solar adoption and energy efficiency, for instance, have been largely approached as questions of growing a market, rather than centralized, planned, equitable transitions.

But the contingent uncertainty posed by opaque utility regulation risks rendering strategic or neighborhood-level decommissioning risks a piecemeal or ineffective change for two reasons. First, gas utilities approach strategic decommissioning as one of many strategies to enable "decarbonization", with the other strategies largely including "greening" or "cleaning" the gas supply using compressed natural gas or gas captured from other industrial processes including aerobic digestion in landfills or livestock operations (U.S. Department of Energy n.d.)[18]. Gas decommissioning, then, is not necessarily a gas wind-down; 'strategic' decommissioning risks being a piecemeal, small-scale project, while gas infrastructure is entrenched in other geographies. Second, the purported benefits of targeted gas decommissioning are, themselves, uncertain. Targeted decommissioning is intended to lead to managed gas rates into the future, and a purely techno-economic understanding of rate-setting would suggest that decommissioning older sections of the gas network rather than upgrading them would lead to lower gas costs for customers. Rate-setting, however, is not a straightforward calculation but a political process; both the reporting of utility costs and the process of determining which costs are recoverable by ratepayers is an inaccessible process. As established above, rate cases have little broad participation, and are inaccessible to all but the most resourced organizations.

## Contingent uncertainty and fragmented funding

> "Who the hell's gonna pay for it all? How's it gonna get done? Single family homes are easiest…but when you have a 12 unit building with long term tenants, or with nine units occupied in one way or another…how are you going to do this sort of thing?...Nobody knows how to answer these things. And we all just jawbone and try to find money here or there to make it happen." *Interview with Bay Area-based labor advocacy organization staff member*

> "So from a tenant level, one is who's gonna pay for the upgrade? But then it also gets very complicated…how substantial is this work? Does it require vacating a unit? For how long? Can you do this unit by unit? Or does the whole building get emptied out?" *Interview with San Jose-based affordable housing advocacy organization staff member*

> "This topic of [building electrification] is so new that even veteran community organizers are not sure what kind of discussion we're supposed to be having…the most basic question which we still don't have the answer to is: who's gonna finance this?" *Interview with Bay Area-based environmental justice advocacy organization staff member*

Local equitable electrification efforts are incapacitated by the uncertainty of funding availability; the quotes above are a sampling of a recurrent confusion about how electrification will be paid for. This uncertainty can feel contradictory when considered alongside the millions of dollars that are being infused into home electrification at the state and federal levels (Energy Solutions 2021; U.S. Department of Energy 2022), but I argue that the uncertainty produced by

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[18] Both publicly and privately, gas utilities acknowledge that these methods have limited potential to actually "decarbonize" the gas supply; rather, they are used as a form of social and investment license to expand conventional, polluting gas extraction and infrastructure build-out (Energy and Policy Institute 2022).

funding regimes is, again, contingent. This contingency is produced both by funding programs that frame electrification as a market development project rather than a retrofitting and repair project, which interacts with household income and tenure to produce uncertainty in the ability of local actors to deliver equitable electrification interventions.

The market development goals of large funding allocations for residential electrification lead to incentive structures that only partly cover the cost of electrification equipment and decline or disappear over time by design. The assumption underlying these programs is one of access to both capital and homeownership: the recipient of such an incentive is expected to both pay for part of their home retrofit and to have the autonomy to make major material changes to their home. Though both the IRA and TECH – the two largest funding allocations for residential building electrification in the US and California, respectively – have provisions for low-income homeowners and tenants, they do so through relatively small allocations specifically to deed-restricted affordable multifamily building owners (Bigger et al. 2022; TECH Clean California 2023), which constitute about 8% of all renter households and 21% of all low-income renter households in California (California Housing Partnership 2023; National Low Income Housing Coalition 2023).

Beyond limiting the scope of who can access incentives, these recent infusions of funding into residential electrification approach electrification as an appliance-swapping exercise, rather than as part of a project of continuous and sustained repair that also assures resilience. Interviews with local actors at advocacy, affordable housing development, and city departments involved in implementation of electrification projects pointed to how electrification required sustained funding: actually doing residential electrification in a low-income or multifamily home could require vacating units and temporarily relocating residents, engaging in mold, asbestos, or lead remediation, electric panel upgrades, or weatherization, to name a few steps. To install an electric heating appliance requires addressing compounding operational and maintenance needs that are shaped by the material conditions of a home. These needs push local actors to "stack" funding sources wherever possible, pairing heating electrification-specific incentives with overenrolled and underfunded programs like WAP, LIWP, the LIHTC, or Medicare benefits, some of which provide funds for rehabilitation beyond the installation of specific appliances. Yet the largest amounts of money for building electrification are allocated to facilitate the development of a market for homeowners with capital, making the local prospect of electrification more uncertain for the homes meant to be served by more redistributive, repair-oriented programs.

Funding for home retrofits is fragmented in two senses. Different types of funding reach only a fraction of Californian or US residents, with most money allocated to homeowners with capital, and different types of funding use residential electrification to advance two different political projects, with one-time rebate-based programs working to advance a market and underfunded redistributive programs working towards material repair and habitability. Still, uncertainties about the future of redistributive programs have been used by local actors to encourage an emerging reframing of electrification as a project of whole-home repair rather than, or in addition to, a market development project.

## Navigating funding uncertainty through reframing

As local actors navigate the equity turn, they are challenging the idea of electrification as a market development project. Local actors that have operated within the market development paradigm, like staff members at a regional energy program administration office that manages electrification rebates and incentives, are reconsidering their work, influenced by the increasing discourse around “equity”. For instance, a staff member whose work involves connecting with building managers and owners to increase uptake of their rebate programs offered this reflection on the outreach portion of their job:

> “I'll get questions from renters, like what can I do? And [our organization] just doesn’t really offer a lot for them. And so that's a big priority right now, thinking through what we can do…I think we’re all energized to reimagine that renter-landlord relationship a little bit and have that be more of a two-way relationship.”

Similarly, a staff member at a CCA offered their reassessment of “good” incentive design (where subsidies decline as a market grows), considering their organization’s reorientation towards equity and their lessons from California’s now-retired solar incentive structure:

> “…what happened is that those who have the most cash on hand, who own their homes, who were well poised to take advantage of those incentives, were the first to join the party. So we got a bunch of wealthy individuals, upper income households that were installing rooftop solar and taking advantage of incentives, those incentives dropped over time, making it further out of reach for customers in the lower income segments…now as we look back at that history, we’re facing this new market transformation effort associated with electrifying our built environment.”

In parallel, local actors at housing and environmental justice organizations who have long approached housing retrofits as a project of health and habitability, rather than a question of exclusively reducing carbon emissions, have searched for ways to reframe electrification as a redistributive project. One local energy democracy organizer positioned electrification as a source of collective, rather than individual, benefits:

> “We're advocating for reaching people who don’t own their homes, we’re advocating for electrifying public transportation or municipal fleets. How do we make it so that it's shared benefit, as opposed to you know, if you can pay for it, then you benefit?”

Similarly, an Oakland-based housing advocacy organization staff member framed electrification as “one part of creating a healthy community”. And an equity director within a larger industry coalition mused that one strategy to mobilize support for equitable electrification might be to frame electrification as a means to achieve air conditioning for all (since many heat pumps have cooling capabilities) in a region with intensifying heat waves.

Two concurrent reframing efforts are occurring, then, through the local equity turn: actors that have historically worked within a market transformation paradigm begin to reframe their work as redistributive, and actors that have historically worked within a redistributive paradigm begin to reframe electrification as a collective and redistributive project. Investigating emerging advocacy and coalition efforts around funding allocations for residential electrification shows that this reframing has stimulated a growing consensus around "whole-home repairs" to navigate the uncertainty posed by fragmented funding.

As the State of California designs a new direct installation program (California Energy Commission 2023b), public comments – from individual and coalitions of local environmental justice organizations, housing organizations, CCAs, local branches of larger environmental organizations – now frequently advocate for a "whole home" approach, including the use of funding for non-energy related household remediation. (BEEP Coalition 2023; Building Decarbonization Coalition et al. 2023; California Energy Commission 2023a). This early public comment period indicates a reframing of electrification from a market transformation project to a project of redistribution and material repair as a means of navigating the uncertain and fragmented funding for building retrofits in California and the US.

# Discussion and conclusion

In offering a local view on the two scalar arrangements of utility regulation and home retrofit funding, this paper highlights a larger question surrounding the equity turn in local climate planning: if local actors are embedded in larger political and institutional arrangements, many of which they seemingly do not have authority over, how can we understand the meaning and function of local equity work? By tracing the work of local actors – staff at CCAs, local branches of large environmental organizations, environmental justice and housing advocates, and city staff – this paper establishes that while larger political and institutional arrangements can make residential electrification an uncertain proposition particularly for low-income residents and tenants, the equity turn also leads local actors to generate upward pressure to reshape larger political and institutional arrangements to be more favorable to disadvantaged residents.

To understand this simultaneous inhibition and reframing, we can return to Christopher Brown and Purcell (2005)'s characterization of scale as both fixed and fluid. The regulation of corporate electricity and gas utilities, which is opaque and labor- and capital-intensive, maintains power for utilities at the expense of diverse local actors attempting to advocate within, or even just to understand, the utility regulation and rate-setting process. The obduracy of this scalar arrangement contributes to uncertainty among local actors and lower-income residents about the affordability of electric and gas heat and thus hesitation around a universal promotion of residential electrification. With growing local, regional, and state impulses to reframe climate change as a question of social justice, some of the most crucial processes – like rate-setting, core to the utility profit model – remain impenetrable. Without a broadened application of procedural justice and democratic decision-making (Goh 2020) in California energy regulatory processes to circumvent these corporate political relationships, local approaches to equitable electrification, including "place-based" solutions like targeted gas network decommissioning, will be constrained by institutionally-produced uncertainty.

Yet, looking towards the arrangements that dictate funding allocation for home retrofits show that local impulses *can* help begin the reframing of larger institutional contexts. The limited and precarious funding for energy retrofits as part of a larger project of redistribution and material repair stifles equitable residential electrification by making resources inaccessible to low-income households and tenants. In turn, however, equity as a framing contributes to a reassessment of local energy transition strategies, with local actors both questioning the place of exclusively market transformation-oriented approaches and advocating at the state-level to reframe electrification as a means towards material repair, habitability, and redistribution of resources. In this way, we can understand the equity turn as a contributor to creating fluidity in entrenched scalar arrangements, as new consensuses emerge among local actors about how electrification should be framed.

While this paper analyzes utility regulation and home retrofit funding as scalar arrangements, it does not consider in detail at least two other scalar arrangements that shape local equity considerations around residential electrification: tenants' rights and labor standards. As a home retrofit, residential electrification brings with it the real concern of displacement, eviction, or rising rents for residents of retrofitted homes (e.g. see SAJE (2021) for an analysis of potential tenant impacts of residential electrification in Los Angeles). Lack of tenant protections contributes to hesitations and anxieties around universally promoting residential electrification. Additionally, the residential building sector is often un-unionized and poorly compensated (Jacobs and Huang 2021), leading local actors – particularly city staff and local labor advocacy organizations – to consider how 'high-road' labor standards can be implemented in a labor market with few protections. These topics deserve future concerted work. Exploring these scalar arrangements might provide additional insights on how the equity turn interacts with, shapes, and is shaped by wider institutional contexts.

Utility regulation and funding for home retrofits are two scalar arrangements, among others, that can make the equity turn uneasy for local actors, like Emily[14], who opened this paper: "trying not to hurt people" becomes a challenge in navigating (equitable) climate policy and implementation. Unpacking these scalar arrangements, and particularly understanding them from a local view, can help us understand how these trepidations are produced, maintained, and challenged. The equity turn at the local level interacts dynamically with larger institutional and political arrangements, revealing both where broadened understandings of procedural justice are needed and where emerging local reframings might shape the larger contexts in which local actors are embedded.

# Conclusion

My goal for this dissertation was, in short, to understand what is going on with residential heating electrification in the Bay Area, and to understand what we can learn about infrastructural transitions, more broadly, from the case of residential heating electrification. The dissertation offers multiple contributions to that end.

Chapter 1 presents one of the first estimates of how electric distribution grid may need to adapt to residential heating electrification, combining bottom-up modeling and utility-specific integration capacity limit data in the PG&E service area. In doing so, this chapter offers both methodological contributions in determining feeder-level energy use projections, and several practical insights. This analysis finds that feeder upgrades are needed on circuits that serve larger populations, that the number of feeder upgrade projects could exceed PG&E's current rate of upgrades, and that upgrade needs are spatially heterogenous, concentrated in counties in the San Francisco Bay Area and in parts of the Central Valley, including Fresno County.

Chapter 2 analyzes access to both space heating and cooling in Northern California, combining household-level energy usage data with census data. This chapter offers methodological contributions, building on existing studies that use statistical methods to detect cooling usage to detect both heating and cooling, for both gas and electricity use. We find that analyzing household-level energy use data suggests that fewer homes heat with gas and cool with electricity than surveys do, potentially indicating that the surveyed presence of heating and cooling equipment does not necessarily mean that that equipment is used consistently. We find that heating and cooling have shared socioeconomic indicators of access, but diverging modes of provision. Ensuring access to heating while meeting climate mitigation goals might necessitate similar strategies as ensuring access to cooling, but because heating is often provided by gas rather than electricity, ensuring access to heating requires additional careful planning of the gas system.

Chapter 3 turns our attention to the “equity turn”, or the increasing centering of equity and justice in climate planning. This chapter, which asks how ideas and imperatives around equity are constructed in municipal climate mitigation and decarbonization planning, emphasizes that equity is constructed through existing and evolving relations within cities, with consultants at the center of this construction of equity. This chapter provides one of the first examinations of how consultant-led planning interacts with climate equity imperatives, contributing to the emerging literature on how technocratic planning approaches are reinforced or challenged throughout the equity turn. Specifically, this chapter highlights the heterogeneity of consultants, their work as equity advocates or gatekeepers, and the implications of the inherently marketable and transferable work of consultants for climate equity more broadly.

Chapter 4 extends this examination of the equity turn by investigating how local actors that have undertaken discursive commitments to equity navigate utility governance and home retrofit funding, two corporate and federal scales that local actors have ostensibly limited control over. This chapter finds that local actors encounter a fixed and obdurate institution in investor-owned utilities: the opaque regulation of corporate electricity and gas utilities maintains power for utilities at the expense of diverse local actors attempting to advocate within, or even just to understand, the utility regulation and rate-setting process, ultimately making electrification an uncertain proposition for low-income residents and tenants. But in the provision of funding for home retrofits, local actors can exercise more agency, and equity as a framing contributes to a reassessment of local energy transition strategies, with local actors both questioning the place of exclusively market transformation-oriented approaches and advocating at the state-level to reframe electrification as a means for material repair, habitability, and redistribution of resources.

Two themes emerge across these four empirical chapters. First, residential heating electrification is shaped by, and can shape, forms of energy provision, both institutional and physical. This is true in both obvious and not-so-obvious ways, and we see energy provision foregrounded especially in Chapters 1, 2, and 4. Chapter 1 establishes that residential heating electrification depends on an upgraded, maintained electrical network, which might necessitate accelerated or more proactive infrastructure upgrade strategies. In Chapter 2, we find that socioeconomic indicators interact with networked energy provision: access to networked heating and cooling is correlated with income, linguistic isolation, and building type, among other variables. These correlations potentially result from persistently and increasingly high residential energy rates and a broader a cost-of-living crisis in the study area. In Chapter 4, we turn to the institutional characteristics of a corporate energy provision, where the opacity and power dynamics embedded in the utility rate-setting process limit the reach of local equity pledges, though local actors find limited ways of circumventing that process.

These results point to a utility system that neither fully serves climate mitigation goals (as seen in Chapters 1 and 4) nor the energy services it is meant to provide (as seen in Chapters 2). In Goh (2020)’s exploration of a Green New Deal’s implications for urban planning, she calls for “political relationships based on a broader notion of public participation and democratized decision making.” Household energy transitions and the equity turn have led to an emphasis on participation at city and regional (as discussed in Chapter 3) and sometimes state levels (as discussed in Chapter 4’s look at home retrofit funding provision). Investor-owned utilities have, thus far, mostly evaded the public engagement and push to democratization that has accompanied climate policy efforts, and especially equitable climate policy efforts. My dissertation indicates that the political relationships at the heart of the utility profit model are a critical site for future work, both academic and non-academic, in designing systems of energy provision that are accountable to universal access, climate mitigation goals, and transparent governance.

Second, energy transitions have the potential to move us, to paraphrase Lennon (2017), from an alienating understanding of energy – where the connections between energy systems and people, places, and ecology are obscured – to a relational understanding that foregrounds those connections. This theme emerges particularly in Chapters 2, 3, and 4. Chapter 2 establishes that, though investments in residential heating electrification center on providing rebates for appliances, access to the services that heat pumps are meant to deliver – residential heating and cooling – are, themselves, uneven. We can move towards a relational understanding by understanding energy as a service that is accessed through intersecting social and infrastructural factors. Chapter 3 establishes how dominant planning practices and incentives can alienate energy transitions and climate policy from their local context, through, for instance, the use of transferable tools or policy approaches across geographies. Conversely, Chapter 3 also points to other, emergent modes of policy making that foreground long-term relationship building. In Chapter 4, we see that the equity turn pushes local actors to adopt a framing of electrification that deals not just with carbon emissions, but with the potential for electrification funding to create healthier, more habitable homes overall. This framing, too, is more relational: electrification moves from being a singular, isolated, carbon emission-focused intervention, to one that is embedded in broader household-level inequalities.

Conceiving of energy in terms of relationality can make more explicit who is or is not served by energy transitions, and can inspire new framings and imaginaries of the energy system. Here, there are also possibilities for future work, both academic and non-academic. For instance, extensions of Chapter 2 can further explore heating and cooling as shared services amidst an energy transition, provisioned not only by networked utilities at the household level but also in the different spaces – workplaces, schools, and more – where energy services are needed. Chapter 3 and 4 indicate the importance of studying these emerging framings of climate mitigation, like whole-home retrofit programs, to investigate how knowledge is produced, how local actors participate, and distributional effects.

Energy and infrastructural transitions are undeniably shaped by existing structures and inequities. They can also be hopeful processes, with the potential to remake institutions, uneven service access, and dominant approaches to planning and knowledge production. Each of the chapters of this dissertation point to the dual dependencies and promises of a residential heating transition as it interacts with physical networks of energy provision, socially and economically mediated access to energy services, incomplete and emerging ways to plan for equity, and local movements for an equitable transition.

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