Meter-Based Targeting for Beneficial Electrification at Scale

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ABSTRACT

California aims to create a carbon neutral economy by 2045. Doing so requires electrifying most of the State's building stock. To spur market development for electrification, the Technology and Equipment for Clean Heating (TECH Clean CA) initiative aims to enable distributors and contractors to stock, sell, and install low-emissions heat pumps (HP) for residential retrofit projects. This initiative supports and extends heat pump space and water heating incentive programs statewide, with an emphasis on increasing access and affordability for low-income households. While these goals are laudable, the high cost of electricity compared to natural gas may have equity and bill impacts that need to be understood and mitigated. To ensure favorable electrification outcomes for customers and the grid, it is necessary to identify and recruit those customers best suited for heat pump retrofits. Analyzing meter-level consumption data enables targeting of specific usage characteristics, such as high cooling or heating loads. By maximizing customer benefits, this approach increases the chances for successful market transformation (Mukherjee 2020).

This paper examines results from analyzing over 350,000 northern California residential meters. Disaggregation of temperature-dependent loads with electrification impact projections enables insights into the range of expected bill impacts. Under typical current rate structures, the 24% of optimally targeted customers could save over $200 per year. However, 30% of customers were projected to see bill increases, while another 46% would see marginal savings. Results indicate the need for programs to consider individual meter data to find the customers ideally suited to electrification.

Introduction

California has adopted a series of legislation geared toward accelerating the decarbonization of buildings, transportation, and the electricity grid. With Senate Bill (SB) 100 the State makes 2045 the target year for a fully decarbonized electricity grid.[1] This follows SB 350, which doubles targets for energy efficiency savings in existing buildings by 2030 and AB 802, which motivates[2] accelerated replacement of old equipment or "stranded potential" and prioritizes meter-based measurement of grid impacts. In addition, California is prioritizing building electrification as a key decarbonization strategy. SB 1477 laid the groundwork for two major electrification initiatives. The Technology and Equipment for Clean Heating (TECH)[3]

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[1] SB 100, full bill text at https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201720180SB100

[2] SB 350, full bill text at https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160SB350

[3] SB 1477, full bill text at https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201720180SB1477

initiative intends to facilitate market development of “low-emission space and water heating equipment for new and existing residential buildings.” The Building Initiative for Low-Emissions Development (BUILD) program is more geared toward implementation, requiring “deployment of near-zero-emission building technologies to significantly reduce the emissions of greenhouse gasses from buildings.” Equity is a major consideration in both programs. For TECH, 40% of program incentives must go to low-income and disadvantaged communities.

A frequently-cited analysis conducted by E3 in 2019 estimates that the majority of California households would see net bill savings from whole-home electrification (E3 2019). As with other large-scale electrification research known to the authors to date, however, this analysis relies on simulated homes with “average” weather by climate zone. Weather-dependent (space heating and cooling) loads in actual homes can vary far from expected averages used in simulations. With the widespread availability of advanced metering infrastructure (AMI) data in California, combined with open-source methods for disaggregating heating and cooling loads (CalTRACK), program implementers can gain new insights into which households stand to benefit or suffer financially from electrification with current capital costs and rate structures.

Building electrification carries unique long-term and short-term equity implications. In the short term, the higher cost per unit of absolute energy of electricity versus natural gas could mean higher bills for many low-income customers, even taking the greater efficiency of heat pumps and other electrification technologies into consideration. For example, the current average cost of residential electricity in California is $0.22 per kWh, while the average delivered cost of natural gas is $1.40 per Therm (EIA 2020). In terms of absolute energy, 1 Therm is equivalent to approximately 29.3 kwh. Hence, 1 Therm of energy converted to electricity would cost $6.45. In other words, electricity costs over 4.6 times more than natural gas in terms of absolute cost of energy per unit. While heat pumps are a much more efficient space heating technology, it is unlikely that this efficiency will balance out the cost disparity between electricity and gas to produce savings under current rate structures, except in households with moderate space heating burdens combined with outsized space cooling burdens. These low-heating, high-cooling households may realize extra peak-period electricity savings from significantly more efficient cooling (e.g., replacing old, inefficient units) that offset a smaller increase in overall space heating costs due to fuel substitution.

With fuel substitution interventions, current disparities in the cost of electricity and natural gas (“gas”) per unit of energy mean that there are utility customers who could switch from gas space heating to an electric heat pump system and, with zero behavior change, see significant increases in total net energy costs–despite using less total energy in absolute terms. Given that a third of low-income households in the state already experience energy insecurity (Evergreen Economics for CPUC, 2016), any increase in net energy costs risks negative impacts to liquidity and energy security in these households.

In addition to these immediate concerns, there are also long-term equity risks to consider. Regulators are concerned that low- to moderate-income households may be saddled with the cost of increasingly stranded gas infrastructure as higher-income households who can afford the high upfront costs to electrify abandon the gas system altogether (Davis & Hausman, 2022). While these long-term concerns are important, addressing short-term equity implications is more urgent, since multiple large-scale electrification programs are already underway in the state. The current California budget allocates a proposed $1 billion to electrification initiatives (State of California 2022). If these initiatives provided approximately $5,000 in incentives per household for space heating electrification, they would impact 200,000 households, or 1.5% of the state's population. This level of market penetration will not yet risk stranding major proportions of gas infrastructure. It could, however, cause increased energy bills for tens of thousands of low-income households if poorly suited customers are actively recruited to participate. For that reason, this paper will focus on a method to address short-term equity implications of actively recruiting customers into electrification programs who carry high short-term risks of paying higher overall net energy bills after participating.

Electrification of Residential Space Heating: Meter-Based Targeting

East Bay Community Energy (EBCE), a non-profit community choice aggregation (CCA) program in the San Francisco Bay Area, partnered with Recurve and Ardenna Energy to estimate potential bill impacts from heat pump HVAC conversions in single-family homes across its service territory. Recurve is a software company whose revenue-grade, open-source platform enables deployment of demand flexibility as a metered grid resource. Ardenna Energy is a clean energy consulting practice focused on bringing residential energy efficiency, electrification, and storage technologies to market.

EBCE serves 14 cities in Alameda County, California, plus the unincorporated communities in the county. The service territory extends from the mild bayside cities of Berkeley and Oakland (California Energy Commission climate zone 3) to the warmer inland communities of Livermore and Pleasanton (climate zone 12). Climate zone 3 is characterized by mild winters (~2900 HDD) and mild summers (~128 CDD) and less than half of the single family households have mechanical cooling. Climate zone 12 has even milder winters (~2600 HDD) but warmer summers (~1580 CDD) and about 84% of single family households have mechanical cooling.

EBCE approved the use of aggregated meter data to this research effort because it directly supports the nonprofit's purpose of providing clean power at competitive rates. With EBCE's goal of purchasing 100% clean power for all customers by 2030 (a full 15 years before the state's goal date) (EBCE 2022), electrification retrofits in the CCA's territory have the potential to deliver even greater overall carbon reduction benefits than elsewhere in the state. EBCE is also committed to equity, affordability and transparency. Understanding the range of real-world energy usage for space heating and cooling in their territory supported the CCA's goals of delivering climate benefits while also ensuring the best possible bill outcomes for their customer base in any future electrification programs.

Data and Methods

EBCE provided hourly interval electricity usage data and monthly gas usage data for 359,501 residential customers in 2019. After data eligibility criteria were applied, 297,148 customers remained in the sample.

Eligibility criteria applied included:

- Minimum data sufficiency of at least 328 days with meter readings for each fuel
- Outliers removed: top 2% of values excluded
- Reasonable model fit[4]: model fit error under 100%

[4] An average error threshold (Coefficient of Variation of Root Mean Squared Error) of the daily CalTRACK model of 100% was set.

- Solar: households flagged as having solar were excluded in order to most readily isolate weather-dependent usage patterns.

The data provided did not include a definitive way to exclude customers who may already have electric-only heating systems, so that was not factored into exclusion criteria. Energy usage on all meters was modeled via CalTRACK 2.0 daily and hourly methods[5] which are applied to AMI data using OpenEEmeter software[6] to disaggregate temperature dependent, baseload, and discretionary usage within each fuel. The CalTRACK daily model defines a building's energy consumption based on a linear relationship with outdoor weather conditions. The CalTRACK hourly model defines a building's energy use as the interaction between the building's temperature dependence, the occupancy status and the time of week. The CalTRACK methods are based on industry guidelines established by The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE 2017) and the Uniform Methods Project: Chapter 8 - Whole Building Methods (Li 2018) and meet all International Performance Measurement and Verification Protocol (IPMVP Option C) requirements (IPMVP 2001). CalTRACK also specifies rigorous steps for data cleaning and organization and weather station selection, among other technical factors (details are available at www.caltrack.org). Both the CalTRACK methods and Python implementation via the OpenEEmeter are open-source and publicly available through www.caltrack.org and references therein. A combination of daily and hourly models were used to disaggregate metered usage for customers in the EBCE sample.

Disaggregated usage categories are defined as follows:

- **Temperature-dependent usage** is energy consumption that increases or decreases with temperature, with warm-weather dependent usage defined as space cooling, and cool-weather-dependent usage defined as space heating.
- **Average baseload** (always on) consumption is computed by first finding days where the CalTRACK daily model does not detect temperature-dependent usage. For these days hours are rank-ordered from lowest to highest according to kWh usage. The average usage of hours ranked 2 - 4 are then averaged across the year and extrapolated to 8,760 hours. This would capture always-on end uses such as refrigeration and "vampire" loads from electronic devices in standby mode.
- **Discretionary usage** is an estimate of a customer's non-baseload usage that is also independent of temperature. For example, cooking on an electric stove or using an electric clothes or hair dryer would be examples of discretionary usage.

Heating and Cooling Load Disaggregation

The integral of temperature-dependent natural gas usage below the heating balance point is considered "heating load." Similarly, temperature-dependent electricity consumption above the cooling balance point is summed as "cooling load." These were analyzed in a matrix of combined heating plus cooling loads. Customers were categorized into five 20-percentile bins by ranked gas heating load, then ranked electric cooling load. These temperature-dependent load

[5] See the CalTRACK methods documentation and technical appendix at www.caltrack.org
[6] See OpenEEmeter documentation at https://github.com/openeemeter/eemeter/

bins were then cross-referenced into a combined heating vs. cooling load bin matrix seen in Figure 1.

Temperature-dependent loads were analyzed together because of the unique nature of fuel substitution interventions. In non-fuel-switching HVAC interventions, such as insulation, savings for one temperature-dependent load is not expected to increase the costs of the other, and therefore either one may be helpful as a targeting parameter. With HVAC fuel substitution, natural gas heating is replaced by an electric heat pump, and, ideally, inefficient electric cooling (AC) is also replaced by the more efficient equipment. Some proportion of natural gas bill savings will transfer to increases in electricity costs. Even though heat pumps can use 3-4 times less total energy to provide space heating in absolute terms, the shift from one fuel to the other carries the risk of higher total net energy bills. Targeting for HVAC heat pumps using combinations of natural gas heating loads and electricity cooling loads can help find customers who are more likely to see bill savings. A previous evaluation of metered heat pump impacts found a 48% reduction in cooling load for customers who replaced pre-existing air conditioning units when installing a heat pump (Scheer 2020). Meter-based targeting can identify customers who carry outsized electric cooling burdens along with more moderate gas heating burdens where the cooling savings are likely to offset increased electric heating costs. Additionally, this approach helps maximize potential grid and GHG benefits since AC usage tends to drive summer peaks when the grid is most stressed.

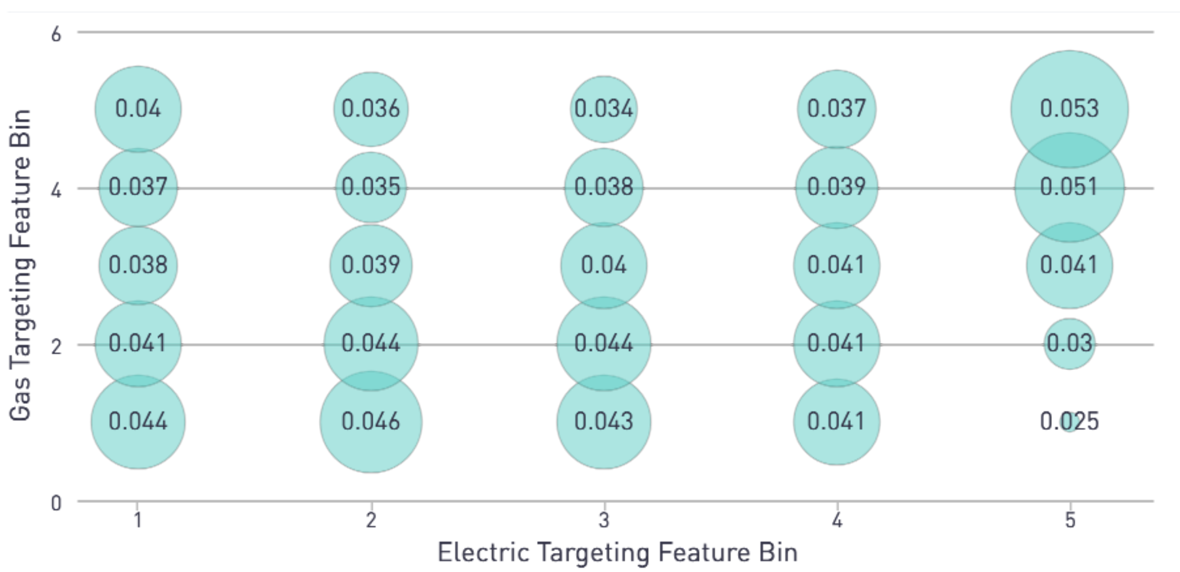

Figure 1. Proportions of customers by combined heating + cooling load “bin” in EBCE territory in 2019. The Y-axis represents the 20-percentile ranking “bin” for each customer’s annual natural gas heating usage. The X-axis represents the 20-percentile ranking “bin” for each customer’s annual electricity cooling usage.

As shown in Figure 1, customer’s combinations of heating + cooling loads vary widely. We witness customers in each cooling bin also exhibiting usage from a full range of heating bins, indicating that usage of one fuel is not a reliable predictor of the other. Median (and maximum) usage in the lowest 20-percentile bin for electric cooling usage is 0 kWh per year, indicating that at least 20% of customers either don’t have AC systems, or don’t use them in any detectable weather-dependent pattern. These 0-cooling customers exhibit gas heating usage from a median value of about 16 Therms per year for gas bin 1 (0-20th percentile), up to 636 Therms per year for gas bin 5 (81st - 100th percentile). With current utility rates, virtually all customers with zero cooling would expect negative bill outcomes with electrification, but customers with the lowest electric cooling usage and highest gas heating usage would see the most severe negative impacts.

At the other extreme, we expect customers in cooling bin 5 (81st - 100th percentile), to have the highest electric savings potential due to heat pump air conditioners potentially providing more efficient cooling than an existing AC unit. However, these savings could vary appreciably by how much electric load is added due to converting heating usage to electricity. Customers in electric cooling bin 5 exhibit gas heating usage ranging from a negligible 6 Therms per year to over 500 Therms per year. High-cooling, low-heating customers would be much better potential electrification candidates in terms of bill outcomes than the low-cooling, high heating cohort.

Figure 2 illustrates the same heating vs cooling load spread for the more than 65,000 low-income[7] customers in EBCE territory. While there is a slightly smaller proportion of low-income customers in the highest bins for each fuel, the overall range is not significantly smaller than for the full population. More importantly, there is still a large range of high-low combinations across fuels in the low-income group. This indicates that suitability for fuel substitution as a bill savings measure may vary as much among low-income residential customers as it can for the population as a whole.

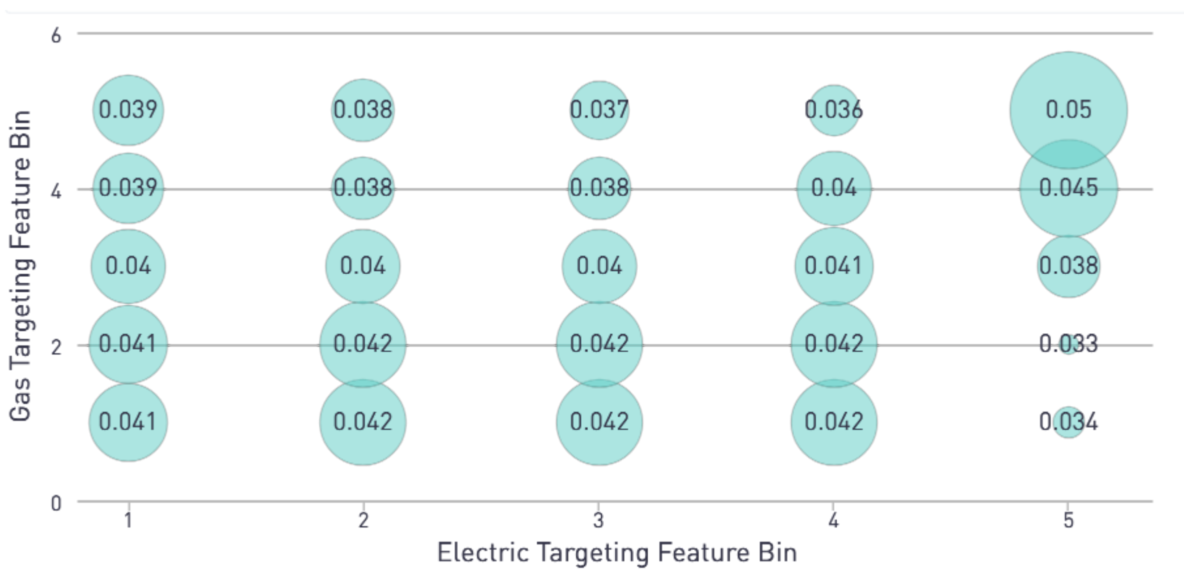

Figure 2. CARE (low income) households only: Proportions of customers by combined heating + cooling load "bin" in EBCE territory in 2019. The Y-axis represents the 20-percentile ranking "bin" for each customer's annual natural gas heating usage. The X-axis represents the 20-percentile ranking "bin" for each customer's annual electricity cooling usage.

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[7] "Low income" here defined as households on a California Alternate Rates for Energy (CARE) rate plan which provides income-qualified energy bill discounts https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/electric-costs/care-fera-program#:~:text=California%20Alternate%20Rates%20for%20Energy,on%20their%20natural%20gas%20bill.

Results: Bill Impact Estimates

Ardenna Energy conducted a bill impact analysis using the high-level load disaggregation calculated by Recurve to analyze one possible HVAC electrification scenario for EBCE customers. For this analysis, Ardenna was provided a 10x10 version of the space heating and cooling matrix illustrated in Figure 1; that is, the customer gas heating and electric cooling usage was binned into ten percentile ranges and then cross-tabulated, for up to 100 unique combinations.

The analysis assumed that

- All homes started out with standard efficiency furnaces and air conditioners (i.e, 0.78 AFUE and 10 SEER, respectively)
- HVAC systems were upgraded to heat pumps with 10 HSPF heating efficiency and 18 SEER cooling efficiency
- No changes were made to the building envelope or ventilation system, such that whole house heating and cooling loads remained unchanged.

Applying these assumptions, along with prevailing retail gas and electricity prices, Ardenna calculated the electrification bill impact for each cell in the 10x10 matrix.

Total bill savings = (winter gas rate * baseline gas heating usage - winter electric rate * HP heating usage) + summer electric rate * (baseline cooling usage - HP cooling usage)

Where

- Baseline gas heating and cooling usage are direct outputs from Recurve's disaggregation
- HP heating usage (kWh) = baseline gas heating usage (Therms) * furnace efficiency (COP) * 29.31 kWh / Therm / HP heating efficiency (HSPF) * 0.29307 HSPF / COP
- HP cooling usage (kWh) = baseline cooling usage (kWh) * baseline AC efficiency (SEER) / HP cooling efficiency (SEER)

As a final step, Ardenna aggregated the resulting bill savings into bins with $80 increments. The results are shown in Figure 4.

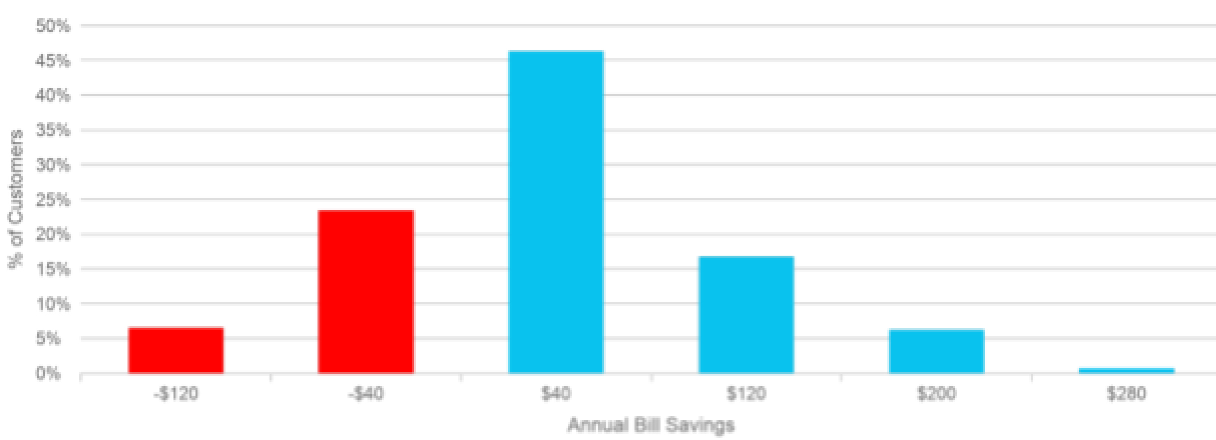

Figure 4. Histogram of estimated annual bill savings in EBCE reference case with HP HVAC + HPWH.

As shown in Figure 4, the analysis projects that 30% of EBCE customers would see net bill increases with these two measures applied under current rates. The single largest group saves an average of $40 per year (46% of all customers), a narrow enough margin so as not to be worth the risk of the significant upfront investment required for electrification retrofits. That leaves about 36% of the population who are prime candidates for electrification as a bill savings measure based on their pre-electrification metered usage in this high-level estimate. Put another way, program implementers would have a high chance of picking mediocre to poor participants through non-targeted outreach. This underscores the critical need for fuel substitution interventions to target customer recruitment and outreach based on metered usage characteristics to mitigate the risk of financial harm. It also underscores the need for electrification programs to consider additional measures to complement electrification interventions that result in significant savings.

Conclusion and Next Steps

One of the most important takeaways is that this demonstrated potential variation within one residential population in a single geographic area. The exact savings estimates are less important in this analysis than the understanding that electrification bill outcomes can be expected to vary widely in a relatively small, homogeneous population–even assuming that equipment performs to specifications and no occupant behavior change is observed. Real-world electrification outcomes will be significantly more varied, which underscores the need for targeting that takes into account disaggregated heating and cooling usage in combination for each potential participant.

Residential building electrification programs can significantly reduce carbon emissions and will play a key role in getting power systems to net-zero emissions. While electrification can save money for some residential customers, it is not a guarantee. Therefore it is important to identify customers who would be a good fit for heat pumps. Otherwise there are significant ethical risks due to the potential for the unintended consequence of increasing overall energy burdens, especially for low-income customers. Traditional indicators of inefficient usage in one fuel or the other cannot be relied upon to accurately target outreach for electrification programs because of current tradeoffs in fuel costs. Temperature-dependent loads must be considered independently for each household to evaluate their vulnerability to increased energy cost burdens with fuel substitution.

Meter data and open-source methods are available to plan ethical outreach strategies that optimize grid impacts. These methods are being integrated into California's electrification efforts at scale. As part of the TECH Clean California initiative, Recurve will be the first to analyze and evaluate a representative sample (approximately 90%) of all California customer energy meters using CalTRACK methods. Published outputs will include metered heating and cooling distributions, which will be invaluable to future program and rate designers. Recurve will also measure the metered impacts of electrification for all participants in TECH Clean California, generating real-world electrification results at a scale previously unavailable in the industry. Results will contribute insights about which characteristics in pre-retrofit usage drove the highest bill savings and ideal grid impact outcomes. As a combined body of work, these results will enable electrification decision makers to maximize the individual, grid, and societal benefits of program funding while mitigating harm to vulnerable populations. By maximizing customer benefits, a meter-based targeting approach can also increase the chances for successful market transformation through delivering more positive outcomes for early-stage participants.

References

ASHRAE. 2017. ASHRAE Guideline 14-2014 www.ashrae.org/technical-resources/standards-and-guidelines/titles-purposes-and-scopes

E3. 2019. *Residential Building Electrification in California*. San Francisco: E3 www.ethree.com/wp-content/uploads/2019/04/E3_Residential_Building_Electrification_in_California_April_2019.pdf

EBCE. (2022). About EBCE. Ebce.Org. Retrieved June 15, 2022, from ebce.org/about/

EIA (Energy information Administration). 2020. *California Natural Gas Prices: Residential Price (annual)*. EIA: Washington, DC. www.eia.gov/dnav/ng/NG_PRI_SUM_DCU_SCA_A.htm
& State Electricity Profiles: California (annual) www.eia.gov/electricity/state/

Davis, L. and Hausman, C. 2022. “Who Will Pay for Legacy Utility Costs?” Energy Institute Working Paper 317. Revised version forthcoming in the Journal Association of Environmental and Resource Economists https://doi.org/10.1086/719793 haas.berkeley.edu/wp-content/uploads/WP317.pdf

IPMVP. 2001. *International Performance Measurement & Verification Protocol. Energy Project Financing: Resources and Strategies for Success.* Springfield, VA: US Department of Energy www.nrel.gov/docs/fy02osti/31505.pdf

Li, M., Haeri, H., and Reynolds, A. 2018. *The Uniform Methods Project: Methods for Determining Energy Efficiency Savings for Specific Measures January 2012 — September 2016.* Golden, CO: National Renewable Energy Laboratory (NREL)

Mukherjee, S. et al., .2020, September. “Attitudes to Renewable Energy Technologies: Driving Change in Early Adopter Markets.” UCD Centre for Economic Research Working Paper Series 2020. WP20/26. Researchrepository.Ucd.Ie/Bitstream/10197/11646/1/WP20_26.Pdf. Retrieved June 14, 2022, from researchrepository.ucd.ie/bitstream/10197/11646/1/WP20_26.pdf

Scheer, A. 2020. "Electrification: Meter Data Analysis of Grid Impacts and the Opportunity for Efficiency" In *Proceedings of the 2020 ACEEE Summer Study on Energy Efficiency in Industry* 2:268–282. Washington, DC: ACEEE. www.aceee.org/files/proceedings/2020/event-data (note - direct paper urls are broken)

State of California. 2022. *Budget Summary: May Revision.* www.ebudget.ca.gov/FullBudgetSummary.pdf