Balancing Electrification Costs and Savings with Machine Learning: High-ROI Pathways for Heat Pump Space and Water Heating Retrofits

Dylan Sarkisian, Energy Solutions
Gagan Atreya, Energy Solutions
Jackie Kinsler, Energy Solutions
Damian Perez Marrero, Energy Solutions
Jess Kursman, Energy Solutions
Rebecca Schloemann, Energy Solutions
Danielle Goldberg, Recurve
Adam Scheer, Recurve

ABSTRACT

Residential heat pump adoption is central to building decarbonization, yet high upfront costs and uncertain bill savings continue to constrain heat pump market growth, particularly as the energy affordability crisis intensifies. This study evaluates customer return on investment (ROI) for heat pump space and water heating retrofits using data collected by the Technology and Equipment for Clean Heating initiative (TECH Clean California), a statewide market transformation initiative that has supported over 75,000 electrification projects since 2022. Leveraging detailed heat pump retrofit project data, utility advanced metering infrastructure data, and gas alternative cost estimates, the authors develop a customer ROI metric that integrates both incremental upfront cost and lifecycle operating cost impacts.[1]

The authors estimate customer ROI for 11,727 real single-family heat pump retrofits that meet rigorous data sufficiency requirements, then use regression analysis to identify the most influential drivers of ROI for air-source heat pumps and heat pump water heaters, separately. The analysis largely encompasses utility rate schedules in place from 2022–2024.

Results show substantial heterogeneity in customer ROI, but high-ROI adoption pathways emerge. These depend on equipment replacement context, preinstallation energy consumption, utility rate structures, and contractor business and licensing practices. Sensitivity analyses demonstrate that rate design and financing assumptions materially affect customer value propositions, particularly for low-income households. These findings highlight actionable levers for programs and policymakers that can improve affordability while continuing to catalyze decarbonization, without increasing reliance on programmatic incentives.

The conclusions highlight that the most salient driver of customer ROI is pre-retrofit cooling demand: ASHP retrofits in homes with sufficient AC use deliver high returns across utilities and income levels, but ROI decreases substantially for customers in coastal/northern climates. More broadly, ROI improves when equipment is properly rightsized, while oversizing reduces customer returns. HPWH ROI is generally less variable but typically negative under current rates, though reforms that lower volumetric electricity prices could make ROI positive for most HPWH customers. Low-to-moderate-income customers often realize higher ROI, especially on CARE/FERA rates, but upfront costs remain a major barrier. Finally, retrofits performed by larger, unspecialized contractor companies tend to yield lower ROI.

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[1] DISCLAIMER: This analysis is not a program evaluation of the Technology and Equipment for Clean Heating initiative, but a means to share insights from the ongoing measurements sourced by the implementer.

Introduction

The authors would like to acknowledge significant data contributions from the California Public Utilities Commission (CPUC); California Energy Commission (CEC); and Opinion Dynamics, an E Source Company.

The Technology and Equipment for Clean Heating initiative (TECH Clean California) is a statewide market transformation initiative designed to accelerate residential heat pump adoption. Since 2022, TECH Clean California has engaged over 1,500 contractors and incentivized over 75,000 space and water heating electrification retrofits. Leveraging utility meter data and detailed project data collected from heat pump retrofits, TECH Clean California measures installation costs and benefits for heat pump customers across the state.[1]

Purpose

TECH Clean California's mission is to reduce greenhouse gas (GHG) emissions by accelerating home electrification (California Senate Bill 1477). At the outset of the initiative, there was insufficient empirical data available to predict most outcomes of home electrification, like customer financial costs and savings. This uncertainty prevented decarbonization decision-makers from being able to forecast the outcomes of major heat pump investments. Part of the TECH Clean California market transformation strategy was therefore to build a robust public dataset with detailed, project-level results. By 2026, TECH Clean California had assembled data on upfront costs, energy consumption impacts, peak demand impacts, and utility bill impacts for over 13,000 heat pump space and water heating retrofit projects in homes across the state.

As TECH Clean California implementation progressed, the energy affordability crisis in the United States further intensified (National Energy Assistance Directors Association, 2026). Accordingly, TECH Clean California has prioritized improving customers' return on investment (ROI). Although many customers do not purchase heat pumps with strictly financial motivations, affordability remains a major barrier to large-scale adoption (Northeast States for Coordinated Air Use Management, 2025). The scale of adoption needed to meet California's GHG reduction goals demands that programs identify and vet heat pump installation pathways with a positive ROI for customers, without relying on programmatic incentives.

Previous TECH Clean California analyses illustrate high variability in financial outcomes for customers who electrify. Dozens of variables contribute to project costs and utility bill savings, many of which depend on individual customer behavior (Scheer, 2025) (Sarkisian, 2025). Furthermore, many project features that increase costs are also expected to increase savings, like increased efficiency and quality installation measures. Programs like TECH Clean California have limited control over each installation and must prioritize a handful of variables to require, incentivize, or encourage. This creates a need to isolate the top drivers of customer ROI and to develop programmatic strategies that optimize ROI.

In this study, the authors first estimate customer ROI, a holistic metric capturing both incremental costs and lifecycle benefits of heat pump ownership. We then apply machine learning modeling techniques to identify and quantify top ROI drivers. Based on these drivers, we recommend practical ways to improve financial outcomes for heat pump customers without relying on incentives. These findings are meant to inform programs and policies that seek to decarbonize homes and improve customer financial outcomes, a necessary balance in order to accelerate heat pump market transformation.

Research Questions

The authors set out to answer the following research questions in this study:

1. Is there correlation between upfront cost and utility bill savings, the core parts of ROI?
2. How does customer ROI vary geographically across utility rate structures and climates?
3. Which project, home, contractor, and customer characteristics are the top drivers of ROI?

Major Data Sources

The analysis used three main data sources: the Project Dataset, provided by Energy Solutions; the Metered Impacts Dataset, provided by Recurve; and the Base Case Costs Dataset, provided by Opinion Dynamics. The Project Dataset covers 75,000 individual air-source heat pumps (ASHP) and heat pump water heater (HPWH) retrofits in homes across California, primarily documenting installation features reported by contractors. The Metered Impacts Dataset includes electricity, gas, and utility bill savings measured at the meter for a sample of projects from January 2022 through March 2024. Electricity and gas utility data were made available by CEC for customers of four investor-owned utilities (IOUs): Pacific Gas and Electric (PG&E), Southern California Electric (SCE), Southern California Gas (SCG), and San Diego Gas & Electric (SDG&E); and two publicly-owned utilities (POUs): Los Angeles Department of Water and Power (LADWP), and Sacramento Municipal Utility District (SMUD). Finally, the Base Case Costs Dataset includes installation cost quotes collected from California contractors for gas furnace, air conditioner (AC), and gas water heater installations in 2024. Collection methods are described in the Gas Baseline Incremental Cost Study (Opinion Dynamics, 2025).

Methods

The authors developed a customer ROI metric by combining incremental upfront cost with estimated lifecycle operating cost savings for each TECH Clean California participant. ROI estimates a customer's net present value (NPV) financial outcome. We then joined customer ROI with a variety of project-level data describing the equipment, home, installer, and pre-retrofit energy usage, and we trained machine learning models on this dataset for inferential analysis.

The customer ROI metric was developed for the analysis discussed herein only. It is not intended to evaluate programmatic impacts, nor to estimate participants' true financial outcomes, as many simplifying assumptions were made to facilitate project comparison. For example, some customers financed their heat pump purchase, while others paid out-of-pocket. This affects their true ROI, but since gauging the effect of financing on customer ROI is not one of the goals of this analysis, it was assumed that customers did not use financing. Additionally, the ROI metric only applies to customers who buy their own equipment, so it does not apply to most renters.

Throughout this study, the terms "measure case" and "base case" are used. The measure case represents the actual project documented in the Project Dataset. It assumes that the customer will operate the heat pump consistently over the full lifetime of the equipment, maintaining the same heating and cooling setpoints. The base case represents a scenario where the same customer *instead* performed a like-for-like replacement and operated new equipment the same way it had previously been operated, adjusting for weather only, for another full equipment lifetime. All supplemental project costs, including increased efficiency or capacity, quality installation measures, duct work, and electrical upgrades, are attributed to the measure case only.

Because the authors obtained cost and savings values from sources spanning multiple years, we inflated all cost data to May 2026 dollars using the Consumer Price Index prior to calculating customer ROI.

Components of Customer Return on Investment

Incremental upfront cost.

Upfront cost is the total cost paid by the customer for the equipment installation. The authors sourced measure case upfront costs from the field "Total Project Cost ($)" in the Project Dataset. TECH Clean California requires that contractors report total project cost prior to deducting incentives. Total project cost includes the cost of equipment, materials, and labor related to the heat pump installation. For example, the cost of a required electrical panel upgrade would be included in total project cost and recorded as a project feature.

We sourced base case upfront costs from the Base Case Costs Dataset. Bids were aggregated into common scenarios based on home and equipment characteristics. Water heating bids were grouped into tankless and storage, then by the tank size. HVAC bids were grouped by previous AC type and climate zone. In homes with both a furnace and AC, we assumed that both are replaced simultaneously in both the measure case and base case. We assigned a base case upfront costs to each project in the Project Dataset by matching it to the best-match base case scenario, based on data gathered from the contractor on equipment replaced by the heat pump.

We estimated incremental upfront cost for each project by subtracting base case upfront cost from measure case upfront cost.

Lifecycle operating cost savings.

The authors calculated the present value (PV) of lifecycle operating cost savings as the sum of PV lifecycle utility bill savings and PV lifecycle maintenance cost savings.

We sourced utility bill savings from the Metered Impacts Dataset. To estimate the first-year utility bill savings for each project, Recurve employed the OpenDSM methods to estimate monthly gas and hourly (except for monthly, for LADWP) electric load in the base case (counterfactual) and measure case (Linux Foundation, 2024). Next, Recurve used gas and electricity counterfactuals, along with the most recent utility rate the customer was using prior to the heat pump retrofit, to estimate the base case utility bill. Finally, using the customer's actual post-retrofit consumption, along with the most recent rate the customer was using in the year following the heat pump retrofit, Recurve estimated the measure case utility bill. The difference between the base case bill and the measure case bill is the utility bill savings.

The authors assumed that the analysis period was equal to the estimated useful lifetime (EUL) of the installed equipment: 23 years for ASHPs and 20 years for HPWHs, per the latest CPUC Residential EUL Study (Det Norske Veritas, 2024). Because empirical data on TECH Clean California project lifetimes is not available, the authors did not prioritize measuring the effect of equipment lifetimes on ROI. Therefore, it was assumed that the EUL of measure case and base case equipment is identical for each project.

Following the first year after the installation, we assumed that real electricity and gas utility bills in both the measure case and base case would increase at a constant compound annual growth rate (CAGR) specific to the utilities serving the home. Electricity rate CAGRs were derived from the California Integrated Energy Policy Report (California Energy Commission, 2024) and gas rate CAGRs from the California Energy Demand Forecast (California Energy Commission, 2026).

In addition to annual gas and electricity bills, we assigned annual maintenance costs to each project in the measure case and base case using typical annual maintenance costs for the installed and replaced equipment (U.S. Energy Information Administration, 2023). We assumed that annual maintenance costs will increase at the same rate as inflation.

We used a 7% annual real discount rate to calculate the PV of cash flows, with sensitivity analyses conducted at 5% and 9%. The 7% discount rate aligns with the Internal Revenue Service rate for individuals, three percentage points greater than the federal short-term rate.

Customer return on investment.

The authors' assumptions used in the ROI methodology are summarized in Table 1. Sources used for assumptions listed in Table 1 are discussed in the previous section.

Table 1. Summary of assumptions used to calculate customer ROI

Parameter	Discount rate	Effective useful life	Currency	Electricity rate CAGR (real)	Natural gas rate CAGR (real)
Value	7%	HPWH: 20 years ASHP: 23 years	May 2026 USD	1.8-3.3%, varying by utility	4.6-5.2%, varying by utility

We calculated Customer ROI for each project as the PV of lifecycle operating cost savings minus incremental upfront cost, as shown by the equation below. In other words, ROI is the difference in NPV lifecycle cost of ownership between the base case and measure case.

$$\text{Customer ROI} = \sum_{t=0}^{n-1} \frac{(\text{Utility Bill Savings}_t + \text{Maintenance Cost Savings}_t)}{(1+d)^t} - \text{Incremental Upfront Cost}$$

Where *n* is the analysis period (the EUL), *t* is the number of years since installation, and *d* is the discount rate. Because calculating customer ROI depends on robust estimates of multiple project outcomes, we only estimated ROI for a subset of projects in Project Dataset. For example, not all projects were eligible for utility bill savings measurement.[2] After applying necessary filters, the number of projects to which we assigned an ROI estimate was 11,727.

The authors acknowledge an inherent inconsistency in the definition of "base case" across cost and savings inputs. The Base Case Costs Dataset assumes a new, like-for-like replacement, whereas the Metered Impacts Dataset assumes continued operation of preexisting equipment. While this discrepancy is a limitation of the analysis, no empirical data is available to characterize energy use of a new, like-for-like replacement. The authors mitigate this by assuming that all additional measures included in the heat pump installation, such as duct work and Manual-D/J calculations, are solely part of the measure case.

[2] To measure utility bill savings, a project needed sufficient meter and utility rate data for both the baseline period and reporting period, per the OpenDSM methods. See https://docs.caltrack.org/en/latest/methods.html#section-2-data-management. In addition, homes with multiple known interventions in the measurement period or multiple electric and gas meters associated with a single project were also omitted from ROI analysis.

Machine Learning Analysis

To identify the top drivers of customer ROI, the authors employed machine learning. The research questions emphasize inference more than prediction accuracy, therefore supervised machine learning models with interpretable results were chosen. These models are trained to predict a dependent variable, or "outcome", based on independent variables, or "covariates".

The goals of this study demanded that the analysis focus on covariates that are actionable for programs and policymakers. To that end, the authors began the modeling process with a list of covariates that could be measured and controlled by programs and policymakers, such as baseline home energy consumption, equipment specifications, utility rate codes, location features, and quality installation measures. Covariates were excluded that were missing data for more than 5% of projects, had high imbalance, or had low variance. Additionally, we excluded homes with on-site solar photovoltaic systems because baseline energy consumption in these homes is materially distinct from homes without on-site solar.

After initial covariate selection, we split the data used to train the models into two datasets: HPWHs and ASHPs. We developed an initial covariate importance ranking using a random forest regression (RFR), selected for its robustness to multicollinearity and nonlinearity. We tuned RFR hyperparameters (e.g., number of trees, maximum depth) first using a randomized search over 33 hyperparameter combinations, then a grid search around the optimal hyperparameter space. This optimized RFR was used to generate a variable importance ranking. Next, we used elastic net regression (ENR) to isolate a list of minimally correlated covariates with maximal explanatory power. We selected final covariates based on the RFR importance ranking, ENR coefficients, and the authors' judgment in order to maximize interpretability.

Finally, we fit a hierarchical linear model (HLM) using the final covariate list. HLMs account for inherent clustering among groups while still providing interpretable relationships between each covariate and the outcome (Gelman & Hill, 2007). The authors modeled crossed random (clustering) effects for two variables: (1) contractor business name and (2) the combination of electric utility and California climate zone. These were chosen because of observed clustering of ROI by climate and electric utility, discussed in Results, and by contractor, omitted herein due to the large number of contractors. We modeled fixed effects for the remaining covariates available in the final covariate list. This approach allowed the HLM to estimate more precise relationships between each covariate and customer ROI after accounting for inherent variance in ROI across contractor, utility, and climate contexts.

Results

Customer ROI is reported in May 2026 dollars. Unless stated otherwise, ROI does not deduct incentives received by the contractor from incremental upfront cost and is calculated using a 7% discount rate. Bill savings were largely measured using 2022–2024 rates, so they do not include the Base Service Charge. Over 99% of homes studied are single-family homes, 31% of which have on-site solar and use net energy metering (30% ASHP, 34% HPWH).

Medians and interquartile ranges (IQRs) are used to compare results. This is because, for individual projects, both upfront cost and utility bill savings are often affected by exogenous factors unrelated to the heat pump installation.[3] Comparing IQRs for groups of projects mitigates the effects of exogenous factors and outliers, while still illustrating in-sample variance.

Table 2 describes the key components of ROI for the full dataset (n = 11,727), grouped into portfolios based on the replaced and installed equipment: *Space Heater Electrification, AC Detected*; *Space Heater Electrification*, *No AC Detected*; and *Water Heater Electrification*.[4] Among replaced ACs, over 99% were centrally ducted, and the rest were portable/room units. Among replaced gas water heaters, over 97% were storage type and the rest were tankless.

Table 2 shows that *Space Heater Electrification, AC Detected* had the most positive ROI, indicating that the presence of AC in the home is an important predictor of ASHP ROI. While incentives improve ROI across the board, they only bring ROI from negative to positive for *Water Heater Electrification* due to the relatively low incremental cost of HPWHs.

Table 2. Project counts and median ROI component results (2026 PV $) by portfolio

Portfolio	Project count	Incremental upfront cost	First-year electric bill savings	First-year gas bill savings	Lifecycle operating cost savings [1]	Customer ROI [2], *without* incentive(s)	Customer ROI, *with* incentive(s)
Space heater electrification, AC detected	6,425	5,978	-161	383	6,526	658	2,535
Space heater electrification, no AC detected	2,761	9,124	-464	338	750	-8,440	-6,517
Water heater electrification	2,541	2,604	-244	287	1,554	-898	3,537

[1] Lifecycle operating cost savings include estimated utility bill savings and maintenance cost savings. Lifecycle operating cost savings and ROI are calculated using a 7% real discount rate.

[2] Customer ROI is the difference between Lifecycle Operating Cost Savings and Incremental Upfront Cost.

For both HPWHs and ASHPs, the authors found that no statistically significant linear relationship exists between total project cost and utility bill savings. In other words, paying more for a heat pump retrofit *in total* is not associated with achieving greater utility bill savings. However, clear trends exist between income level, climate, utility territory, and ROI.

Figure 1 shows IQRs of customer ROI for each portfolio, further subdivided into market-rate versus income-qualified utility rate program participants. Most income-qualified rate participants in the Project Dataset participated in California Alternate Rates for Energy (CARE), which discounts electricity by 30–35% and natural gas by 20%.

The Total columns in Figure 1 show that the three portfolios differ in both median and variance of customer ROI. The *Space Heater Electrification* portfolios have similar variance,

[3] For example, a change in occupancy could affect energy consumption in the home. This should not be attributed to the heat pump retrofit, but its effect cannot be isolated from heat-pump-driven energy impacts at the meter level.
[4] The *Space Heater Electrification* portfolios are delineated using Recurve's AC detection algorithm, which determines that the home not only possesses AC equipment but uses it consistently.

both having an IQR of about $20k, but the median ROI of the *AC Detected* portfolio is $9k greater than that of *No AC Detected*. Meanwhile, *Water Heater Electrification* has an IQR under $10k, less than half that of the *Space Heater* portfolios, and a median of -$0.9k.

For all three portfolios, both the median and the IQR of customer ROI is more positive for customers using income-qualified rates. The apparent benefit is greatest for *Space Heater Electrification, No AC Detected*, where the median customer ROI is over $2k greater for income-qualified rate users. Customers using income-qualified rates see a more positive ROI, on the median, largely because of the greater electricity discount relative to gas that CARE offers, but also partially because these customers typically installed less expensive heat pump equipment.

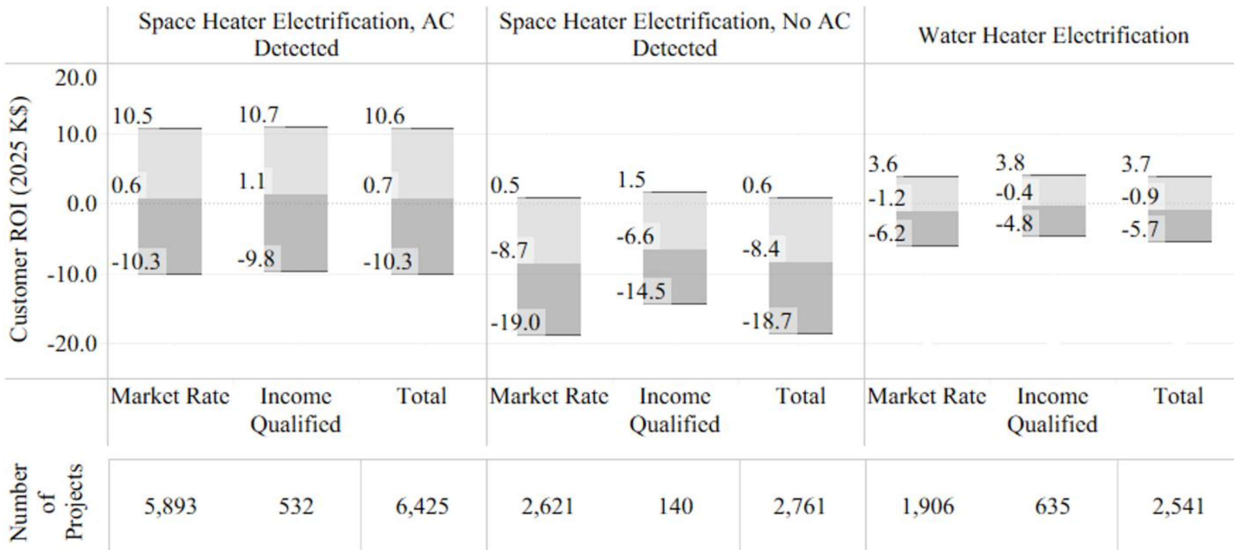

Figure 1: Quartiles of customer ROI, grouped by portfolio (top) and utility rate income qualification (bottom). ROI does not include any project cost reduction resulting from the contractor receiving incentives.

Customer ROI also varies significantly by climate region and electric utility. Figure 2 illustrates that ASHP retrofit customer ROI is highly sensitive to both the cost of electricity and the climate. HPWH retrofits are less sensitive but follow a similar directional trend. The Inland/Desert region[5] comprises the majority of projects, and most of these are in the *Space Heater Electrification, AC Detected* portfolio. Across portfolios, Coastal/Northern projects in IOU electric service territories have the most negative median ROI, followed by Inland/Desert IOU customers, and Inland/Desert POU customers have the greatest ROI. Results were omitted for Coastal/Northern POU customers due to insufficient sample size.

For reference, the average annual levelized cost paid by customers in the measure case, in 2026 $ per kWh, was 0.18 for SMUD, 0.27 for LADWP, 0.38 for SCE, 0.40 for PG&E, and 0.47 for SDG&E. ROI is not shown disaggregated by gas utility because the levelized cost of gas did not vary as greatly among customers studied. The average annual levelized cost paid in the measure case, in 2026 $ per Therm, was 2.4 for SCG, 2.7 for SDG&E, and 2.8 for PG&E.

[5] Climate regions are assigned by mapping the home zip code to one of CEC's 16 California building climate zones, then grouping the climate zones as follows: 1–8 are Coastal/Northern, and 9–16 are Inland/Desert.

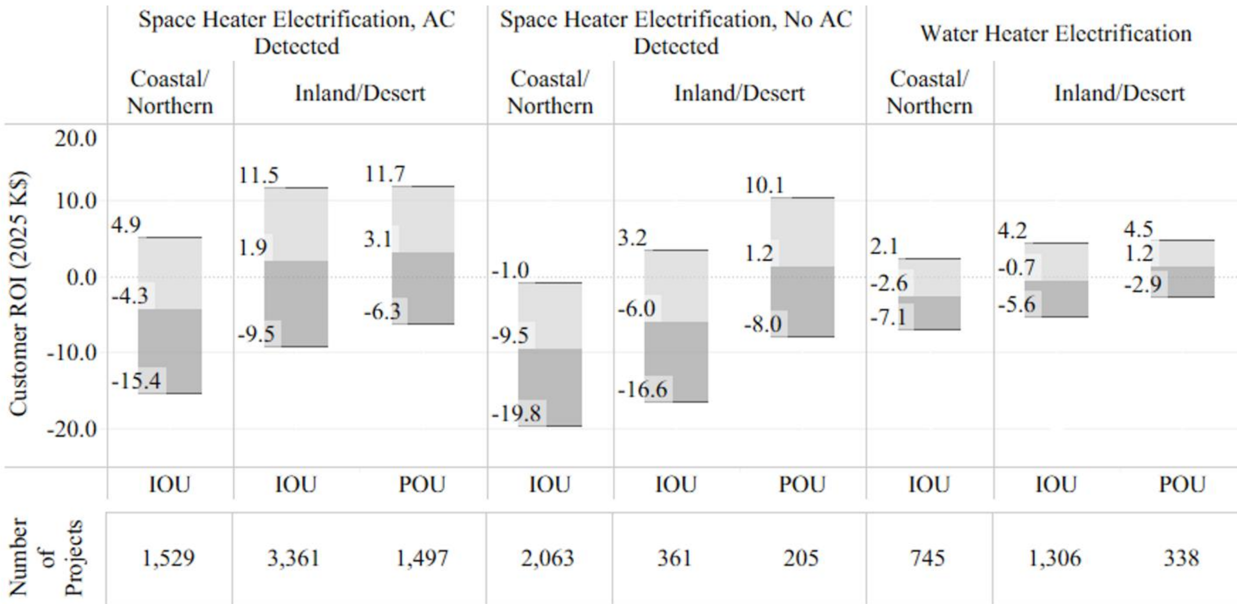

Figure 2: Quartiles of customer ROI, grouped by portfolio and climate region (top) and electric utility (bottom). ROI does not include any project cost reduction resulting from the contractor receiving incentives. Groups comprising less than 100 homes were omitted due to low sample size.

While Figures 1 and 2 illustrate that equipment type, utility territory, climate region, and utility rates affect ROI, they only indicate correlation, not causation. To identify top predictors and infer their relationships with ROI, the authors employed machine learning analysis.

Machine Learning Analysis

Results of final HLM fits for HPWHs and ASHPs are provided in Table 3 and Table 4, respectively. As explained in Methods, the authors excluded projects in homes with on-site solar photovoltaic systems from the machine learning analysis. The separate model fits for HPWH (n = 1,509) and ASHP (n = 5,585) explain 27% and 31% of the total variation in customer ROI, respectively. This suggests that substantial variation in customer ROI remains unexplained, which likely reflects the influence of exogenous factors on both total project cost and utility bill savings that are not fully captured in the training data. However, the models nonetheless identified several covariates robustly associated with customer ROI ("ROI drivers").

Table 3 shows that, after accounting for contractor-, climate-, and utility variation, six drivers significantly affect HPWH retrofit ROI. ROI increases as the home's pre-retrofit (baseline) annual electricity use and summer gas use increases. In other words, homes that consume more total electricity and more gas in the summer tend to have greater ROI, all else held equal. The fact that ROI increases with baseline summer gas use is intuitive, as summer gas use is primarily driven by water heating demand, and is therefore an indicator of gas savings potential from water heating electrification. However, the positive relationship between baseline electricity use and HPWH ROI is less intuitive. The authors expect that baseline electricity use does not directly affect HPWH ROI but rather indirectly, by encapsulating other ROI drivers like the home's energy use intensity and rate structure. This is reinforced by the fact that ROI is also greater for customers enrolled in an electric home ("ELEC") rate plan, like PG&E E-ELEC, which includes a greater fixed charge in exchange for a lower volumetric price paid per kWh.

HPWH retrofits in disadvantaged communities (DACs)[6] have a greater ROI, all else held equal. Analysis of the HPWH dataset indicates that this is largely due to lower upfront costs in DACs and secondarily due to the greater rate of income-qualified utility rate enrollment in DACs. Conversely, ROI tends to decrease as the first hour rating of the installed HPWH increases, largely due to an increase in upfront cost without a commensurate increase in utility bill savings, all else held equal. Finally, projects installed by a contractor company with a C20 (HVAC) license have lower ROI, also driven by higher average upfront costs. For reference, contractors can have multiple licenses. 89% of HPWH projects involve a contractor with a C36 (plumbing) license, 9% a C46 (solar) license, 23% a B (general contractor) license, and 35% a C20 license. However, only the presence of a C20 license significantly affected HPWH ROI.

Table 3. Top drivers of HPWH electrification customer ROI, after accounting for baseline differences between contractors, climate, and utility contexts

Variable Name	Average value (units)	Average linear effect per unit ($)	Standard error ($)	P value	Primarily correlated with
Total annual electricity use in baseline period	7.25 (MWh)	264	74.3	< 0.001	Savings
Total summer gas use in baseline period	66.1 (therms)	28.9	6.26	< 0.001	Savings
Electric rate includes 'ELEC' (Electric home rate utility plan)	11% True	1,834	884	< 0.05	Savings
Disadvantaged community	22% True	1,826	783	< 0.01	Cost
First hour rating[1]	68.3 (GPH)	-96.9	43.8	< 0.05	Cost
Contractor license type: C20 (HVAC contractor)[2]	35% True	-2,083	809	< 0.05	Cost

The following fields were available but excluded due to lack of statistical significance:
[1] Rated Storage Volume was not retained due to high correlation with First Hour Rating
[2] Other contractor license types included C36 (plumber), C46 (solar) and B (general).

Table 4 shows that, after accounting for contractor-, climate-, and utility-level variation, ten drivers significantly affect ASHP retrofit ROI. ROI increases as the home's pre-retrofit cooling electricity use increases, indicating that ROI increases not just with the *presence* of AC in the home (per Table 2) but with the *extent* of AC use. Similarly, ROI increases as the home's pre-retrofit heating gas use increases. Both of these variables improve ROI because they increase utility bill savings, all else held equal. However, ROI has a negative relationship with heating capacity of the installed ASHP. Heating capacity is primarily correlated with total project cost.

ASHP retrofits involving packaged unitary equipment tended to have greater ROI, while multi-split equipment had the opposite effect. Among equipment in the Project Dataset, packaged unitary is one of the least expensive and multi-splits are the most expensive. Also,

[6] Each project location's DAC status was determined at the census tract level based on CalEnviroScreen 4.0.

projects involving duct replacements tended to have lower ROI. This suggests that the added cost of duct replacement is not typically offset by a resulting increase in utility bill savings.

ASHP retrofit ROI is generally more negative for customers using time of use (TOU) rates and those using electric vehicle (EV) rates. Both TOU and EV rates typically feature increased peak-period pricing, which is highly coincident with space cooling demand, and thus makes sense as a negative cost driver for ASHPs—especially those that added AC load instead of reducing it. While TOU rates are increasingly common, only 41% of homes studied used a TOU rate. The most common non-TOU rates in the dataset were SMUD 'RT02' (13%), SCE 'Domestic' (8%), PG&E 'HE1' (7%) and 'E1' (4%), and LADWP 'ER1A-STD' (4%).

Finally, two contractor-related drivers were identified. Customer ROI tended to increase if the installer was part of a company incorporated as a sole proprietorship, rather than a corporation or partnership. Meanwhile, ROI was substantially lower if the installer had a C36 (plumbing) license. These are covered further in the Discussion section.

Table 4. Top drivers of ASHP electrification customer ROI, after accounting for baseline differences among contractors, climate, and utility contexts

Variable Name	Average value (units)	Average linear effect per unit ($)	Standard error ($)	P value	Primarily correlated with
Annual electricity use for cooling in baseline period	1.54 (MWh)	1,614	131	< 0.001	Savings
Annual wintertime gas use for heating in baseline period	177 (therms)	16.7	1.37	< 0.001	Savings
Electric rate includes "TOU"	40% True	-1,064	417	< 0.05	Savings
Electric rate includes 'EV'	2.5% True	-2,427	1,130	< 0.05	Savings
Heating capacity of ASHP	3.30 (tons)	-2,590	214	< 0.001	Cost
ASHP type is Packaged Unitary[1]	12% True	3,372	612	< 0.001	Cost
ASHP type is Multis-split[1]	12% True	-2,963	585	< 0.001	Cost
Duct replacement performed[2]	14% True	-4,108	543	< 0.001	Cost
Contractor company type: Sole Proprietor[3]	2.9% True	3,884	1,428	< 0.01	Cost
Contractor license type: C36 (Plumbing contractor)[4]	50% True	-3,223	718	< 0.001	Cost

The following fields were available but excluded due to lack of statistical significance:
[1] Other options included split unitary and mini-split.
[2] Other quality installation measures included duct sealing, smart thermostat, and Manual-D/J calculations.
[3] Other contractor incorporation types included partnership and corporation.
[4] Other contractor license types included C20 (HVAC), C46 (solar), and B (general).

Sensitivity Analysis

In addition to the top drivers analysis, the authors conducted sensitivity analyses to measure the extent to which customer ROI responds to changes in modeling assumptions. One assumption, discount rate, gauges the value of future costs and savings relative to equivalent amounts today. Comparing discount rate scenarios is helpful to assess the value of an investment for customers with different risk tolerances. Figure 3 shows IQRs for customer ROI, grouped by portfolio and utility rate income qualification, measured at three discount rates: 5%, 7%, and 9%.

The discount rate at which the ROI of an investment becomes zero is the internal rate of return (IRR). The IRR is the interest rate at which a customer could beneficially finance a heat pump retrofit. For the median customer, *Space Heating Electrification, AC Detected* had an IRR over 9% for income-qualified rate program participants and over 7% for market rate. The other two portfolios do not have a meaningful median IRR because their median ROI is negative.

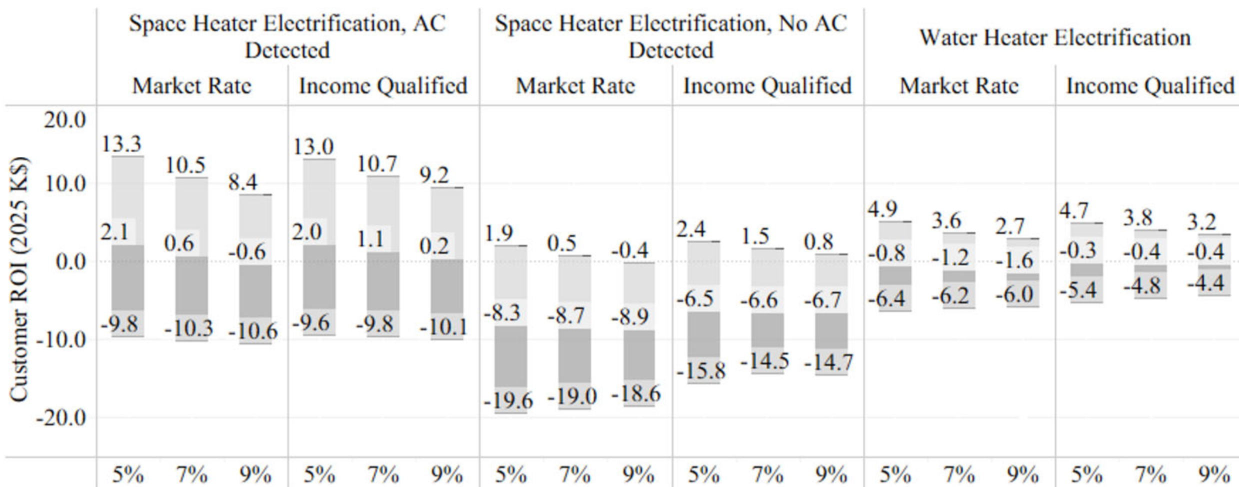

Figure 3: Quartiles of customer ROI, grouped by portfolio and utility rate income qualification (top) and discount rate (bottom). ROI does not include any project cost reduction resulting from the contractor receiving incentives.

Changing utility rate assumptions also significantly affects customer ROI. Recurve estimated utility bill savings in a scenario where all IOU customers used the Base Service Charge (BSC) required by Assembly Bill 205. For IOU customers, first-year median annual bill savings increased by $42 to $104, depending on the project portfolio. This boost to bill savings would increase ROI for the median IOU customer by $814 for *Water Heater Electrification* and by $2,218 for *Space Heater Electrification, No AC Detected*.

Recurve also modeled utility bill savings for PG&E HPWH customers using a hypothetical rate with a HPWH baseline allowance of 2.4 kWh/day in the summer and 4.0 kWh/day in the winter. Using this rate increased annual bill savings by $96 for the median PG&E HPWH customer and would thereby increase median ROI by $1,844.

Discussion

Is there correlation between upfront cost and utility bill savings, the core parts of ROI?

Multiple distinct perspectives suggest that there is no significant relationship between upfront cost and utility bill savings. First, the authors fit a linear regression of utility bill savings and total project cost, but this did not yield a significant regression coefficient. Because results were insignificant, they are not shown herein. Second, among the top drivers identified by the machine learning analysis, almost all were strongly correlated with either total project cost or utility bill savings, but not both.

It is important to recognize that there are multiple potential reasons why the machine learning models did not identify variables as top ROI drivers. It could be that the variable has no significant relationship with upfront cost or utility bill savings, or it could be that the variable has a significant relationship with *both* cost and savings but tends to increase both equally. However, the latter case seems to be uncommon among the variables studied, given the lack of a significant relationship between total project cost and utility bill savings.

How does customer ROI vary geographically across utility rate structures and climates?

Figures 1 and 2 show that the distinct combination of installed and replaced equipment has such a strong influence on customer ROI that one can only meaningfully compare ROI across geographies and climates after dividing the project sample into portfolios.

Space Heating Electrification, AC Detected is the best portfolio from the ROI perspective. This portfolio has an advantage in terms of incremental cost because the ASHP replaces both a furnace and an AC, though this is slightly exaggerated by the way base case scenarios are defined. But this portfolio also has an advantage in terms of operating cost savings. Together, Table 2 and Figure 3 indicate that this portfolio's ROI is the greatest by far, with the median customer having an IRR near 8%. Additionally, this portfolio is robust to changes in spark ratio[7] across utility territories and over time: if electricity prices increase relative to gas, summer electricity bill savings increase; otherwise, winter gas bill savings increase. However, one customer group has a negative median ROI: IOU electric customers in Coastal/Northern climates. These customers' relatively low AC use results in their utility bill savings not typically outweighing the incremental cost of the ASHP.

Conversely, projects in the *Space Heating Electrification, No AC Detected* portfolio do not offer a positive ROI for most customers, and ROI depends much more on spark ratio. Figure 2 shows that it *is* possible for projects in this portfolio to achieve a positive ROI, but only in areas where the spark ratio is best, like POU electric territories. Thus, for IOU customers not previously using AC, the value proposition of an ASHP depends mainly on the value of the newly added AC capacity, which must be worth several thousand dollars to the customer in order to outweigh the incremental upfront cost and the potential utility bill increase.

Water Heating Electrification customer ROI shows less total sensitivity to both spark ratio and climate. For most subgroups studied in Figures 1 and 2, ROI is consistently negative. However, ROI is much less negative than it is for *Space Heating Electrification, No AC Detected* and exhibits far less variability across customers. The *Water Heating Electrification* portfolio's relatively small ROI variance makes it possible for most projects to achieve a positive ROI via multiple interventions: a $1-2k cash incentive, adopting a rate that reduces the volumetric cost of electricity (like the BSC and E-ELEC), or adopting a rate with a HPWH baseline allowance. Combining these measures would increase ROI to the point that most projects studied would achieve positive ROI, both in and outside IOU territories. This is especially true for customers using income-qualified utility rates.

[7] Spark ratio is the ratio in the cost electricity to that of fossil fuels for an equivalent unit of energy. The higher the spark ratio, the more expensive electricity is relative to fossil fuels.

Which project, home, contractor, and customer characteristics are top drivers of ROI?

Together, Tables 3 and 4 show that top ROI drivers for both ASHPs and HPWHs generally fall into a few categories: pre-retrofit energy use, electricity rates, installed heat pump type and size, and contractor company type and license.

For both ASHPs and HPWHs, optimizing ROI requires striking a balance: homes with higher pre-retrofit energy usage tend to have greater ROI, but higher-capacity equipment tends to have lower ROI, all else held equal. This reveals an opportunity for programs to maximize savings by targeting high-consumption consumers, but it also underlines the importance of rightsizing equipment. Simply finding large homes and installing massive heat pumps will not automatically save customers money. Rather, targeting homes with high energy use intensity and installing optimally sized equipment will lead to greater customer ROI.

Contractor-related drivers reveal that ROI decreases when the contractor performing the retrofit does not specialize in the technology being installed. For example: HPWHs installed by C20 (HVAC) contractors tend to have lower ROI because upfront cost for these projects tends to be substantially higher. Contractors with C20 licenses that install HPWHs are implicitly not water heating specialists. Furthermore, these companies tend to be larger than average within the dataset, based on the number of counties served and employee count. Meanwhile, ASHP projects installed by C36 (plumbing) contractors have a lower ROI. Again, these are not implicitly HVAC specialists and have larger service territories and employee counts. Furthermore, these companies disproportionately participated in TECH Clean California. Of the 969 ASHP installers in the Project Dataset, 19% had a C36 license, but they received 45% of incentives. This explanation is supported by the fact that sole proprietorships had a greater ASHP ROI. Sole proprietorships had the lowest employee count, service territory size, and extent of participation.

Drivers related to utility rates show that a variety of electricity rate designs can meaningfully improve customer ROI. For HPWHs, the electric home rate plans like PG&E E-ELEC had the most significant positive effect on actual customer ROI, among the rate types studied in the machine learning analysis. Scenario analyses found that the BSC and a HPWH-specific baseline allowance would improve HPWH ROI for IOU customers to a similar extent. Meanwhile, for ASHPs, rates with increased peak-period pricing like TOU and EV rates had the most significant effect on ROI—both tended to reduce it. This negative effect is likely most pronounced for the *Space Heating Electrification, No AC Detected* portfolio, where customers add AC use in the summer peak period. However, scenario analysis showed that the BSC would improve ROI enough to offset the ROI reduction resulting from using a TOU rate.

Finally, for ASHPs only, a few distinct drivers emerged. Packaged unitary equipment had the greatest ROI, and multi-split equipment had the lowest. Each has a use case and value proposition not limited to utility bill savings, but this suggests that being more affordable does not undercut savings for packaged unitary equipment, and being higher cost does not guarantee greater savings for multi-splits. Similarly, projects involving duct replacements tended to have lower ROI. Again, duct replacements have several value propositions. Programs should anticipate that some homes will require duct replacements, and few will realize bill savings commensurate with the added upfront cost. However, other quality installation measures (duct sealing, smart thermostats, and Manual-D/J calculations) were found to have a slight positive effect on ROI, though it was omitted from Table 4 due to lack of statistical significance.

The authors recommend that future studies explore more potential ROI drivers not captured herein, such as more nuanced contractor variables, new rate designs, and EUL assumptions. We also recommend modeling drivers specific to each portfolio, rather than combining all ASHP projects together, and creating new models for homes with on-site solar.

Conclusions

Based on the analysis results and discussion, the authors draw the following conclusions:

1. ASHP retrofits in homes with substantial pre-retrofit AC use have high ROI for customers of all utilities and income levels. However, most IOU customers in Coastal/Northern climates did not use enough AC to achieve a positive ROI.
2. For both ASHPs and HPWHs, homes with greater pre-retrofit electricity and gas use have greater ROI, but oversizing equipment reduces ROI. Targeting homes with high energy use intensity and rightsizing equipment is therefore a way to optimize ROI.
3. ASHP retrofits in homes without preexisting ACs do not offer a positive ROI for most customers. Rate changes like the BSC can make the median customer's ROI less negative, but only POUs have a good enough spark ratio to make median ROI positive.
4. HPWH ROI is less predictable than ASHP ROI, but also less variable. While median HPWH ROI is negative, rate changes that lower volumetric prices like the BSC or HPWH baseline allowances would make ROI positive for most customers.
5. ROI is generally greater for low-to-moderate income customers, especially those who have enrolled in income-qualified utility rates through programs like CARE or FERA. However, the upfront cost barrier remains a critical hurdle for these customers.
6. ROI tends to be lower when the installing contractor does not specialize in the technology. Unspecialized contractors (e.g., a contractor with a C36 plumbing license installing an ASHP) tend to be larger and to consume incentives disproportionately.

Recommendations for Heat Pump Programs

For programs looking to maximize customer ROI, prioritize ASHP installations in homes with preexisting AC, particularly in Inland/Desert climates. Ideally, use utility meter data to target homes with the greatest energy use intensity. Use a small incentive to encourage sales, but the incentive need not equal the incremental cost. Avoid sizing the incentive based on equipment cooling/heating capacity, as this could encourage oversizing. In contractor training, emphasize rightsizing equipment and choosing affordable equipment like packaged unitary systems when possible. Encourage broad contractor participation to reduce incentive monopolization by large, unspecialized companies and assist more small and specialized firms to participate.

To deploy HPWHs and ASHPs in homes without preexisting AC, target regions with a favorable spark ratio and customers eligible for rates that improve the spark ratio, like CARE. Among these targeted customers and regions, allocate most incentive dollars to low- to moderate-income customers for whom the upfront cost barrier is most prohibitive, even if their ROI is expected to be positive. And again: emphasize rightsizing equipment, selecting affordable equipment types, and encouraging broad contractor participation. For ASHP retrofits in homes without preexisting AC, try to enroll customers in a non-TOU rate if one is available.

Recommendations for Heat-Pump-Friendly Policies

Because the ROI metric analyzed herein is similar to regulatory cost-benefit analysis, it is likely that a building code or appliance standard requiring ASHP installations in homes with prior AC could be shown to be cost-effective in Inland/Desert climates. Adopting this standard would spur the heat pump market and enable programs to focus incentive dollars on HPWH retrofits and ASHP retrofits in homes without AC.

For direct install programs serving income-qualified customers, encourage electrification in the form of an ASHP to reduce customer energy burden and/or increase resilience to extreme heat by adding AC capacity to homes lacking it. Ensure that participants are enrolled in CARE rates, if available, and otherwise any available rate that reduces volumetric electricity prices.

Implement rate reforms to improve economics for electrification in IOU territories by reducing the volumetric cost of electricity, especially in the winter. The BSC will improve ROI across the board, but not enough to make median customer ROI positive for HPWH retrofits and ASHP retrofits in homes without AC. The HPWH baseline allowance of 2.4 kWh/day in the summer and 4.0 kWh/day in the winter is an example of a rate change that is expected to improve median customer ROI by over $1,800, helping most customers achieve a positive ROI.

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