Where are the Low Hanging Fruit? Data to Help Understand Geographic and Demographic Characteristics of Households with Inefficient Equipment

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ABSTRACT

California has set aggressive energy efficiency targets to support the Clean Energy and Pollution Reduction Act of 2015 (SB350): 50% of energy production from renewable energy sources and a doubling of efficiency by 2030. Meeting these goals requires, among other things, targeting appliance standard and building code updates. To effectively advocate for these updates, researchers contracted by PG&E collected primary on-site data consisting of appliance, electronics and building characteristics of residences in its service territory.

This paper briefly describes the study effort and focuses on one of many potential uses for these data: identifying where significant efficiency gains may be achieved through demographic analysis. The study provides PG&E's Codes and Standards Program with current equipment saturations, efficiency levels and building characteristics. Subsequent phases of this study will provide equipment load shapes and energy consumption estimates, and will also inform assessments of equipment purchases and occupant behaviors through web surveys. The first phase of the study involved conducting in-home surveys to collect detailed information on appliance and equipment holdings for a representative sample of 1,000 homes. These data provide the basis for the analysis and illustrative results presented in this paper. The second phase of the study will consist of a nested sample of 150 homes that will undergo full-scale metering to measure energy usage at the end use level. The third phase will engage these 150 homes and will include regular online web surveys among the full panel or among subsets that have certain characteristics of particular interest.

Introduction

Pacific Gas and Electric Company's (PG&E's) energy efficiency programs and Codes and Standards (C&S) Program are working to help California meet the aggressive yet necessary energy efficiency targets in support of the Clean Energy and Pollution Reduction Act of 2015 (SB350): 50% of energy production from renewable energy sources and a doubling of efficiency by 2030. While the efficiency programs focus on education and training, emerging technologies and market transformation incentive programs, the C&S Program aims to "lock in" savings by developing and increasing minimum efficiency standards for energy efficient technologies.

To accomplish this, the C&S Program initiates and supports Codes and Standards Enhancement (CASE) proposals, supports federal standards adoption, provides hundreds of classroom trainings regarding existing and new codes and standards, and supports local reach codes (among many other activities).

On its own, PG&E implements Code Readiness projects for the development of CASE proposals and sponsored the Home Energy Use Study (HEUS), which is the study described in this paper. The HEUS covers the residential sector and includes both an on-site saturation survey of 1,000 homes (conducted between October 2015 and April 2016) and a nested sample of equipment metering at 150 homes. The study will be a critical source of data for PG&E to provide more rigorous data to both the California Energy Commission (CEC) and the U.S. Department of Energy (DOE) to inform consideration of more stringent codes and standards.[1] Without such a current and robust data source, the program has had to rely on small datasets, old data and/or data from other regions to try to supports its claims. The HEUS involved recruiting a representative sample of homes and collecting detailed information on appliance and equipment holdings. At present, Evergreen Economics is beginning to collect energy usage data at the end use and whole house levels.

This paper briefly describes the study effort and illustrates two of many potential uses for these data: identifying where significant efficiency gains may be achieved through geographic analysis and demographic analysis.[2] The authors present illustrative findings from original analysis conducted by Evergreen Economics using data collected as part of the HEUS.

Home Energy Use Survey Description

Evergreen Economics and PG&E collaborated with the Northwest Energy Efficiency Alliance (NEEA) to model the HEUS after NEEA's Residential Building Stock Assessment (RBSA), with the dual intentions of reducing setup cost and providing a robust, compatible addition to NEEA's research. In combination, the datasets from the HEUS and the RBSA cover a significant portion of the United States.

Evergreen developed the on-site survey sample frame using PG&E's customer information system data,[3] with stratification based on home type, income and region (see Table 1). We oversampled customers living outside the more populous and dense Bay Area region, multifamily homes, and customers living in one of the DOE climate zones (U.S. Department of Energy 2015) not represented by NEEA's RBSA.[4]

Table 1. HEUS residential survey sample frame

Home Type	CARE* Status	Bay Area	Non-Bay Area	Total	
Single Family	CARE	40	104	144	615
	Non-CARE	233	238	471	
Multifamily	CARE	80	51	131	385
	Non-CARE	222	32	254	
Total		575	425	1,000	

* CARE is the California Alternate Rates for Energy program, which provides energy bill discounts to qualifying low-income households.

We developed the on-site survey instrument based on the content of NEEA's RBSA instrument. Field surveyors from kW Engineering and Michaels Energy used an electronic data collection tool to record information, adhering to protocols and quality control standards. The project team conducted a pre-test with live customers before finalizing the instrument and the data collection and customer recruitment procedures.

The team collected comprehensive data at each household, including a customer interview as well as a detailed inventory of building characteristics, appliances, electric cars, photovoltaic systems,

[1] As of the writing of this paper, it is unclear whether or to what extent the DOE will continue updating appliance standards. Regardless, the California investor-owned utilities (IOUs) and the State of California will continue to support local, statewide, and federal standards via research and advocacy.

[2] The authors conducted geographic analysis for lighting efficiency only.

[3] The sample frame is individually metered accounts with electric service, excluding the very remote portions of the territory (less than 2% of the electric service territory).

[4] The metering study sample is a nested sample of 150 homes from within the on-site survey sample.

electronics and lighting. For all equipment for which we could find the information, we collected product attribute data such as equipment subtypes (specifying the type of furnace, for example), manufacturer, model number, date of manufacture, and efficiency characteristics (e.g., Energy Factor, rated wattage).

For the metering study, Evergreen and kW Engineering have developed a custom suite of monitoring equipment and communication devices in order to monitor and transmit equipment usage and consumption for the majority of study homes' appliances and electronics. We plan to collect one-minute interval data for the whole house, all major end uses and a sample of plug loads and electronics, interior and exterior temperatures, and temperatures at gas appliance burners to estimate run time.

Analysis Methods – Locating Low Hanging Fruit

The first stage of this analysis was to identify and select a group of measures to explore. We settled on three measure categories that are common to most households and have varying degrees of efficiency. The measure categories we chose to explore are lighting, clothes washers and water heaters. Once we selected these measure categories, we developed a standard method to allocate specific measures or specific homes as efficient or inefficient. The criteria used for each measure include:

- **Lighting** – The HEUS data contain data on ten categories of lamps. The research team determined the efficiency of each lamp based on the lamp category. Compact fluorescent lamps and LED lamps are considered efficient, while all other types are categorized as inefficient. Once each lamp was categorized as efficient or inefficient, the percentage of the total number of lamps in each home was calculated by simply calculating the proportion of total lamps that were flagged as efficient. The end result was each home was assigned a value equal to the proportion of lamps that are efficient.
- **Clothes Washers** – Currently, based on the HEUS data, Evergreen has been able to determine the efficiency characteristics of 356 clothes washers in the sample (not every home has a clothes washer, and to date, we have been unable to establish efficiency characteristics for a number of additional clothes washers). Clothes washers were deemed to be efficient if they met ENERGY STAR Version 7.1 requirements (U.S. Environmental Protection Agency and U.S. Department of Energy 2015) and then were flagged as efficient or inefficient.
- **Water Heaters** – Currently, based on the HEUS data, Evergreen was able to determine the efficiency characteristics of 374 water heaters in the sample (to date, we have been unable to establish efficiency characteristics for a number of additional water heaters). Using the criteria of ENERGY STAR Version 2.0 (U.S. Environmental Protection Agency and U.S. Department of Energy 2012), which is based on water heater fuel type, water heater type (storage or instantaneous), and energy factor (all from CEC data), Evergreen flagged each water heater as efficient or inefficient.

The end result of the categorization is a dataset with an efficiency rating, or flag, for each site for each type of appliance mentioned previously. For lighting, each home is given a percentage score equivalent to the proportion of total lamps that are flagged as efficient. Table 2 below presents the proportion of efficient lighting across all homes, and the proportion of efficient homes in the sample for each appliance measure.

Table 2. HEUS equipment binary efficiency overview

Category	Percent Efficient	95% CI	Total N	Valid N
Lighting*	46.4%	1.4%	1,000	1,000
Clothes Washers	41.3%	4.3%	1,000	356
Water Heaters	10.2%	2.6%	1,000	374

* Proportion of lights in home that are efficient.

Once Evergreen characterized each home in terms of efficiency for the selected measures, we investigated potential demographic, housing characteristic and geographic variables that may correlate with measure efficiency. There are over 500 demographic, housing characteristic and geographic variables (collectively referred to as household characteristics throughout the remainder of the paper) available in the HEUS data, making detailed investigation possible. For this paper, Evergreen selected the following high level characteristics that have a theoretical link to efficiency across the selected measures: household income, education level, home vintage, building type, home size in square feet, climate zone and county. All results are unweighted and therefore, no critical policy or other decisions should be made based on the illustrative findings provided in this paper.

Evergreen compared the efficiency characteristics of each measure across each home characteristic, as well as across combinations of home characteristics, to determine if there were statistically significant differences. Because each characteristic category contains more than two groups (or bins)—for example, the income category has ten groups or bins—Evergreen used a two-step approach to measure statistical significance. We first use a standard one-way analysis of variance (ANOVA) test to test the null hypothesis that parameter estimates for groups within each category are all statistically equal, versus an alternative hypothesis that at least one group is statistically different from the others. The ANOVA test tells us if there is evidence that at least one group (bin) has a statistically significant difference from the other groups in our sample. However, the ANOVA test does not tell us which group or groups are different.

Therefore, in order to determine which groups are different when the ANOVA test supports the alternative hypothesis that there is at least one group that is different from the others (a "rejection of the null hypothesis"), Evergreen conducted an additional statistical procedure, the Bonferroni Procedure. The Bonferroni Procedure is a post-hoc statistical method for comparing the means, or proportions, of multiple (more than two) populations based on pairwise comparisons. The procedure tests each unique pair in a group to determine if the difference is statistically significant, while applying a correction to account for the fact that we are conducting several dependent statistical tests simultaneously on a single data set.

Low Hanging Fruit: Lighting

The initial ANOVA test found that the saturation of efficient lighting is highly likely statistically related to home size, and potentially also related to income and home vintage.

Further investigation of these three characteristics reveals some interesting trends. The following boxplots show the median proportion of efficient lighting as a solid horizontal line within each box, and the second and third quartiles as the lower and upper edges of the box, respectively. The mean percentage is represented by a solid dot and is bound by the 95% confidence interval, represented by the vertical line with small horizontal lines at either end.

While the ANOVA test rejected the null hypothesis that the income groups are equal at the 90% confidence level, the Bonferroni Procedure did not find any statistically significant differences between any paired groups. The boxplot for income in Figure 1 supports the results of the Bonferroni Procedure as all confidence intervals overlap at least somewhat, indicating that there are no statistically significant differences between groups. Thus, this finding shows that household income is not a good predictor of the percentage of efficient lighting in a home.

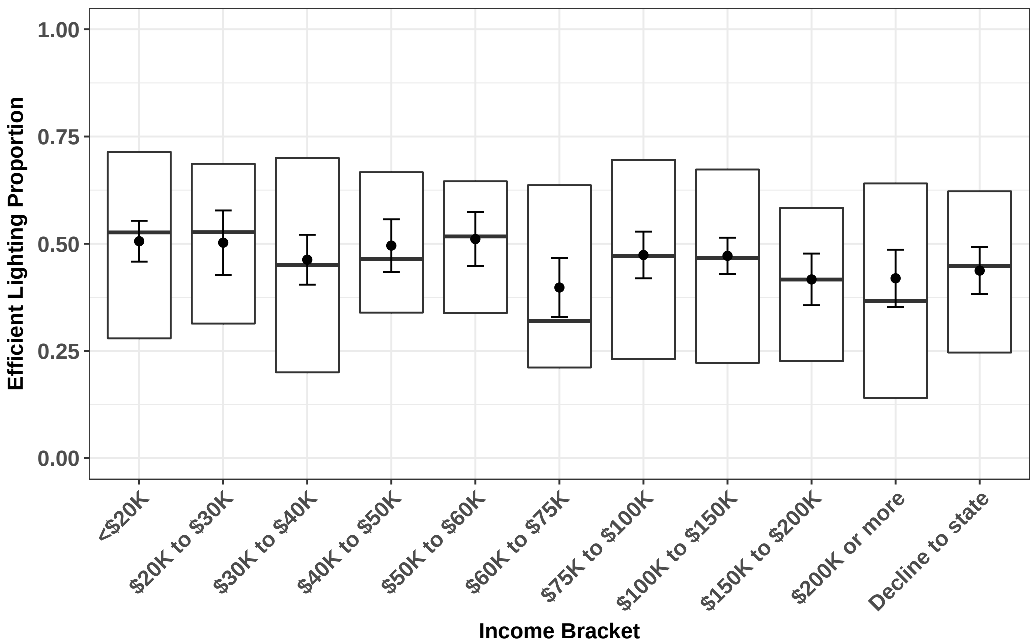

Figure 1. HEUS lighting efficiency by income.

A similar pattern is found with home age. While the ANOVA test found that there was statistically significant evidence to reject the null hypothesis that all groups are equal, the Bonferroni Procedure did not identify any pairs that were significantly different.

However, we did find that the prevalence of efficient lighting might be related to home size. We separated homes into increments of 500 square feet up to 3,000 square feet. The ANOVA test rejected the null hypothesis at greater than the 99% confidence interval, and the Bonferroni Procedure found that differences were statistically significant between several groups. These results are reflected in the box plot in Figure 2, which indicates that smaller homes tend to have a higher proportion of efficient lighting in general. There are many possible reasons why smaller homes tend to have higher proportions of efficient lighting. While the saturation data are unable to address this, the empaneled households provide an opportunity for a follow-on study (i.e., a web survey) to better understand this dynamic.

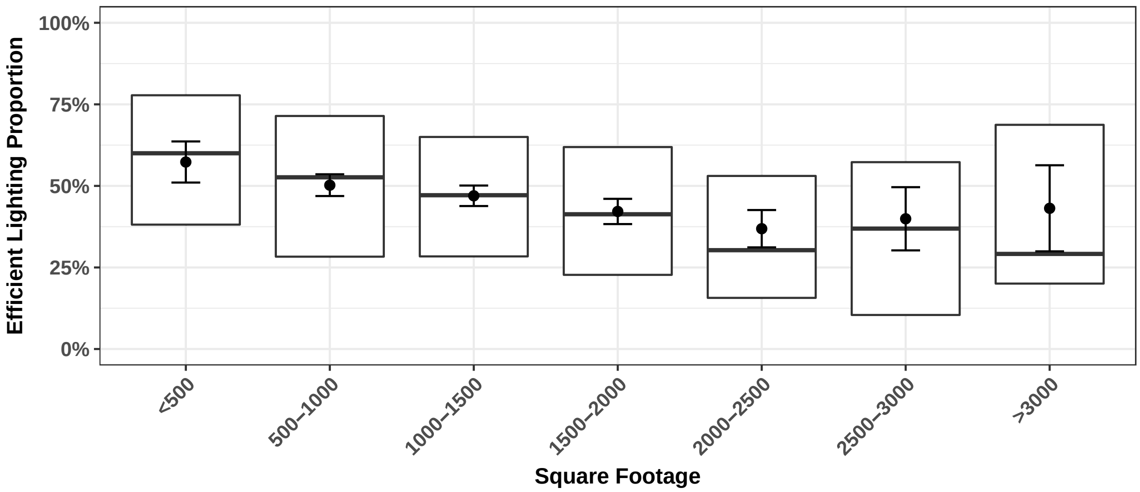

Figure 2. HEUS lighting efficiency by home size (sq. ft.).

Low Hanging Fruit: Clothes Washers

For clothes washers, the ANOVA test found that the prevalence of efficient models is highly likely statistically related to income, building type and home size, and potentially also related to level of education.

The Bonferroni procedure found that the difference between the "Less than $50,000/year" and the "Over $100,000/year" categories are statistically significant at the 99% confidence level, shown in Figure 3. Similar to the lighting efficiency analysis, we are able to use the saturation and demographic data to identify that households with lower incomes tend to have fewer efficient clothes washers, but the data are not suited for determining why this tendency occurs (though a lack of disposable income among lower income households may exacerbate the upfront cost barrier of more efficient models).

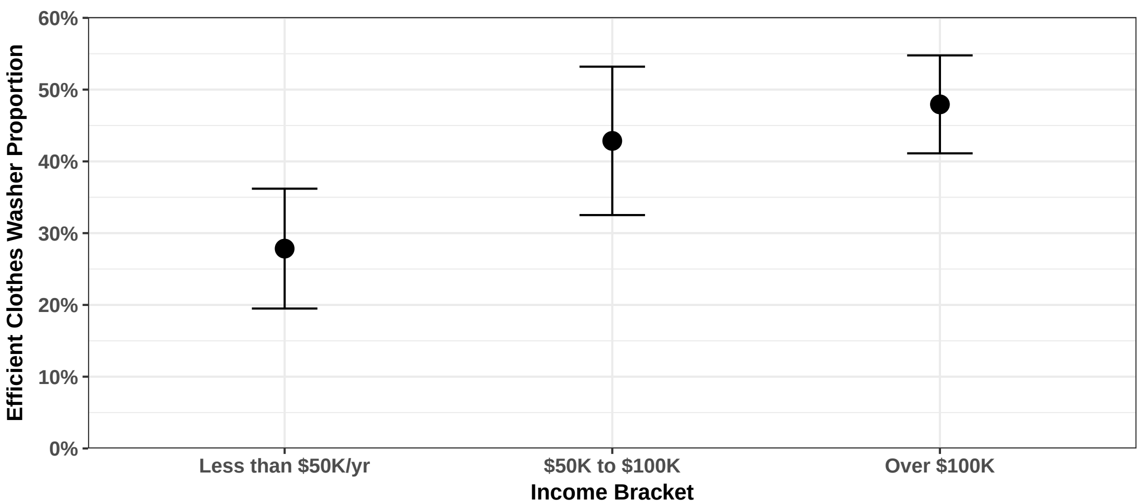

Figure 3. HEUS clothes washer efficiency by income.

Home type also appears to be indicative of the presence of efficient clothes washers (Figure 4). Of homes with clothes washers, 45% of single family homes had an efficient clothes washer, versus only

23% of homes in multifamily buildings. The difference is statistically significant at the 99% confidence level.

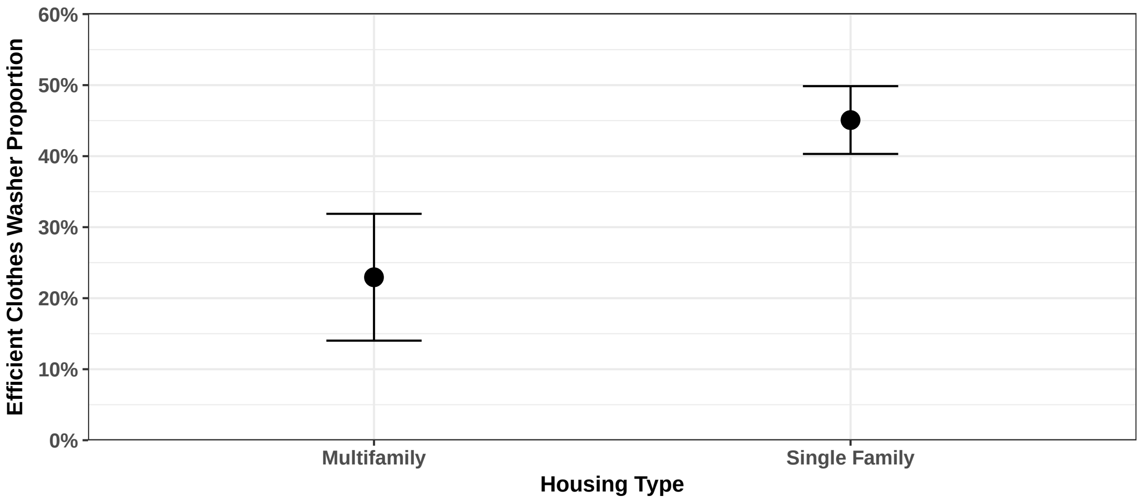

Figure 4. HEUS clothes washer efficiency by home type.

Figure 5 shows that smaller home size appears to be associated with the presence of less efficient clothes washers. Of homes with clothes washers, fewer than 20% of homes of less than 1,000 square feet have an efficient clothes washer, compared to over 40% of homes above 1,000 square feet. The difference between homes under 1,000 square feet and all other size groups is statistically significant at the 95% confidence level. The differences between the other groups are not statistically significant. Note that home type and home size are highly correlated: 78% of multifamily homes are less than 1,000 square feet in size.

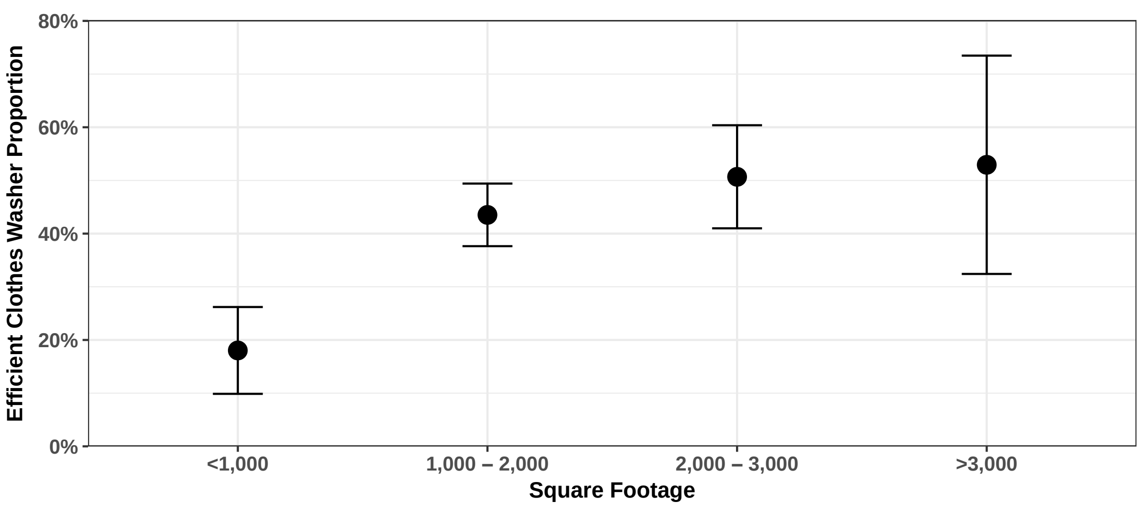

Figure 5. HEUS clothes washer efficiency by home size (sq. ft.).

While the ANOVA test for evidence of variance across education groups found evidence of statistically significant differences at the 95% confidence level, the Bonferroni procedure yielded no statistically significant difference between any education groups. Thus, this finding suggests that household education is not a good predictor of clothes washer efficiency.

Low Hanging Fruit: Water Heaters

For water heaters, the ANOVA test suggests that whether a household has an efficient water heater is highly likely dependent on building vintage and type, and may also depend on household income. The following bar charts show the results of the Bonferroni procedure for the proportion of homes with efficient water heaters in each group within each category bound by the 95% confidence interval.

The Bonferroni procedure indicates that the proportion of homes with efficient water heaters is statistically different for the "Less than $50,000/year" and "over $100,000/year" categories at the 95% confidence level (Figure 6). This indicates that a greater proportion of inefficient water heaters are found in homes with lower household incomes.

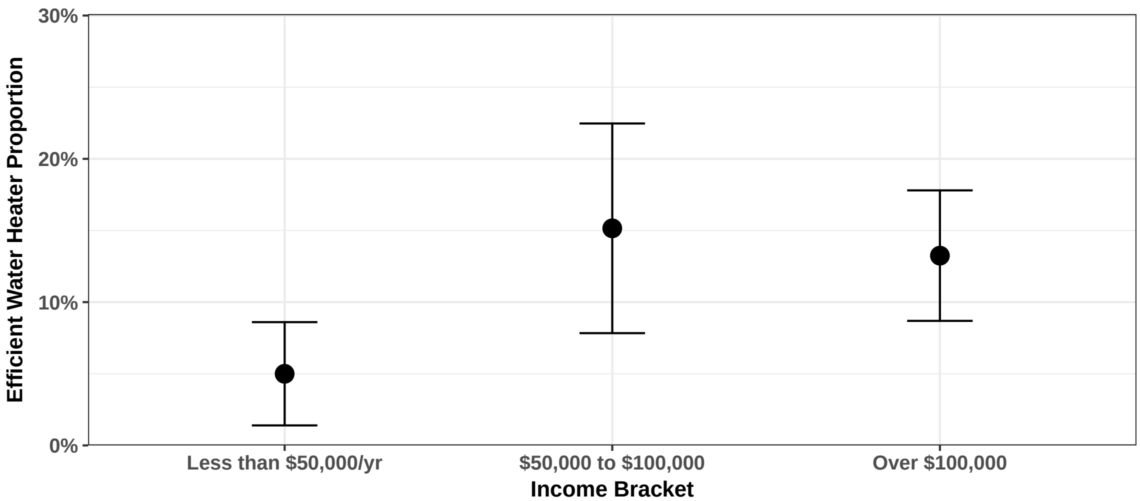

Figure 6. HEUS water heater efficiency by income.

Home vintage could also be used to predict the prevalence of efficient water heaters within the population. Figure 7 shows that of homes with known water heater characteristics, fewer than 3% of homes built between 1980 and 2000 have efficient water heaters. This is significantly lower than for homes built before 1980 (including homes built before 1940 as well) and homes built after the year 2000. This may indicate that more homes built before 1980 have replaced older, less efficient water heaters than homes built between 1980 and 2000 (where a higher proportion of water heaters installed at the time of construction are still likely functional and have not been replaced). In conjunction with market research to better understand this dynamic, program implementers could use this type of information to target water heater programs (i.e., a marketing push in areas with large proportions of homes built between 1980 and 2000). Additionally, these data could be used to show the impacts of appliance standards; the first ENERGY STAR standard for water heaters was developed in the 2000s and finalized in 2008 (the second version—which is the basis of this analysis—maintained the same minimum efficiency specifications for natural gas storage water heaters, and included electric storage water heaters for the first time).

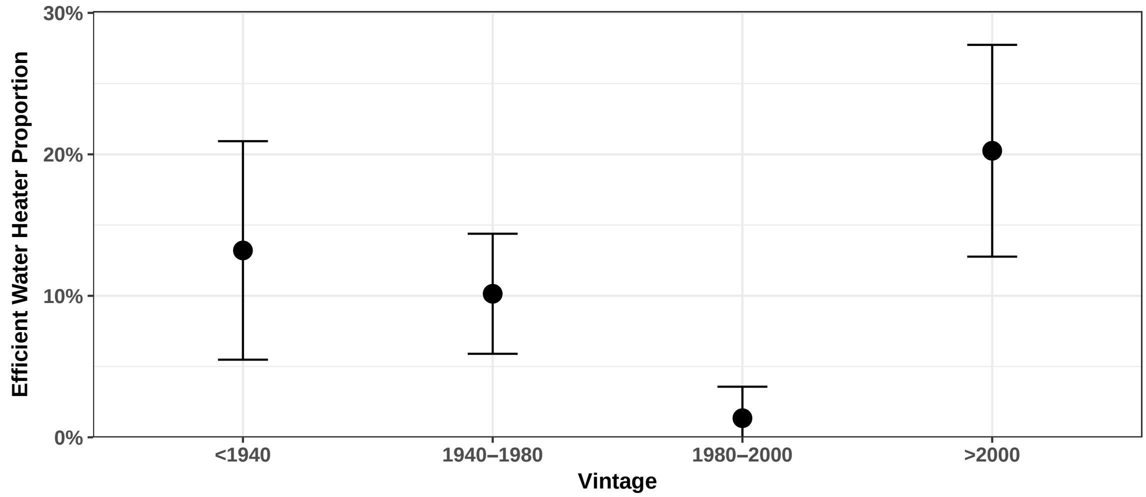

Figure 7. HEUS water heater efficiency by home vintage.

Lastly, similar to the other equipment types, home type appears to be indicative of the presence of efficient water heaters, with 12% of single family homes owning an efficient water heater—triple the proportion of multifamily homes (4%). The difference of approximately 8%, as shown in Figure 8, is statistically significant at the 95% confidence level. Since many multifamily households pay their own utility bills, but the property manager/owner pays for equipment upgrades, the split incentive may lead to relatively lower prevalence of efficient water heaters among multifamily properties. Despite this finding, it is evident that both multifamily and single family homes share low saturations of efficient water heaters.

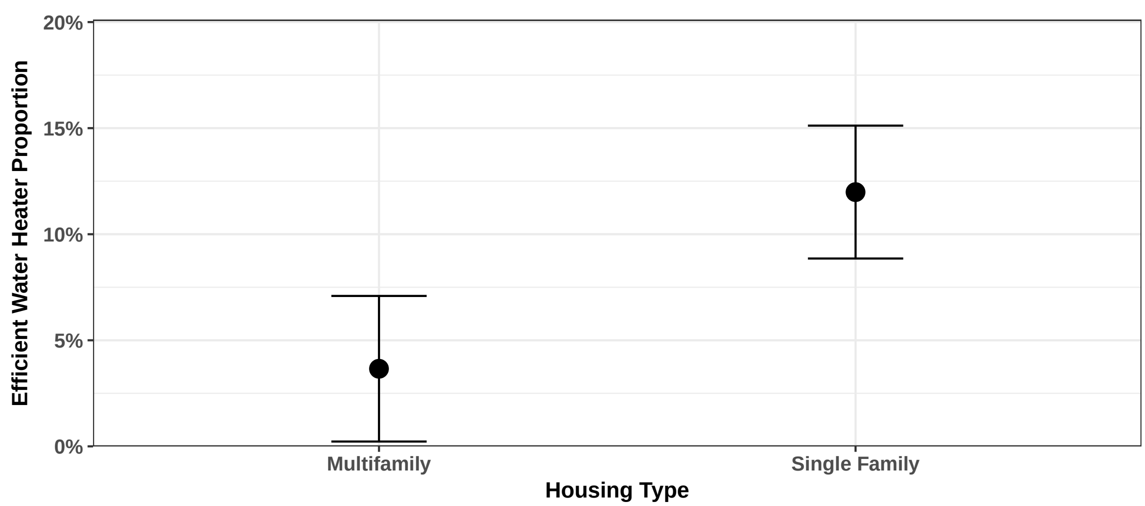

Figure 8. HEUS water heater efficiency by home type.

We conducted a limited analysis to assess whether the prevalance of inefficient water heaters could be associated with geographical characteristics of counties. First, we divided counties into quartiles based on the percentage of homes with efficient water heaters (represented by the number within each county in Figure 9, with quartile 1 having the lowest proportions of efficient water heaters). Next, we defined each county as urban or rural based on the National Center for Health Statistics (NCHS) 2013 definitions of urban and rural (with “large central metro” and “large fringe metro” categorized as urban) (U.S. Center for Disease Control 2014).

Shown in Figure 9, eight out of 10 urban counties are in the top two quartiles in terms of the proportion of efficient water heaters, and all 10 of the counties with the highest prevalence of inefficient water heaters are defined as rural. While a number of rural counties are in the top two quartiles, this analysis shows that targeting rural counties for water heater upgrades may be more efficient than targeting urban counties where the prevalence of inefficient water heaters tends to be lower.

Beyond investigating whether there may be a link to geographic characteristics of counties, this type of mapped data clearly indicates which specific counties have higher and lower proportions of innefficient water heaters. This type of analysis and information could be used by program planners to develop or justify targeting energy efficient program outreach to specific counties.

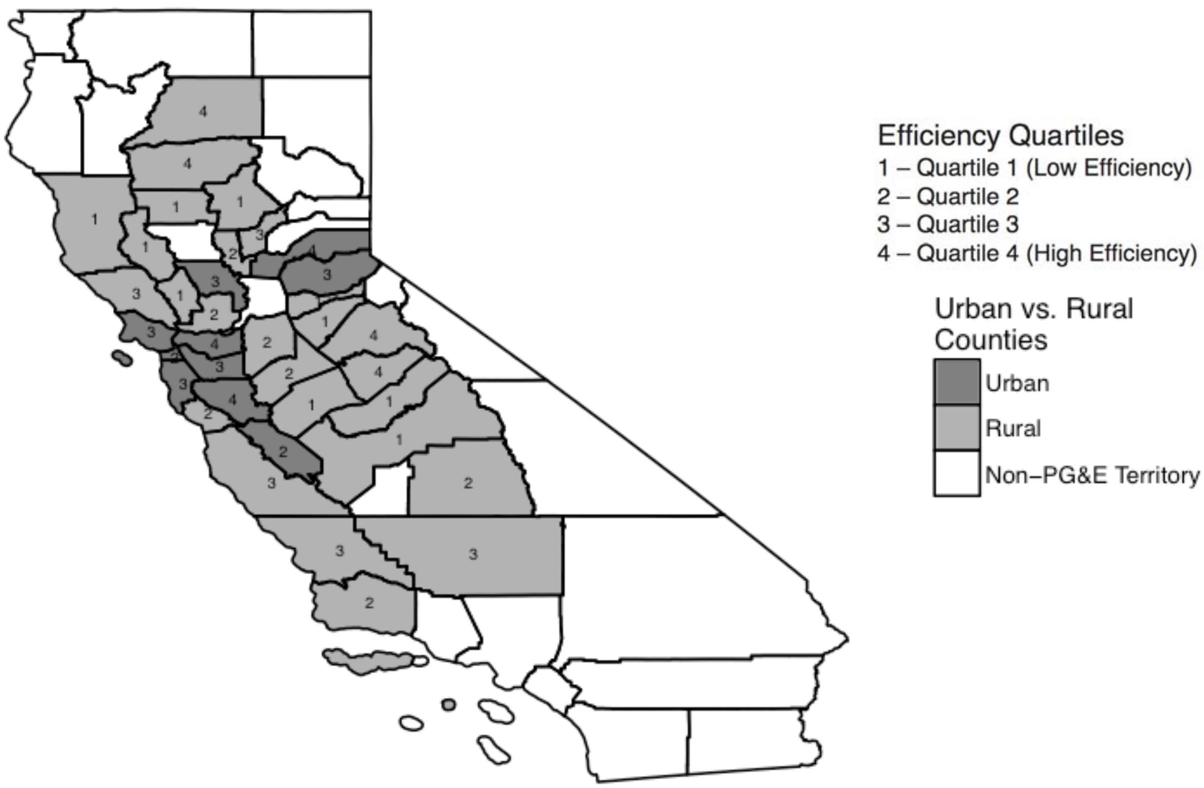

Figure 9. HEUS water heater efficiency map by county quartiles, by urban and rural.

Conclusions and Implications

This paper is intended to be an illustrative proof of concept or demonstration of one of many ways PG&E's HEUS data can be analyzed and used: to better understand what types of homes and households—based on their location, building characteristics and occupant characteristics—have more opportunity for efficiency gains than others. While this type of analysis could be very useful for program planners to better target specific segments within the residential market, our conclusions and implications do not focus on any of the findings from the above analysis. Rather, the important takeaway from this paper is that PG&E has developed a very useful resource intended to support its building codes and equipment standards advocacy efforts, but with wide-ranging applicability within the energy efficiency industry. These data are specific to PG&E's service territory, are current, and were collected onsite instead of via resident self-report. When combined with NEEA's RBSA, the detailed equipment and home characteristics data cover approximately 17% of the U.S. population (U.S. Census Bureau 2016) and covers five of the 13 U.S. DOE climate zones (with limited coverage of a sixth climate zone).

Evergreen Economics is currently supporting PG&E's Codes and Standards program by conducting analysis using the HEUS dataset on an as-needed basis, and providing cleaned and anonymized data for analysis. The implications of PG&E owning these data have not been fully realized, but PG&E is already using these data to support Codes and Standards CASE studies and for federal appliance standard advocacy, and will likely use these data for many other purposes in the coming months and years.

These data can be used to identify where inefficient technologies remain—as shown in the analysis for this paper—which could be used by California IOU program planners to better target energy efficiency incentives to ratepayers. These data can also be used in conjunction with previous and future saturation studies to inform longitudinal trends in the characteristics and equipment holdings of California homes.

To date, PG&E has leveraged the HEUS in many ways, including its Codes and Standards advocacy but also to:

- Inform saturation estimates included in annual business plans;
- Provide equipment saturation estimates to the California Energy Commission (CEC);
- Inform comments on evaluation research reports;
- Assist in updating the DOE's 2010 Residential Lighting Market Characterization, which was prepared by Navigant Consulting in 2012; and
- Conduct targeted market research among homeowners with specific types of equipment (i.e., a web survey related to clothes washer and dishwasher usage patterns).

Additionally, we anticipate that these data will be used to estimate the future impacts of potential standards and building code updates, which are an important component of the IOUs' strategies to help California meet the goals of the Clean Energy and Pollution Reduction Act of 2015 (SB350). To meet these goals—50% of energy production from renewable energy sources and a doubling of efficiency by 2030—requires, among other things, targeting appliance standard and building code updates. The HEUS data provides representative and current equipment saturations, efficiency levels and building characteristics. Subsequent study phases will provide equipment load shapes and energy consumption estimates, and also will inform assessments of equipment purchases and occupant behaviors through the web surveys. Together, these data will allow PG&E to effectively and efficiently target relevant standards and code updates that may have the most impact on energy demands.

In conclusion, PG&E's Codes and Standards Program's investment in the HEUS project will lead to more effective and accurate codes and standards advocacy on behalf of ratepayers in California as the state continues to pursue aggressive climate change goals. In addition, the dataset and follow-on studies (including the metering study) provide a wealth of information for program planners, evaluators, regulators and other agencies focused on meeting the challenges of climate change through energy efficiency.

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