Climate, Grid, and Customer: Three Dimensions of Heat Pump Impacts

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ABSTRACT

Building electrification is a key element of climate policy and decarbonization strategies and is essential for reducing greenhouse gas emissions (GHGs) and advancing climate goals. At the same time, widespread electrification of space and water heating will lead to large increases in the demand for electricity, creating new challenges for the grid and customer affordability. In this paper, we present learnings from the impact evaluation of a large and ongoing statewide pilot in California that incentivizes the adoption of heat pump HVACs and heat pump water heaters (HPWHs) in existing housing stock. Using meter-based consumption analysis of about 4,000 primarily single-family homes, we assess the pilot's impacts from three dimensions: (1) The climate: Participants achieve an average reduction in greenhouse gas emissions of 17 percent, driven by substantial reductions in natural gas consumption and more modest increases in electric consumption. (2) The grid: Electrification has a negligible average impact on summer peak demand statewide, with impacts varying based on cooling consumption and presence of baseline cooling equipment. Electrification of space heating also introduces a new winter morning peak that is greater than the winter afternoon peak. (3) Customer energy bills: Electrification has a negligible impact on energy bills for the average participant but there is significant variation in bill impacts depending on climate zone and other customer and project attributes. This study demonstrates the importance of quantifying the impacts of building electrification comprehensively by reporting on multiple outcomes and assessing variation across subgroups such as geography, measure adopted, and customer segment.

Introduction

Residential energy use contributes to about 20% of total greenhouse gas (GHG) emissions in the United States (Goldstein, Gounaridis, and Newell 2020). As a result, policymakers have identified electrification of residential space and water heating as an important tool for meeting decarbonization goals. When combined with grid decarbonization, electrification policies work by displacing energy from fossil fuels with energy generated from zero-GHG emissions sources such as solar, wind, and nuclear.

In California, the legislature passed Senate Bill (SB) 1477, which called on the California Public Utilities Commission (CPUC) to develop the Technology and Equipment for Clean Heating (TECH) Initiative (Low-Emissions Buildings and Sources of Heat Energy 2018). The TECH Initiative is designed to accelerate market adoption of low-emissions space conditioning and water heating technologies for existing single-family and multifamily residential housing units. It was launched in December 2021 and as of April 2025 has supported nearly 50,000 residential heat pump incentive claims in California (Energy Solutions 2025).

The shift to efficient electric space and water heating brings challenges and considerations. As the transition accelerates across the country, it is important to monitor the impact on three key outcomes:

- The Climate: The efficacy of electrification towards reducing GHG emissions depends on the willingness of residential utility customers using fossil fuels for space or water heating to adopt more energy-efficient heat pumps. At the same time, the regional electricity generation systems need to meet the rising energy demand from electrification with adequate clean energy sources.

- The Grid: By definition, electrification involves electric load growth. The impact on peak demand may vary depending on regional heating and cooling needs and the prevalence and efficiency of space cooling prior to heat pump adoption. Monitoring how electrification impacts load shapes and peak demand patterns will help grid planners prepare for widespread electrification.
- The Customer: Customers may have misconceptions and concerns about making the switch to electric heat pump technologies. While barriers include lack of consumer awareness, contractor misperceptions, lack of trust in the utility, and the need for panel or wiring upgrades (Malinowski et al. 2025; Opinion Dynamics 2024), a predominant concern relates to costs, including the potential for increased energy bills (Opinion Dynamics 2024). Observing the impact of electrification on customer energy bills under different scenarios can help us to assuage customer concerns and to develop more effective electrification policies and rates where necessary.

This study assesses the impact of heat pump adoption as part of the TECH Initiative on gas and electricity consumption, hourly and peak electricity demand, GHG emissions, and customer bills. Participants in the program were switching from natural gas to electricity for their space and/or water heating. Thus, these changes in fuel consumption are reflected in the baseline and post-intervention consumption patterns. We separately report impacts for ducted heat pump systems, ductless heat pumps, and heat pump water heaters (HPWHs), net metered (NEM) and non-net metered customers, and by California climate zone to assess variation in impacts. In addition, we report electric impacts by season, day-type, and hour of the day and gas impacts by season and month to capture temporal differences in TECH Initiative impacts.[1]

Methodology

The study estimated the impact of residential heat pump technology adoption on energy (electric and natural gas) consumption, electric demand and load shapes, GHG emissions, and customer bills for projects completed as part of the TECH Initiative, supported by the gas investor-owned utility (IOU) cap-and-trade program, and occurring between July 2021 and July 2023. In this timeframe, there were 14,686 TECH incentive claims associated with over 10,000 residential premises statewide. We conducted a consumption analysis of participating sites using whole-home, meter-based consumption data and leveraged a matched comparison group of similar nonparticipants to construct a baseline. Our results were obtained using two-way fixed effects, difference-in-difference (D-in-D) models, and were normalized to represent a typical weather year.

Data Overview, Cleaning, and Sample Selection

The study included data from a variety of sources. The TECH Initiative program tracking data, obtained from the initiative implementer, was used to identify the participants in the evaluation period, the measure(s) installed and date(s) of installation, and locational attributes such as the site address and California climate zone (CZ). We also connected the program and claim information to utility meter data using the program tracking data. Household hourly electric consumption, monthly natural gas consumption, and associated metadata were extracted from a centralized database maintained by the California Energy Commission. Customer information, such as rate code, NEM status, utility, and address, was also obtained from this database. The analysis leveraged both historical actual and typical year

[1] Additional details can be viewed in the full evaluation report: Opinion Dynamics. 2025. "TECH Population-Based Pathway Impact Report."
https://www.calmac.org/publications/TECH_Population_Pathway_Impact_Analysis_Report_FINAL.pdf

weather data, which was derived from the National Centers for Environmental Information (NCEI) and the California Measurement Advisory Council (CALMAC), respectively.[2] To calculate GHG emissions impacts, we used climate zone marginal hourly emissions rates and a static single GHG emission factor for natural gas from the California Energy Commission's Time Dependent Valuation (TDV) methodology (California Energy Commission 2022). The rate schedules used for calculating bill impacts were compiled based on historic utility tariffs.

For this study, the unit of analysis was the unique utility customer-premise.[3] The study developed separate electricity and natural gas analysis samples. A small number of participants who heated with propane prior to participation were excluded, as were projects that received incentives for both HPWH and heating, ventilation, and air conditioning (HVAC) measures.[4] For each fuel, we included all participating customer-premises that could be matched with consumption data for that fuel and that met the inclusion requirements. To be included in the analysis sample, the project had to be completed between December 2021 and December 2022 and the participant had to receive electric service from Pacific Gas & Electric Company (PG&E), Southern California Edison (SCE), or Sacramento Municipal Utility District (SMUD) and receive natural gas service from PG&E or Southern California Gas Company (SoCalGas).[5] To be included in the gas or electric analysis sample, a customer-premise was required to have at least nine months of usable pre- and post-participation electric or natural gas consumption data. Master-metered buildings and customer-premises with a change in their NEM status during the evaluation period were excluded. The final sample included 4,129 electric and 3,684 gas customer-premises—50% and 43% of the study frame, respectively. The sampled sites were generally representative of the broader participant population in terms of observed customer and participation attributes to allow for extrapolation.[6]

Comparison Group Design

The study developed separate matched comparison groups for the electricity and natural gas consumption analyses. The matched comparison group was used to construct the counterfactual of what would have happened in the absence of the program. It controls for the naturally-occurring adoption of heat pumps and other efficient heating technologies and for other non-programmatic shifts in energy consumption. The matching process was conducted in two stages. First, participants were exactly matched to the universe of nonparticipating California households based on climate zone, receipt of a low-income utility bill discount, net metering status, electric utility rate type (i.e., time varying or flat), and whether the customer resides in a disadvantaged community. Second, Euclidean distance and propensity score matching algorithms were used to match each participant to a nonparticipant in the same stratum (i.e., with the same combination of attributes) with similar energy consumption patterns in the period prior to their program participation. This process was repeated separately for each fuel so that every participant was matched to the most similar nonparticipant on their unique electric and natural gas consumption. Participants for whom a suitable match could not be identified were excluded from the modeling process. This two-stage matching ensured alignment on key customer characteristics in addition to energy consumption. For electricity matching, the second stage considered the 24-hour load profiles

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[2] California normal year weather files are maintained at https://www.calmac.org/weather.asp. The study used CZ2022 files unless they were unavailable for a site's closest weather station, in which case CALEE2018 was used.
[3] The utility customer-premise is defined as all meters at a premise for a period of time where the same account is associated with the premise. If the account changes, this would become a new utility customer-premise.
[4] This choice was made to isolate measure-specific impacts.
[5] These were the utilities for which consumption data was available for this study.
[6] The vast majority (98%) of the participating homes in this study were single family.

as well as disaggregated consumption to account for weather sensitive consumption across typical, critical, and extreme temperature days. The matches were validated in two ways. First, we compared baseline consumption of participants and the matched comparison group. Second, an event study analysis was completed, leveraging the staggered program participation design to further test for differences in consumption prior to measure adoption. In both cases, no energy impacts were observed prior to treatment, confirming the equivalency of participants to the matched comparison group.

Modeling Methodology

The study estimated average electric and natural gas impacts per TECH Initiative participant using panel regression models with matched nonparticipants. Electric impacts were analyzed by season, day type, and hour of the day, while gas impacts were assessed by month and season. We also estimated impacts by measure, geography, and customer segment.

For electric energy impacts, we estimated two-way, fixed-effect D-in-D models of hourly electricity consumption (kWh_{it}), where i indexes the customer and t the hour of sample (Bertand, Duflo, and Mullainanthan 2004).[7] For each customer segment, we estimated a separate model for each season (summer, shoulder, winter) and day type (weekday and weekend).[8] Equation 1 shows the winter season model. It includes customer (α_i) and hour-of-sample fixed effects (t_t) and allows the impact of weather as represented by heating degree hour (HDH) on consumption and savings to depend on hour of the day.

Equation 1. Electric energy model specification (winter model with HDH terms only)

$$kWh_{it} = \alpha_i + \tau_t + \sum_{j=1}^{24} \theta_{HDH,j} HDH_{it} \, x \, HourofDay_j + \sum_{j=1}^{24} (\gamma_j TECH_{it} x HourofDay_j + \gamma_{HDH,j} TECH_{it} x HDH_{it} x HourofDay_j) + \varepsilon_{it}$$

Equation 1 assumes TECH program participation denoted by $TECH_{it}$ (=1 if customer i was treated on or before hour-of-sample t, =0, otherwise) could have non-weather sensitive impacts (γ_j) and weather-sensitive impacts ($\gamma_{HDH,j}$) on consumption that vary by hour of the day *j*. The summer season and shoulder season consumption models have the same basic structures as Equation 1. The only differences are that the summer model allows consumption and savings to depend on cooling degree hours (CDH), and the shoulder season models allow consumption and savings to depend on CDH and HDH. By specifying separate models for each season and day type, incorporating customer and time-period fixed effects, and allowing the impact of weather to depend on the hour of the day, our modeling approach enabled us to flexibly model electric energy consumption and obtain precisely estimated and accurate program impacts on the grid.

For gas energy impacts, as Equation 2 shows, the dependent variable is average daily therm consumption (for customer i in month-year of sample t), and the model includes month-year of sample (τ_t) and customer fixed effects (α_i). The model only includes average daily heating degree days (HDD_{it}) since natural gas is not used in cooling homes.

Equation 2. Gas energy impacts model specification

[7] The two-way fixed-effect D-in-D regression model is the standard approach for estimating energy impacts when the timing of intervention varies between participants. "Two-way" refers to the inclusion of customer and time-period fixed effects in the model.

[8] Throughout the report, summer is defined as June through September, winter as December through March, and the shoulder season includes April, May, October, and November.

$$therm_{it} = \alpha_i + \tau_t + \sum_j \theta_j HDD_{it} x\, CZ_{ij} + \beta_1 TECH_{it} + \beta_2 TECH_{it} x HDD_{it} + \varepsilon_{it}$$

β_1 is the coefficient on the standalone TECH indicator variable, and β_2 is the coefficient on the interaction between the TECH indicator variable and HDD. The β_1 coefficient captures TECH impacts on baseload consumption and β_2 captures impacts on weather-sensitive consumption. We estimated the electricity and gas consumption models by ordinary least squares and clustered the standard errors on the customer and time period (hour of the day of sample for electricity/month-year of sample for gas).

Bill and Greenhouse Gas Impact Analysis

The study calculated the GHG emissions impacts by fuel and combined these to estimate net GHG emissions impacts. To estimate GHG emissions from increased electricity consumption, the study applied marginal emissions factors defined by climate zone and hour of the year to the estimated hourly climate zone-level electric energy impact estimates. Since natural gas emissions are not location- or time-dependent, we applied a static GHG emission factor to the natural gas impact estimates.

The study calculated electric and gas average bill impacts per participant by multiplying the average energy baseline and modeled post-participation usage by the respective average retail cost of energy.[9] As many participants were on time-of-use electricity rates, the study calculated an average electricity retail cost by season, day type, and hour of the day. In addition, because customers in the study are served by a variety of utilities and there is varying incidence of rate type, NEM participation,[10] and receipt of low-income bill discounts across the study population, the average retail energy cost was calculated separately by customer segment and fuel type. For each fuel, the bill impacts were calculated by multiplying the energy impact for that fuel by the average retail energy cost. Net energy bill impacts were calculated by adding together the bill impacts from each fuel type. Energy costs are based on participants' rates as of January 2022.[11]

Results

The Climate: Energy and GHG Impacts

Table 1 summarizes the average energy and GHG emissions impacts of heat pump adoption per participant in this study. Adoption of residential building electrification measures (heat pump HVACs and HPWHs) leads to an annual increase of 1,451 kWh (17% of baseline electric consumption) and an annual decrease of 165 therms (38% of baseline natural gas consumption). In aggregate, there is a reduction in whole-home, annual energy consumption of 16%, consistent with the idea, as expected, that the heat pump technology is more efficient than the fossil-fuel based technology it displaces. The shift from fossil

[9] The average energy costs for the two separate fuels were estimated, excluding taxes and flat fees. The estimation procedure also assumed that the customers retained their gas service. While reliable data was unavailable to differentiate between participants who terminated their natural gas service vs. those for home gas billing data was missing, available data suggests that most participants retained gas service following TECH Initiative participation. The full report includes estimation of bill impacts for participants that terminate gas service (page 80): https://www.calmac.org/publications/TECH_Population_Pathway_Impact_Analysis_Report_FINAL.pdf.
[10] All NEM customers were assumed to be on the CA NEM tariff version 1.0 or 2.0, since projects were completed by December 2022. These versions allow excess generation to be reimbursed at the cost of electricity. CA NEM tariff version 3.0, which has a lower reimbursement rate, became effective after April 2023.
[11] The study referenced historic tariffs as close to January 2022 as available to calculate the price of energy by rate.

fuels to electricity for heating leads to an annual net reduction in GHG emissions of 17%, or 0.73 metric tons of CO_2-e per participant, which is the equivalent of 81 gallons of gasoline.[12]

Table 1. TECH Initiative annual per-participant energy and GHG emissions impacts

Impact outcome	Units	Baseline	Impact	Lower CI	Upper CI	% Impact
Electric	kWh	8,421	1,451*	1,315	1,587	17.2%
Natural Gas	Therms	432	-165*	-172	-158	-38.2%
Total Energy	mmBTu	71.9	-11.55*	-12.72	-10.39	-16.1%
Total GHG Emissions	tonnes CO2-e	4.26	-0.73*	-0.77	-0.69	-17.2%

Note: Normal weather estimates based on fixed-effects D-in-D panel regression analysis of TECH Initiative participant and matched nonparticipant electric interval data. (*)Results are statistically significant at 95% confidence level.

Given the weather sensitivity of space heating and cooling, and to a lesser extent water heating, we examined the electric and natural gas impacts by season. As shown in Table 2, we found electric consumption increases and gas consumption decreases for all seasons, except for summer electric consumption. Here we found a small decrease in average electric consumption, likely due to the adoption of more efficient space cooling among some participants that had existing space cooling prior to participation in the program.

Table 2. TECH Initiative energy impacts by fuel and season

	Electric Impacts			Gas Impacts			Total Energy Impacts		
Season	Baseline (kWh)	Average Impact (kWh)	% Impact	Baseline (therms)	Average Impact (therms)	% Impact	Baseline (MMBtu)	Average Impact (MMBtu)	% Impact
Summer	3,398	-100*	-2.9%	65	-17*	-25.6%	18.10	-2.00*	-11.1%
Winter	2,917	1,215*	41.6%	246	-101*	-41.2%	34.55	-5.98*	-17.3%
Shoulder	2,106	336*	15.9%	121	-47*	-39.1%	19.26	-3.57*	-18.5%

Note: Normal weather estimates based on fixed-effects D-in-D panel regression analysis of TECH Initiative participant and matched nonparticipant electric interval data. (*) Results are statistically significant at 95% confidence level.

The Grid: Hourly Electric Demand

Given the increase in electric consumption from building electrification, it is critical for grid planners to know when those increases in consumption are occurring. Figure 1 illustrates the hourly electric impacts on winter weekdays. There is a statistically significant increase in electric consumption during all hours of the day, ranging from a 0.14 kW increase in the 2:00 p.m. and 3:00 p.m. hours to a 0.60 kW increase in the 7:00 a.m. hour. The absolute impact is greatest during the morning heating hours between 3:00 a.m. and 10:00 a.m., when the average participant increases electric consumption by 62% compared to baseline. The increase in winter heating load shows up as more prominent peaks in both the morning and afternoon periods. There is a new morning peak greater than the afternoon peak by 0.14 kW or 10% (1.54 kW at 7:00 a.m. compared to 1.40 kW at 7:00 p.m.).

[12] The estimate that each gallon of gasoline emits about 8.89 kg of CO_2 is sourced from the U.S. Environmental Protection Agency (EPA). This value is detailed in the EPA's Greenhouse Gas Equivalencies Calculator and the GHG Emission Factors Hub.

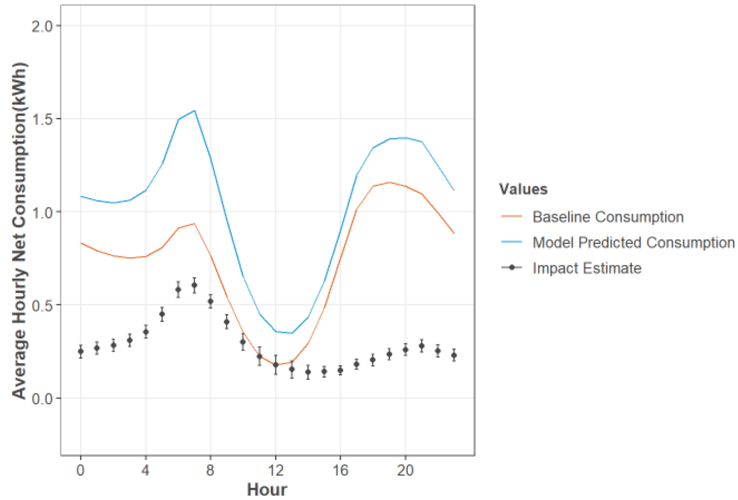

Figure 1. Average winter weekday electric load shape and impacts. Normal weather estimates based on fixed-effects D-in-D panel regression analysis of TECH Initiative participant and matched nonparticipant interval electricity consumption data. Error bars show 95% confidence intervals.

As may be expected from the relatively neutral summer electric energy consumption impacts, the summer load shape does not shift much. Figure 2 summarizes these impacts. The only hours with a statistically significant change in energy consumption occur between 5:00 p.m. and 8:00 p.m., which show a reduction in demand between 0.06 kW and 0.10 kW (3.4% to 5.1%). All hours with a measurable change in electric demand exhibit a decrease rather than an increase in electric consumption among our study population, 51% of whom had central air conditioning prior to participating in the program. On average, the summer afternoon peak also remains substantially higher than the winter morning peak.

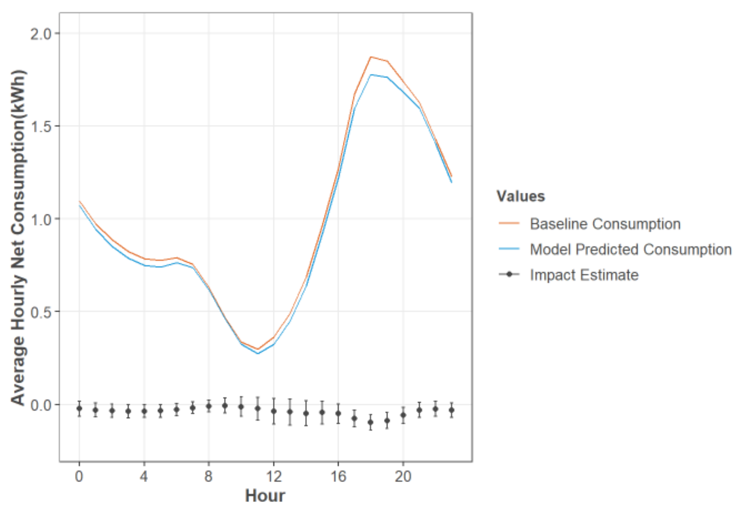

Figure 2. Average Summer Weekday Electric Load Shape and Impacts. Normal weather estimates based on fixed-effects D-in-D panel regression analysis of TECH participant and matched nonparticipant interval electricity consumption data. Error bars show 95% confidence intervals.

The Customer: Energy Bill Impacts

As summarized in Table 3, the average annual net energy bill impact is estimated to be -$11. In a normal weather year, the average participant experiences a substantial decrease in natural gas bills and a significant decrease in electric bills, but does not experience a statistically significant change in their combined energy bills. The average participant does experience an increase in their winter energy bills, but this is offset by decreases in the summer and shoulder season bills. While not a focus of this study, survey research with a sample of TECH Initiative participants has shown that most participants generally report their bills are lower than before (a little less than half of participants) or about the same as before (between one in five and one in four, depending on equipment type), suggesting these results align with customer perceptions (Opinion Dynamics 2025). The relatively neutral overall bill impacts also do not appear to affect satisfaction. In another study, when asked about likelihood to recommend heat pump equipment, most participants were "extremely likely" to recommend, with the equipment's cost effectiveness being the most common reason for this response (Opinion Dynamics 2023).

Table 3. Change in customer energy bills by fuel and season

	Electric	Natural Gas	Net Change		
Season	Estimate	Estimate	Annual Change	Lower CI	Upper CI
Winter	$316	-$222	$94*	$79	$108
Summer	-$33	-$24	-$56*	-$74	-$39
Shoulder	$50	-$99	-$49*	-$62	-$36
Overall	$333	-$344	-$11	-$37	$15

Note: Normal weather estimates based on fixed-effects D-in-D panel regression analysis of TECH participant and matched nonparticipant monthly natural gas consumption data and interval electricity consumption data, combined with utility rates. Summer is defined as June through September, winter as December through March, and shoulder as April, May, October, and November. (*) Results are statistically significant at 95% confidence level.

Variation in Outcomes

Thus far, our report has presented the average impacts of building electrification across all TECH Initiative participants, but there is important variation by geography, measure type, and customer segments in the energy, load shape, and bill impacts.[13] In this section, we report impacts by heat pump technology, low-income status, net metered customers, and for key climate zones.[14] As summarized in Table 4, there is substantial variation in both energy and bill impacts across subgroups. All groups achieve statistically significant increases in electric consumption and reductions in gas consumption, but bill impacts range from neutral to a significant energy bill increase or decrease, depending on the segment.

Table 4. Annual energy and bill impacts by subgroup

		Electric Consumption		Natural Gas Consumption		
Group	Modeled Sites (Electric/Gas)	kWh Baseline	kWh Impact (%)	Therms Baseline	Therms Impact (%)	Combined Energy Bills ($)
Overall	4,129 / 3,684	8,421	1,451 (17.2%)*	432	-165 (-38.2%)*	-$11
Geography						
CZ2 (northern)	235 / 205	6,509	2,769 (42.5%)*	506	-210 (-41.5%)*	+$242*
CZ4 (central)	154 / 120	5,797	1,583 (27.3%)*	452	-201 (-44.5%)*	-$57
CZ10 (southern)	340 / 250	9,045	619 (6.8%)*	424	-172 (-40.6%)*	-$30
Measure						
Central Heat Pump	2,528 / 2,483	9,480	1,064 (11.2%)*	422	-154 (-36.6%)*	-$25
Ductless Heat Pump	936 / 765	7,392	2,123 (28.7%)*	433	-180 (-41.4%)*	+$72*
HPWH	644 / 424	6,681	1,845 (27.6%)*	466	-164 (-35.1%)*	-$184*

[13] The TECH Initiative participants in this analysis live primarily in single family homes (98%).

[14] The climate zones presented in this paper are examples of particularly cold and hot climate zones in which there were enough participants to confidently compare the results.

Customer Segments						
Low-income	472 / 349	9,409	861 (9.2%)*	369	-120 (-32.6%)*	-$109*
Not Low-income	3,657 / 3,335	8,281	1,514 (18.3%)*	438	-170 (-38.7%)*	-$34*
Net Metered [a]	1,193	4,079	1,081 (26.5%)*	N/A	N/A	-$76*
Not Net Metered	2,936	10,340	1,544 (14.9%)*	N/A	N/A	-$28*

[a] Net metering status could only be identified for the electric analysis.

Note: Normal weather estimates based on fixed-effects D-in-D panel regression analysis of TECH participant and matched nonparticipant monthly natural gas consumption data and interval electricity consumption data, combined with utility rates. Summer is defined as June through September, winter as December through March, and shoulder as April, May, October, and November. (*)Results are statistically significant at 95% confidence level.

The greatest absolute increase in electric consumption occurs in cooler climate zones such as CZ2. In CZ2, the average participant experiences an annual increase in electric consumption of 2,769 kWh, 447% higher than CZ10, a warmer climate zone in southern California, which experiences an increase of 619 kWh. Customers in cooler climate zones also experience the largest average reduction in gas consumption, but the variation in gas impacts is not as substantial as the variation in electric impacts. The electric impacts are more variable because customers in cooler climate zones are more likely to be adding new cooling load in addition to electric heating load, whereas customers in warmer climate zones are more likely to be offsetting inefficient space cooling. As a result, the average customer in a cooler climate zone experiences a statistically significant bill increase, whereas those in warmer and more moderate climate zones experience a small, statistically insignificant bill reduction on average.

The study team was surprised by the difference in electric energy impacts between central and ductless heat pumps. Central heat pumps have the smallest electric impacts, even though these sites have the greatest average baseline electric usage. This is because central heat pumps tend to replace central air conditioning and therefore cause reduced energy usage in the summer months, while ductless heat pump adopters often add new cooling load, causing an increase in energy consumption in the summer months.[15] Meanwhile, the shoulder season impacts for ductless systems are almost double that of central systems, potentially because these systems tend to be installed in colder climates that require more heating during the shoulder season and where pre-existing air conditioning systems are less common. Most participants in this study adopted heat pump HVACs, but a small proportion adopted HPWHs.[16] Given the combined change in electric and gas consumption throughout the day and the year, participants receiving HPWHs tend to experience the largest decrease in energy bills of all subgroups observed (approximately $15 per month), whereas customers receiving a ductless heat pump experience a modest but statistically significant increase in energy bills (equating to $6 per month).

Two particular customer subgroups of interest in this study are low-income customers and net metered customers. These groups are hypothesized to face particular risks and benefits, respectively, to their energy costs and affordability from home electrification, and the study included a substantial number of participants in these groups. Our analysis showed that low-income customers experience much smaller growth in electric energy consumption (861 kWh vs. 1,514 kWh, or 57%) compared to market rate customers, despite having slightly higher baseline consumption. While the study didn't explore underlying behavioral or structural reasons for this difference, the discrepancy was primarily driven by the winter and shoulder seasons, suggesting that low-income customers may use less electricity for heating than market rate customers. Further supporting this hypothesis, low-income customers experienced a smaller decrease in their annual gas consumption and had lower baseline gas consumption than market rate

[15] 61% of central heat pump sites had existing central cooling, whereas only 29% of ductless heat pump sites did.
[16] Participants could receive a HPWH alone or in combination with another measure. To isolate the HWPH impacts, only those participants that received a HPWH without a heat pump HVAC measure were included in the measure-level HPWH segment.

customers. Ultimately, a primary concern for low-income customers is the impact on energy bills. Our analysis found a statistically significant decrease in annual energy bills for low-income customers (equivalent to about $9 per month), driven by their smaller increase in electric consumption and the protections provided through CARE and FERA, California's low-income utility bill discount programs.

NEM customers made up a substantial portion of TECH Initiative participants (27% in this study). Based on their net energy consumption, they experience a smaller increase in electric energy consumption than non-net metered customers, despite having substantially lower baseline consumption. While the gas impacts of NEM customers were not separately measured, assuming average gas impacts for both subgroups, we found that NEM customers experience statistically significant annual energy bill savings that, while still modest, are nearly three times that of a non-net metered customer.

Depending on geography, measure type, and customer segment, the impacts of heat pump adoption can also have variable impacts on the grid in terms of electric load growth and timing of energy consumption. For example, consider the winter weekday load shape for a typical participant receiving an HPWH vs. a central heat pump, displayed in Figure 3. Sites adopting a HPWH use more energy on winter weekday mornings than before adoption, but their peak remains in the afternoon. The central heat pump produces a higher peak on winter mornings than afternoons, which is a change from the baseline period.

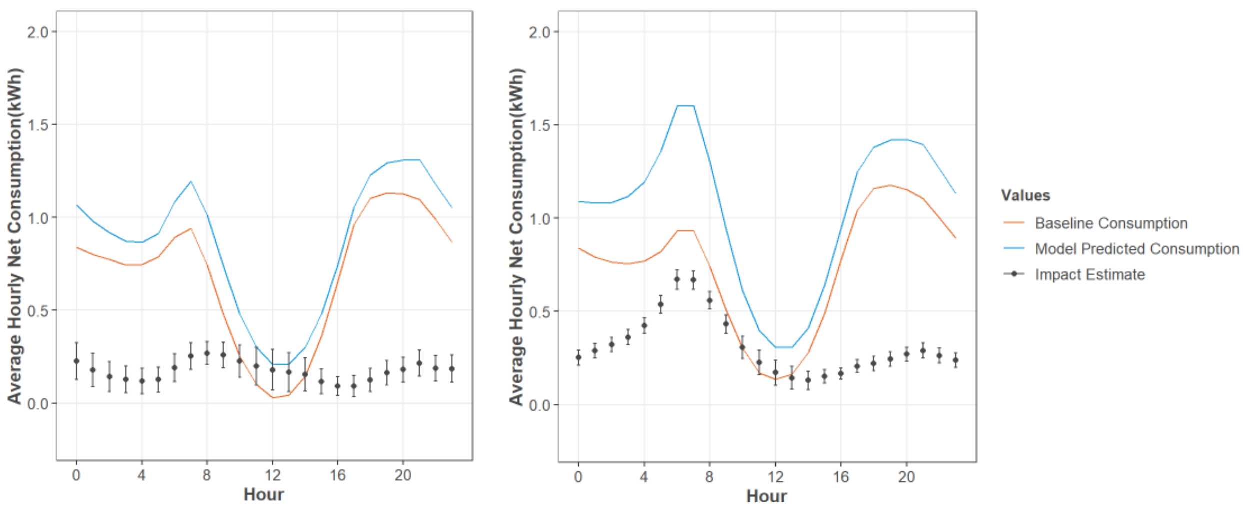

Figure 3. Average winter weekday loadshape by measure. Displayed for customers adopting a HPWH (left) vs. a central heat pump (right). Ductless heat pumps exhibit a similar winter weekday loadshape as central heat pumps. Normal weather estimates based on fixed-effects D-in-D panel regression analysis of TECH participant and matched nonparticipant interval electricity consumption data. Error bars show 95% confidence intervals.

Hourly and seasonal load impacts also vary substantially between climate zones. Consider the summer weekday loadshapes for CZ2 (northern) and CZ10 (southern) displayed in Figure 4. For participants in the northern climate zone, the afternoon peak is much lower than in the southern climate zone. However, in the cooler northern climate zone there is a statistically significant increase in electric consumption in the hours from 1:00 p.m. through 7:00 p.m., while in the warmest climate zone there is a statistically significant *decrease* in electric consumption in the hours from 4:00 p.m. through 9:00 p.m. The load shapes and impacts are consistent with differences in the participant composition and consumption patterns between regions. For example, nearly half (48%) of participants in CZ10 had central air conditioning prior to heat pump adoption, while only 28% did in CZ2.

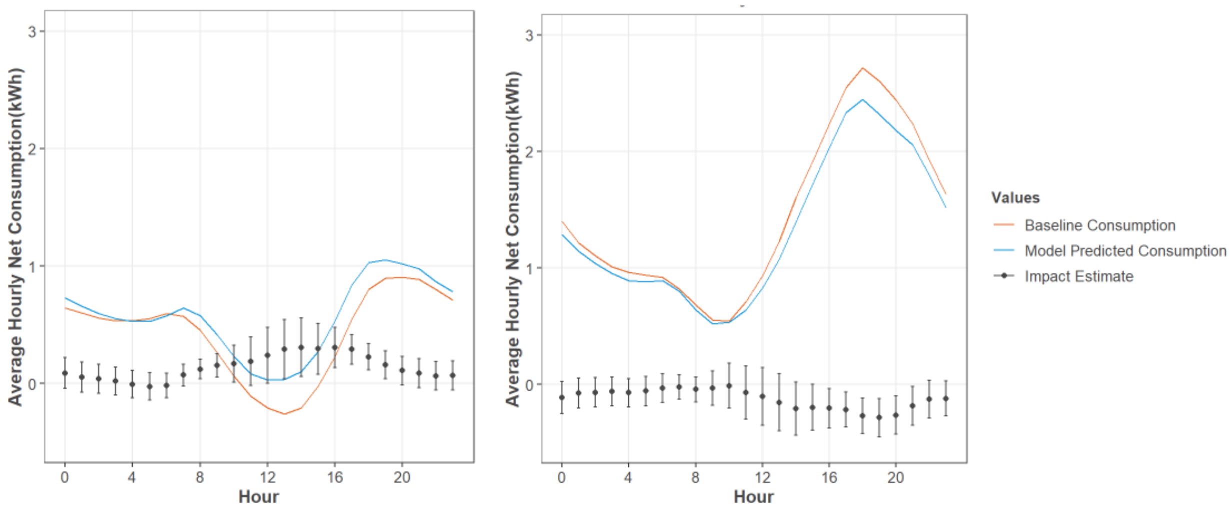

Figure 4. Average summer weekday loadshape by climate zone. Displayed for customers in CZ2 (northern, left) and CZ10 (southern, right). Normal weather estimates based on fixed-effects D-in-D panel regression analysis of TECH participant and matched nonparticipant interval electricity consumption data. Error bars show 95% confidence intervals.

Conclusions

This study shows that heat pumps have important impacts on energy consumption, electricity demand, GHG emissions, and customer bills. It is important for policy makers, grid planners, and program administrators to understand these impacts and how they vary among customer subgroups and across space and time to make cost-effective policies, grid investments, and customer programs.

From the perspective of the climate, we show that residential building electrification effectively offsets heating from fossil fuels with electricity, leading to overall reductions in energy consumption and greenhouse gas emissions. From the perspective of the grid, our study shows that the effect on summer load shapes and peak demand is highly sensitive to space conditioning needs and to the balance between the replacement of less efficient space conditioning versus the addition of new space conditioning. The use of electricity for winter space heating increases consumption across hours of the day, and leads to a new winter morning peak, which is greater than the baseline afternoon peak. In this study, the impact on annual customer energy bills was negligible, although there were significant seasonal changes in energy bills, with customers experiencing bill increases in winter and savings in other parts of the year. For both the energy and customer bill impact metrics studied, there is substantial variation based on measure adopted, geography, and customer subgroup. Some subgroups, such as those adopting an HPWH and low-income customers, see significant energy bill savings on average, while others, like those in the coldest climate zones or adopting a ductless heat pump, tend to experience an increase in their energy bills.

Our analysis points to several areas for exploration in future research. In particular, it will be useful for future researchers to consider how impacts vary by additional customer subgroups, including based on pre-existing air conditioning status, among customers that go all-electric following electrification of their space or water heating, and based on home type or size. While our study only considered the statewide and regional GHG impacts, future studies might explore how GHG emissions impacts vary based on project attributes. Finally, future research might further explore how customer bill impacts correspond with consumer expectations, how they compare to any non-financial benefits they experience from electrification, and how actual customer bill impacts vary across utilities and geographies given differences in energy costs, rate structures, and energy consumption needs and patterns.

When it comes to informing policy and programs in other regions, the evaluation of the TECH Initiative provides a unique case study given the large number of participants, variety of measures, and variation in participating customers – reaching both low-income customers as well as many with net energy metering. While the findings cannot be directly translated – given their dependence on housing stock, baseline equipment, heating and cooling needs, grid generation mix, and rates and energy costs - the variety of climate zones and housing stock in California provides insights into how heat pump impacts may vary. This information will provide valuable directional insights for those designing policies and implementing programs in other jurisdictions.

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