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Energy usage impacts of projects financed through Property Assessed Clean Energy programs in California

Jeff Deason, Sean Murphy, and Charles A. Goldman

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Acronyms and Abbreviations

A/C	Air conditioning
ASHRAE	American Society of Heating, Refrigeration, and Air-conditioning Engineers
CAEATFA	California Alternative Energy and Advanced Transportation Financing Authority
CVRMSE	Coefficient of variation of the root mean squared error
DOE	Department of Energy
EE	Energy efficiency
EIA	Energy Information Administration
HERO	Home Energy Renovation Opportunity
HUP and AHUP	California's Home Upgrade Program and Advanced Home Upgrade Program
HVAC	Heating, ventilation, and air conditioning
IOU	Investor-owned utilities
kWh	Kilowatt-hour
MWh	Megawatt-hour
NMBE	Normalized mean bias error
NMEC	Normalized metered energy consumption methods
NOAA	National Oceanic and Atmospheric Administration
PRISM	Princeton Scorekeeping Method
SCEIP	Sonoma County Energy Independence Program
PACE	Property Assessed Clean Energy
PG&E	Pacific Gas & Electric Corporation
PV	Photovoltaics
SCE	Southern California Edison
SCG	Southern California Gas
SDG&E	San Diego Gas & Electric
TOWT	Time-of-week-and-temperature
TWh	Terawatt-hour

Executive Summary

Residential property assessed clean energy (R-PACE) programs extend financing for improvements (including energy efficiency and solar PV measures) and have attracted a large volume of customers (~280,000 projects and $6.3 billion in investments nationwide at end of 2019).[1] Because R-PACE programs are not funded by utility customer budgets, their impacts are not regularly evaluated. This report provides the first independent, large-scale analysis of the energy impacts of R-PACE projects and programs.

We examine the household-level energy impacts of R-PACE projects using normalized metered energy consumption methods. We combine energy usage data from California investor-owned utilities with project dates and measure categories furnished by the R-PACE programs for projects installed from 2009 through mid-2017. Our models estimate the energy impacts of each project by comparing energy usage in the year prior to the beginning of the project ("baseline period") and the year following completion of the project ("reporting period"), while accounting for weather. We employ a comparison group, drawn from other R-PACE households with similar locational and usage characteristics whose projects were implemented at different times, to control for non-project and non-weather factors that may impact energy use.

Table ES-1 summarizes average impacts from the entire portfolio of California R-PACE projects expressed in terms of percentage and absolute reductions in grid electricity and gas use, along with the sample size of households for each measure category.[2]

Table ES-1. Average energy impacts of R-PACE projects in California.

Measure category	% reduction in grid electricity use	Average household first-year electricity savings (kWh)	Sample size	% reduction in gas use	Average household first-year gas savings (therms)	Sample size
Energy efficiency (EE)	2.9%	245	18,244	3.5%	16	10,008
Energy efficiency without inferred HVAC installations	4.8%	414	15,762	5.9%	28	8,719
Solar PV	68.9%	7,937	5,098	-1.7%	-9	4543
Solar PV and EE	63.6%	6,542	987	4.3%	21	653

We find that projects consisting of energy efficiency technologies save, on average, about 3% of household electricity usage and 3.5% of household gas usage. It is important to note that R-PACE financing can be used to install new energy-consuming equipment (e.g., installing an air conditioner in a home that previously lacked air conditioning) as well as to replace existing

[1] Data from PACENation at https://pacenation.org/pace-market-data/

[2] We calculate a weighted average of the estimated impacts by utility, because we lose more meters due to data sufficiency issues from some utilities than others (see section 3.2 and Appendix A)

equipment (e.g., replacing an existing central air conditioner with a new one). Since our data do not directly indicate which projects are new installations, we develop a simple algorithm for identifying them. Removing these inferred installation projects – which would be expected to increase, not decrease, energy usage – yields average savings of about 5% for electricity and 6% for gas for those households that remain in the sample.

Solar PV projects yield large reductions in grid electricity use, averaging 69% of household consumption. On average, these projects are associated with a small increase in gas consumption, perhaps resulting from reduced rooftop heat gain that requires additional heating to offset. Surprisingly, projects with both solar PV and energy efficiency measures reduced grid-tied electricity consumption by 64% on average, which is somewhat lower than PV-only projects. This result is due to projects in one utility service territory, which we believe may reflect project-specific or contractor-specific idiosyncrasies in that location.

We also mapped each project to a standard set of measure categories that we developed. Examples of measure categories include HVAC equipment, replacement or installation of windows and doors, and other envelope measures (e.g. attic, floor or wall insulation, air sealing). Some projects included combinations of these measure categories. In these cases, we developed combined categories. As shown in Figure ES-1, average electricity savings range between 3-5%, with gas savings ranging between 3-6%, for envelope measures and windows and doors. Average gas usage declined by about 12% for customers that installed more efficient water heaters or other related measures.[3] In general, multi-category projects have higher savings, especially for gas. For example, households that installed HVAC, envelope measures, and new windows/doors reduced average electricity usage by 6% and average gas usage by 10%.

In understanding our estimated energy efficiency impacts, it is important to consider the nature of R-PACE projects in the California context. The vast majority of R-PACE projects affect space conditioning usage only, through HVAC equipment, envelope-related measures, or both. Given the mild California climate, these projects have limited savings potential. We see larger savings in parts of the state where heating and cooling demand is greater. Similar projects and programs elsewhere in the country might be expected to save more energy, both in percentage and absolute terms.

[3] Most California homes use natural gas for water heating, explaining why the savings from these projects are gas and not electric. The small increase in electricity usage for water heating projects may indicate that a small subset of R-PACE customers installed electric water heating in place of previous technologies powered by other fuels, though we cannot directly observe this in our data.

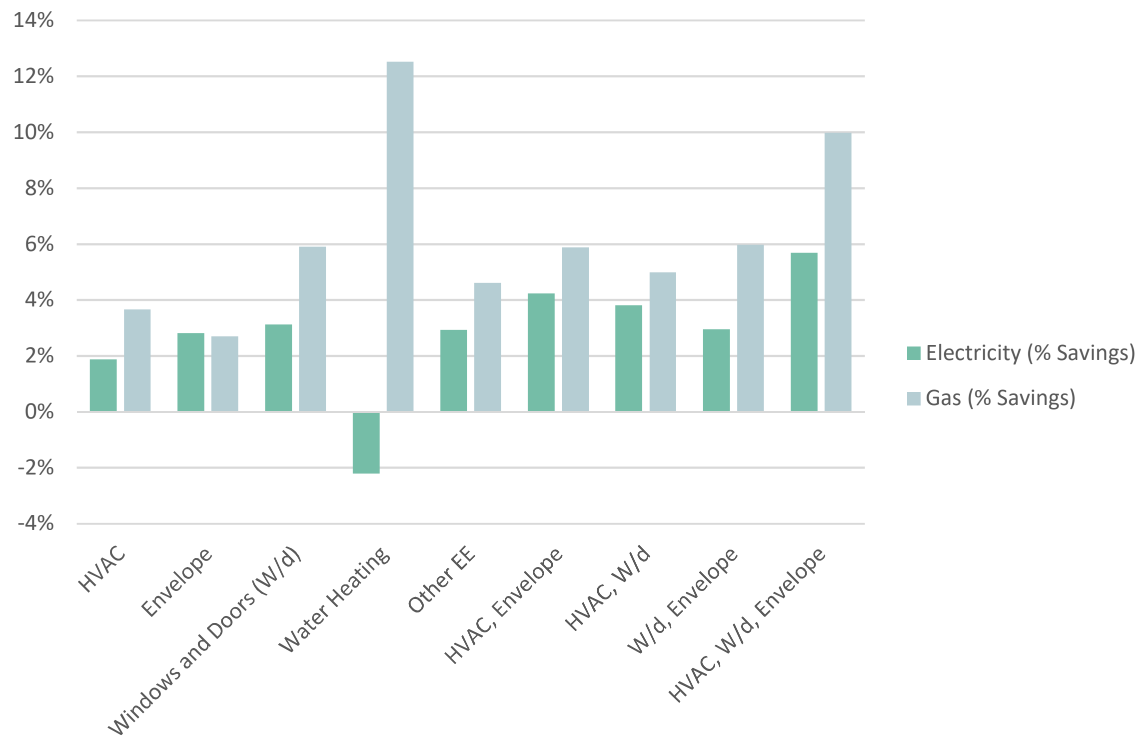

Figure ES-1. Energy efficiency project impacts by measure category

We compare R-PACE average project savings to those estimated for California's Home Upgrade and Advanced Home Upgrade programs, which are whole home retrofit programs administered by California investor-utilities as part of their customer-funded efficiency portfolios. Per-household savings from R-PACE projects are generally slightly lower than those from the home upgrade programs, which is consistent with our expectation that projects under those programs would generally be more comprehensive than R-PACE projects. Total savings from R-PACE project are considerably larger than for the home upgrade programs during the period for which home upgrade results were reported (July 2016-June 2017) due to greater customer volumes for R-PACE (43,000 participants that installed energy efficiency measures during that same time period).

We also estimate total impacts across R-PACE programs, under the assumption that the projects for which we are able to calculate impacts are representative of all R-PACE projects in California. We estimate that, collectively, all R-PACE projects installed to date would generate annual reductions in grid-tied electricity consumption of 506 GWh (506 million kWh, mostly due to solar PV) and gas consumption reductions of 2 million therms in a normal weather year. These impacts are equivalent to the electricity consumption of about 74,000 California households (including both efficiency and PV generation) and the gas consumption of about 4700 California households. Over their full project lifetimes, we estimate that R-PACE projects installed through the end of 2019 will avoid 9.6 TWh in consumption of grid electricity and 37 million therms in gas consumption.

1. Introduction

Achieving significant improvements in the energy efficiency of existing U.S. residential buildings is a major challenge as service providers (e.g., contractors, architects, and engineers) must often overcome a variety of barriers. Some energy efficiency investments have “higher first costs” compared to conventional measures (IEA 2008; Jaffe and Stavins 1994). Examples in the residential market include high-efficiency windows, wall or floor insulation, or a more efficient heating, ventilation, or air conditioning (HVAC) system. These investments deliver energy cost savings and other benefits (e.g., improved comfort, reduced maintenance expenses), although these benefits are realized over long time periods (10-25 years) given the effective useful life of high-efficiency equipment and envelope measures. Solar PV systems are also expensive up front and yield energy cost savings over similarly long time frames. Financing offers an opportunity to better align the timeline of customer costs with energy cost savings for energy efficiency and solar PV projects, enhancing the affordability and attractiveness of these projects.

Many state policymakers and utility regulators have established aggressive energy efficiency savings goals that will necessitate investing billions of dollars in existing buildings over the next decade or two (Goldman et al 2020). There is increasing interest among policymakers in promoting financing programs as a way to supplement or develop alternatives to incentives (rebates) that have traditionally been offered in utility energy efficiency programs (Kramer et al. 2015).[4] Policymakers are also interested in approaches that leverage public/private partnerships to support energy efficiency.

Property assessed clean energy (PACE) programs are operating in 22 states for commercial customers and in three states (California, Florida and Missouri) for residential customers.[5] Residential PACE (R-PACE) programs allow residential building owners to finance certain home improvement measures and repay project costs through a special assessment charge on the property tax bill. While commercial PACE programs operate in many more states, R-PACE programs have deployed more capital in total, as Florida and especially California R-PACE programs have achieved significant scale. Most R-PACE programs are administered as public/private partnerships, with the involvement of state and local governments (who have the authority to place and collect the assessments) and private companies (who source capital for the programs and help administer them). Figure 1 presents a high-level overview of the R-PACE process and actors. We do not show details of the financial transactions between public and private partner administrators in Figure 1.[6]

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[4] Utility ratepayer (or taxpayer) funds are limited, necessitating significant levels of private investment as savings goals increase over time.

[5] Based on data gathered by PACENation at http://pacenation.us/pace-market-data/.

[6] Generally, public partners with the authority to place special assessments issue short-term bonds to fund projects. Private partners then purchase these bonds, and often later sell securities backed by R-PACE payments to the capital markets to replenish their capital.

Most eligible improvements are energy efficiency or renewable energy measures, although R-PACE assessments can also support water efficiency measures as well as certain resilience-related measures.[7] As with other special assessments, R-PACE assessments are secured to the property and senior to the home mortgage, enhancing lenders' prospects for recovery in the event of customer non-payment. This security lowers the cost of capital relative to unsecured lending. The vast majority of R-PACE projects are funded by private capital, which the homeowners then repay via the property tax bill. R-PACE programs have proven successful at bundling and securitizing the cash flows from assessment payments, thereby replenishing their capital through sale of these securities in the secondary financial markets.[8]

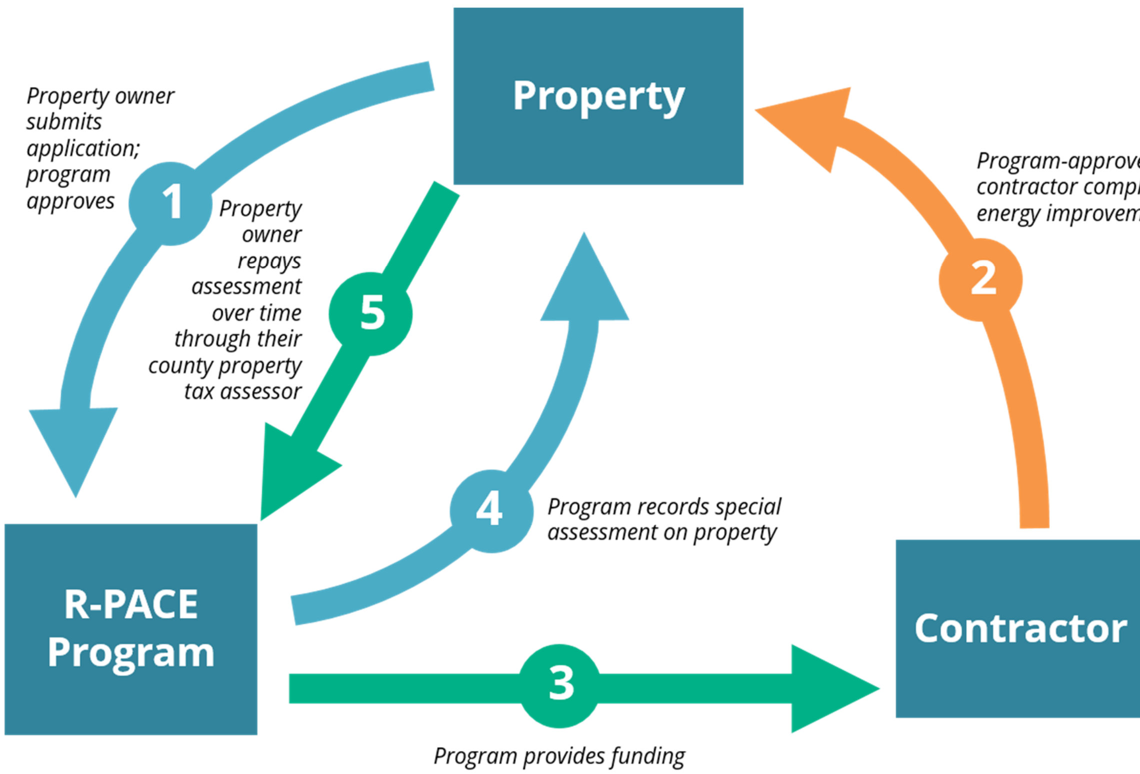

Figure 1. Overview of the R-PACE project process

California's R-PACE programs merit study because they have supported a large volume of investments in certain HVAC equipment and building envelope (e.g., windows, doors, insulation) measures as well as solar PV systems. The state now considers them a channel for energy efficiency delivery that is expected to contribute towards the state's ambitious energy saving goals. California Senate Bill 350, which was passed in 2018, seeks to double state energy efficiency savings by 2030 and identifies PACE programs (both residential and commercial) among the programs that may help achieve this goal.[9]

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7 Eligible improvements in a PACE program depend on a state's authorizing legislation. In California, eligible measures currently include energy efficiency, solar PV, water efficiency measures, and resilience-related measures (e.g., measures that mitigate impact of an earthquake or wildfire).

8 For more on the process of securitizing payments from energy efficiency financing, see Kramer et al. (2015a).

9 See https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160SB350, Section 25310(d)(11).

The first R-PACE programs in California were introduced in 2008 and 2009 as local government programs in specific jurisdictions (e.g., Sonoma County). Soon thereafter, R-PACE programs faced concerns about mortgage market and consumer protection impacts. In 2010, the Federal Housing Finance Agency (FHFA) directed Fannie Mae and Freddie Mac not to purchase and securitize any mortgages on homes with R-PACE assessments.[10] Following these early challenges, which caused some programs to close, R-PACE volumes began to rise quickly after 2012. Capital extended by R-PACE programs more than doubled each year from 2012 through 2015 as the programs expanded throughout California and launched in Florida. R-PACE programs in California accounted for nearly half of programmatic[11] capital for energy efficiency projects nationally in 2014 (Deason et al. 2016), and grew substantially after that point as outlined above.[12] Nationwide investments in R-PACE were $340M in 2014, $960M in 2015, $1.56B in 2016, and $1.48B in 2017.

Nationwide R-PACE investments declined significantly in 2018 to $770M and then increased somewhat to $890M in 2019. California R-PACE volumes, however, continued to decline in 2019.[13] In 2016 and 2017, California passed three bills that increased consumer protections and disclosure requirements.[14] More restrictive legislation on R-PACE eligibility and underwriting requirements may be responsible for the decline in volume observed in the California market since 2018 (DeVries 2018).

Cumulative investments in residential PACE projects nationwide through 2019 total $6.2 billion.[15] Outside California, the R-PACE market in Florida is quite active, and Missouri hosts a small program. A number of other states have passed authorizing legislation for R-PACE but do not have active programs.[16]

In large part due to the rapid growth of residential PACE programs in the mid-2010s, R-PACE has attracted significant interest in California and among policymakers and stakeholders in other states interested in understanding its impact on energy efficiency and solar PV markets, its value to customers and the economy, and its potential risks to lenders and homeowners.

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10 See the FHFA's statement at https://www.fhfa.gov/Media/PublicAffairs/Pages/FHFA-Statement-on-Certain-Energy-Retrofit-Loan-Programs.aspx.

11 By programmatic capital, we mean capital extended through a structure featuring significant involvement of government or utility actors. We consider R-PACE programs to be programmatic since both state legislation and local government action are required to establish and join programs, and since public agencies (counties or joint powers authorities) co-administer the programs even where private administrators and private capital are employed. Capital extended without government or utility involvement – for example, a home equity loan, personal loan, or credit card purchase – is not programmatic.

12 In 2014, R-PACE programs extended $248 million in capital for energy efficiency. The total amount of capital extended to residential customers nationwide by energy efficiency financing programs covered in the report was $537 million.

13 Nationwide R-PACE investment volumes are from PACENation at http://pacenation.us/pace-market-data/. California data are available from CAEATFA at https://www.treasurer.ca.gov/caeatfa/pace/activity.pdf.

14 The new California statutes on R-PACE required income-based underwriting with verification requirements, written disclosure forms modeled after the Federal mortgage disclosure, enhanced underwriting criteria, and Department of Business Oversight authority to regulate private sector PACE administrators.

15 Based on data gathered by PACENation at http://pacenation.us/pace-market-data/.

16 For more specifics on the program-by-program development of R-PACE, see Deason and Murphy (2018); Kaatz and Anders (2014); Bellis et al. (2017).

Several studies (Kirkpatrick and Bennear 2015; Ameli et al. 2017; Deason and Murphy 2018) estimate the impact of R-PACE program availability in encouraging the deployment of residential solar PV and generally find that the presence of R-PACE programs is associated with increased PV deployment while controlling for other relevant factors. Goodman and Zhu (2016) finds that R-PACE participation has a net positive impact on home sale value: the sale value of a R-PACE home, on average, increases by more than the amount of the outstanding assessment. Rose and Wei (2019) evaluates economy-wide impacts of residential and commercial PACE programs in California and Florida co-administered by Ygrene (a private program administrator and capital provider), finding positive macroeconomic impacts in the hundreds of million dollars in each state[17] over the lifetime of the currently funded projects.

1.1 Report objectives and roadmap

We believe that this study represents an important contribution to our understanding of R-PACE because it is the first to conduct an *ex post* analysis of the energy impacts of R-PACE projects. This study draws from a large dataset of ~80,000 California households that participated in R-PACE. It is worth noting that R-PACE programs have neither the requirements nor the funding sources that have historically driven and motivated impact evaluations of energy efficiency programs funded by utility customers.[18] Moreover, it is quite challenging to do impact evaluations of R-PACE programs because it is necessary to compile information and data from multiple organizations and sources. We had to compile information on R-PACE assessment amounts at the household level (sourced from the California Alternative Energy and Advanced Transportation Financing Authority (CAEATFA)) with measures installed by PACE providers (sourced from PACE providers and California solar interconnection data), project start and end dates (variously compiled or estimated from PACE providers, CAEATFA, and solar interconnection data), and metered energy usage (sourced from electric and gas utilities).

We analyze the following questions:

- How much energy (electricity and natural gas) does a typical R-PACE household in California save?
- How much energy (electricity and natural gas) have projects funded by R-PACE programs in California through 2018 saved in aggregate?
- How do the energy impacts vary by investor-owned utility, by type of measure category, and by climate zone?

[17] Ygrene is the largest R-PACE provider in Florida, with about two-thirds as many projects in Florida as it has in California through July 2018 per Rose and Wei. The other large R-PACE programs – run by Renovate America and Renew Financial – are much larger in California than in Florida, and impacts in the two states would therefore be much more disparate.

[18] It is also worth noting that few impact evaluations have been done of financing programs funded by utility customers. These programs have generally been treated as non-resource programs, meaning that savings attributable to these programs are rarely calculated (Kramer et al. 2015). Horkitz et al. (2016) and Stewart et al. (2016) evaluate the HERO R-PACE program, but these studies are akin to process evaluations of utility programs – they explain how well the programs are functioning from a process standpoint, but do not attempt to quantify energy impacts.

- How do energy efficiency impacts from R-PACE projects and programs compare to those achieved by other multi-measure energy efficiency programs?

Cost-effectiveness analysis of R-PACE projects or programs is not in the scope of this study.[19]

The remainder of this report is organized as follows:

- Chapter 2 describes the data on energy usage, measures installed, and project costs that we compiled on participating R-PACE households in California.
- Chapter 3 describes our approach to modeling energy usage impacts for PACE households, including screens for data adequacy and model performance. We estimate the energy impacts of R-PACE projects using normalized metered energy consumption methods (sometimes known as NMEC). These methods leverage household-level energy usage data, comparing energy usage before and after projects were implemented, remove the effects of actual weather on energy consumption, and then project post-project usage for a "typical" weather year. We also account for non-weather factors that might influence energy usage over time by selecting a comparison group of households, drawing from prior and future participants in R-PACE.
- Chapter 4 summarizes our estimated energy usage impacts, disaggregated by utility service territory, California climate zone, and measure category for R-PACE households. We report first-year and lifetime energy savings. We aggregate our results to estimate energy use impacts across all California R-PACE projects in the study period.
- Chapter 5 discusses several issues that provide context for assessing the energy impacts observed for energy efficiency measure categories in California, potential implications if similar measures were offered in R-PACE program in states with a more severe climate, and a comparison of energy impacts from our R-PACE study to other recent multi-measure, residential efficiency programs.
- Chapter 6 offers conclusions for this study, including a discussion of volume of customers participating in PACE in California, typical first-year and lifetime electricity and gas savings for R-PACE households installing varying combinations of efficiency measures and solar PV, and a summary of the electricity and gas savings in aggregate for all R-PACE participants in California from program inception through 2018.

Technical appendices provide additional documentation, background and explanation of our approach and results.

- Appendix A describes our dataset of R-PACE households included in this study and discusses the evolution of our sample as we dealt with attrition of households due to data availability and data quality screens.

[19] R-PACE programs finance the full cost of implemented measures. However, most energy efficiency cost-effectiveness analyses of utility customer-funded programs consider only the incremental cost of efficient measures over some minimum efficiency baseline measure (e.g., building codes or standards). We do not have sufficiently detailed technology or cost data on specific R-PACE project measures to allow such a calculation.

- Appendix B discusses the impact of varying granularity in the energy usage data (e.g. hourly vs. daily energy use) on energy impacts for R-PACE households and provides estimated confidence intervals for the energy usage impacts for R-PACE households.
- Appendix C examines the impact of various data quality filters that can be applied to household energy model results for R-PACE participants.
- Appendix D provides statistics on the goodness-of-fit of our energy (electricity and gas) model for households in each IOU and by type of measure.
- Appendix E provides additional detail on energy impact estimates by fuel, type of measure and utility for R-PACE households and our comparison group of households.

2. California R-PACE data: project assessments, installed measures, and energy usage

In this section we describe the data on energy usage, measures installed, and project costs that we compiled on participating R-PACE households in California.

2.1 Characterizing R-PACE participants, measures, and energy usage

The California Alternative Energy and Advanced Transportation Financing Authority (CAEATFA) administers a loss reserve supporting most R-PACE assessments in the state. CAEATFA collects data on these individual assessments, including financing dates and assessment amounts. We gathered available data from R-PACE projects submitted to CAEATFA through June 2017. By program, these data cover:

- All Sonoma County Energy Independence Program projects, 2009 through June 2017;
- All projects from mPower programs (Placer County and the City of Folsom), 2010 through June 2017;
- Projects from HERO programs, administered by Renovate America, from July 2014 (when the loss reserve was established and new HERO program projects were first enrolled) through June 2017;
- All CaliforniaFIRST projects, administered by Renew Financial, from July 2014 (when the loss reserve was established and CaliforniaFIRST began financing projects) through June 2017; and
- Ygrene Energy Fund projects, beginning late 2015, when Ygrene began enrolling its new assessments in the loss reserve, and ending June 2016.[20]

Based on CAEATFA's project data, we estimate that our data include over 80% of all California R-PACE projects through June 2017.[21]

We obtained data on measures financed from each of these programs. The level of detail on measure classification varied by provider, with some measures being as specific as "floor insulation" or "duct sealing" while installed measures at other projects were characterized at a much higher level (e.g., "HVAC"). In almost all cases, we do not have data on the specific efficiency level of installed measures (e.g., an energy efficiency rating for an air conditioner or an R-value for insulation). Most of the studied R-PACE programs set minimum efficiency standards for allowable measures that exceeded the minimums required by codes and standards.[22]

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[20] At the time we gathered data from CAEATFA, data on Ygrene assessments were not available from July 2016 through June 2017.

[21] We believe that the only projects not covered are HERO projects installed prior to July 2014; later Ygrene projects (July 2016-June 2017); and a small number of projects financed by a handful of smaller R-PACE providers.

[22] There are no specific minimum efficiency requirements in state statutes, nor is there an easily-referenced account of how minimum standards for R-PACE equipment have been set by program over time. We reviewed certain program handbooks that were in use during the study period. In general, these handbooks set standards above codes and standards minimums for most or all of the allowable measures, though there were exceptions.

In order to harmonize across projects and providers, we developed a standard set of measure categories to which we mapped each project. These standard energy measure categories are:

- HVAC, including installation or replacement of heating and cooling equipment, duct sealing, whole-house fans, and similar measures
- Replacement or installation of windows, doors, and skylights
- Other envelope measures, including attic, floor, and wall insulation, roofing (including cool roofs), air sealing (infiltration reduction), caulking, weather-stripping, and similar measures
- Replacement or installation of water heaters or tank insulation
- Other types of energy efficiency projects (i.e., those that did not fit into the above measure categories)
- Solar PV.

Some projects included combinations of these measure categories. In these cases, we developed combined categories, which included:

- HVAC & windows/doors/skylights
- HVAC & other envelope measures
- Windows/doors/skylights & other envelope measures
- Energy efficiency (any measure category) & solar PV.

Relatively few projects included only water-related measures, such as low-usage toilets and showerheads, irrigation systems, and rainwater-related measures We categorized projects that include both water measures and energy measures by their energy measures. For example, we consider a project including both HVAC and water measures to be an HVAC project. We also established a water-only project category. We do not have data on water use over time but do report the energy use impacts of water-only projects in Appendix B.

Collectively, these measure categories account for all R-PACE projects in our data.

In the case of solar PV projects, we cross-checked the providers' classification with Berkeley Lab's Tracking the Sun dataset (Barbose and Darghouth 2018), which includes all residential grid-connected solar PV systems in the service territories of the utilities in this study. In general, the data on PV installations from PACE providers matched well with the Tracking the Sun data.

Figure 2 shows the distribution of projects by high-level measure category (energy efficiency, solar PV, energy efficiency measures and solar PV, water-only) in the full dataset of ~82,000 households.[23] We also show the distribution by measure category for the sample of households for which we were able to estimate reductions in grid electricity (~26,000 households; center

[23] By "full dataset," we mean all projects for which we successfully combined R-PACE assessment data with measures data at the household level. We were able to do this for just over two-thirds of the projects we received from CAEATFA. See Appendix A for a full accounting of our data assembly process.

bar) or gas usage (~16,000 households; right bar). For the full dataset, approximately 24% of households installed only solar PV, while 66% installed only energy efficiency measures, 4% installed both energy efficiency measures and solar PV and 5% installed only water efficiency-related measures. The distribution of projects by measure category is relatively similar between the full dataset and the sub-samples of households for which we estimate reductions in grid electricity and gas use.[24]

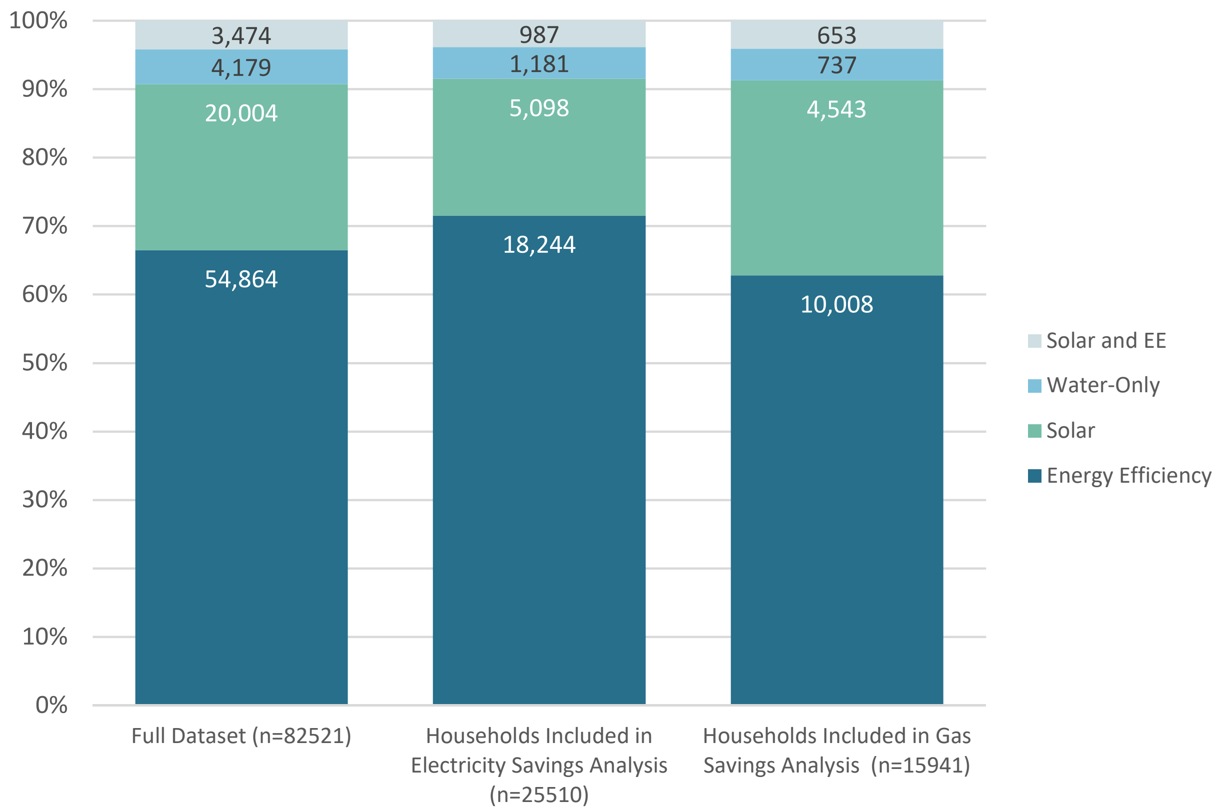

Figure 2. Types of measures installed in CA R-PACE projects

Note: The left bar shows the full dataset of R-PACE households, while the center and right bars show R-PACE projects for which we were able to estimate reductions in grid electricity and gas use, respectively, from billing data.

In Figure 3, we show summary statistics for households that only installed energy efficiency measures and provide a more disaggregated breakdown of the types of energy efficiency measures. Among households in our full dataset that installed only efficiency measures (~55,000 households), approximately 35% installed only HVAC measures, 25% installed only new windows and doors, 21% installed only other envelope measures, 5% installed new windows, doors and other envelope measures, 5% installed HVAC equipment and other envelope measures, 2% installed HVAC equipment, windows and doors, 1% installed water

24 When estimating total impacts across all R-PACE projects, we weight the observed reductions in grid electricity and gas use in our samples to account for differences between the full dataset and the sub-samples of households included in the grid electricity and gas use analysis. See section 4.4.

heating only, and 1% installed HVAC, windows, doors and other envelope measures. About 5% of efficiency projects installed otherwise uncategorized energy efficiency projects that we label "Other EE."

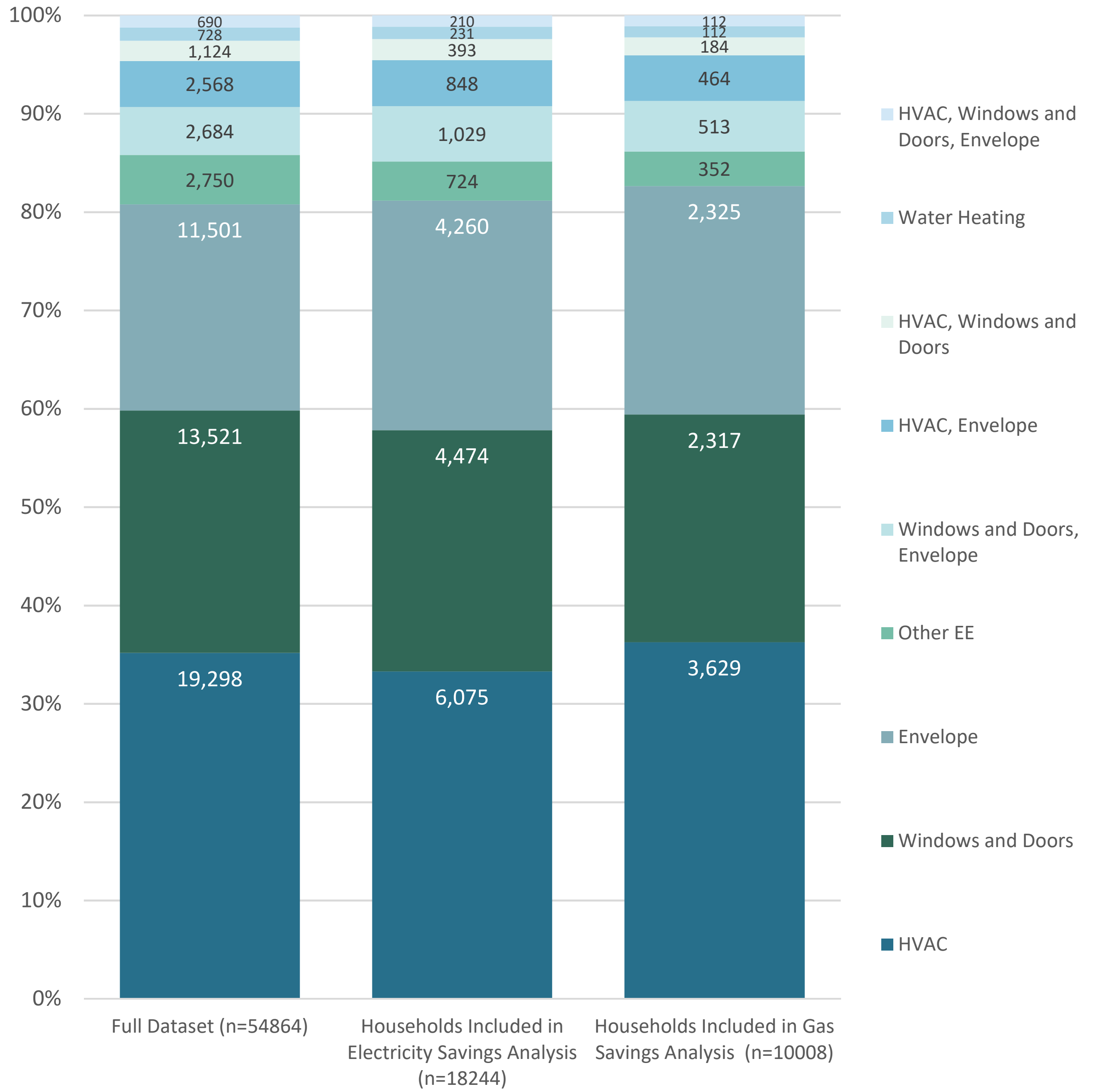

Figure 3. Types of energy efficiency measures installed in CA R-PACE projects

Note: The left bar shows the complete dataset of projects while the center and right bars show the sample of R-PACE projects for which we were able to estimate reductions in grid electricity and gas use, respectively, from billing data.

Figure 4 provides information on the average and median assessment amounts for households that installed only energy efficiency measures, solar PV only, and energy efficiency and solar PV.

We also show the inter-quartile range values (25th and 75th percentile) for assessment amounts for each type of strategy. These assessment amounts include the full cost of the financed measures as well as upfront fees and prepayment of capitalized interest.[25] Upfront fees vary by program and project, typically ranging from 6% to 11% of the project cost. Prepayment of capitalized interest varies depending on the timing of the assessment, typically accounting for 1% to 11% of the project cost.[26] Another difference between these principal assessment amounts and program costs that are typically reported by program administrators of utility customer-funded efficiency programs is that R-PACE finances the full cost of the measures, while utility program administrators often only report their administrative costs and incentives/rebates offered to customers to elicit participation in programs.

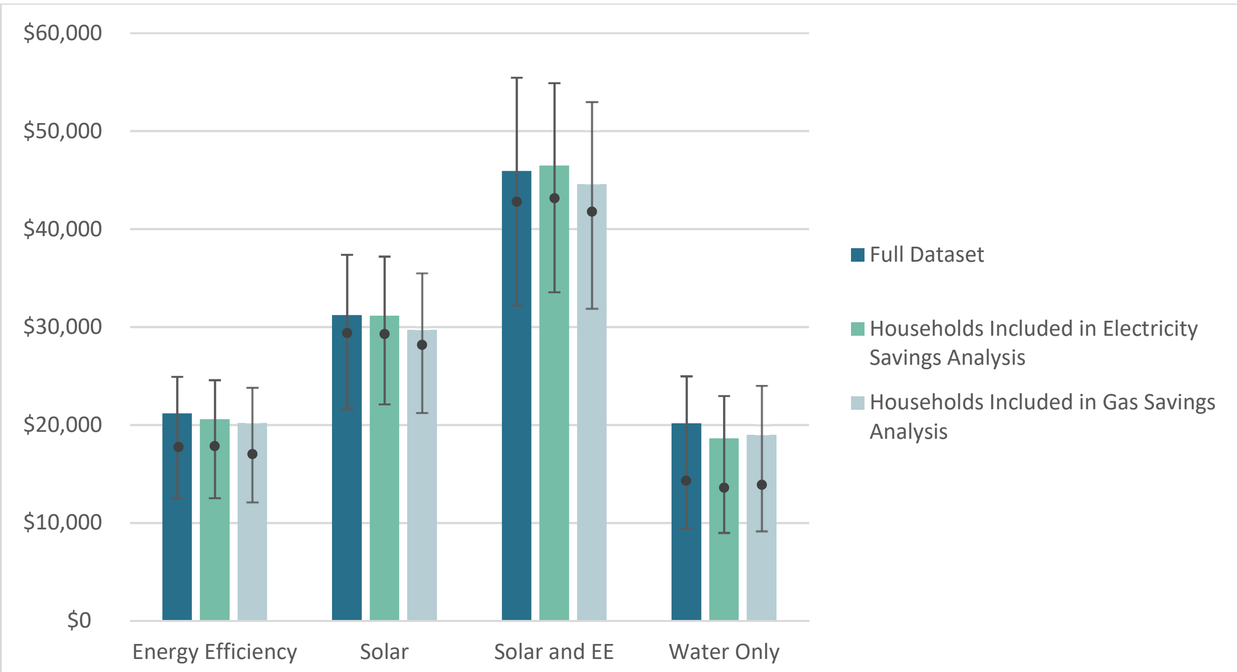

Figure 4. Average, median and interquartile values for assessment amounts for R-PACE households by type of measure

Note: For each measure category, the left bar shows the average assessment amount for the full dataset of projects while the center and right bars show the average assessment amount for R-PACE households for which we estimated electricity and gas savings, respectively, using billing data. The black circles indicate median values, and the brackets denote the interquartile range.

We observe that the average assessment values are comparable for the full dataset of households that installed various types of measures and the sub-set of PACE households for which we estimated reductions in grid electricity and/or gas use. For households in our full

25 For details on R-PACE fees and interest rates as of May 2018, see the Bay Area Renewable Energy Network's summary at https://63bce253-fb1e-40fd-9fe6-f6631fc8865f.filesusr.com/ugd/1ef210_4fd6abdd3ba745c1b829cf9e09ac6953.pdf

26 Per California bond law, prepayment of capitalized interest is charged from the closing date of the R-PACE assessment until September 2 of the year in which the assessment is first due. Depending on when an assessment is placed, the borrower will pay anywhere from two to 14 months of prepayment interest. This range of interest prepayment creates substantial variation in R-PACE annual percentage rates, even for similar projects within the same program, based solely on the timing of the assessment.

dataset, average assessment amounts were about $21,000 for households that only installed energy efficiency measures, $31,000 for households that only installed solar PV, $46,000 for households that installed both efficiency measures and solar PV, and $20,000 for households that only installed water efficiency measures. Median values are consistently several thousand dollars below average values for each measure category, indicating that average values are driven up by a small number of high dollar projects. The interquartile ranges are fairly wide. For solar projects, with and without efficiency, they are about 50% of the median value, but for efficiency and water only projects they are about 70% and 100% of the median value. These large interquartile ranges demonstrate considerable diversity in project assessment amounts in all project categories.

Figure 5 andFigure 6 provide more disaggregated information on assessment amounts by energy efficiency measure categories. Figure 5 shows average amounts for households in the full dataset and for those households for which we were able to generate results in our electricity and gas usage analyses. For households in the full dataset, the average assessment amount was about $18,000 for households that installed only HVAC equipment, $18,000 for households that installed new windows and doors, $22,000 for households that installed only envelope measures, $28,000 for households that installed, HVAC equipment, windows and doors, $34,000 for households that installed windows, doors, and envelope measures, and $41,000 for households that installed HVAC equipment, windows and doors, and envelope measures.

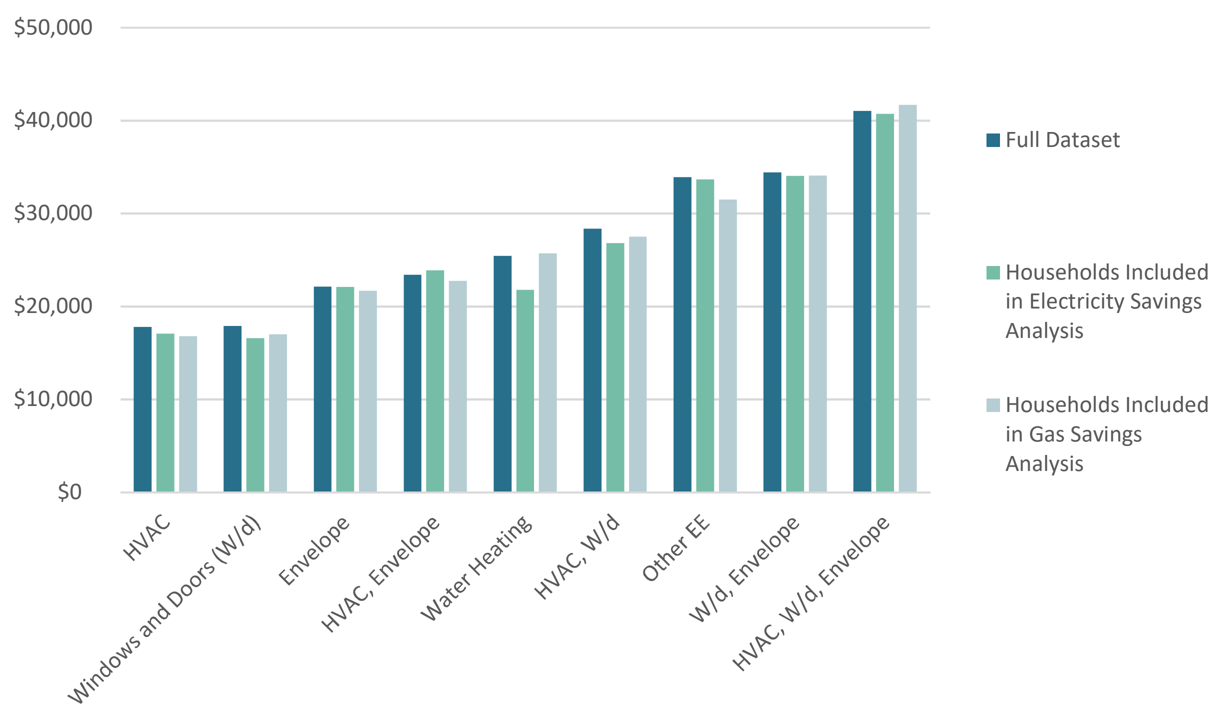

Figure 5. Average assessment amounts by energy efficiency measure category

Note: For each measure category, the left bar shows the average assessment amount for the full dataset of projects while the center and right bars show the average assessment amount for R-PACE households for which we estimated electricity and gas savings, respectively, using billing data.

Figure 6 shows averages, medians, and interquartile ranges of assessments among households in our electricity usage analysis (relationships in the other samples are similar). We again observe that median assessment amounts are several thousand dollars less than average amounts in each measure category. Interquartile ranges are largest for projects that include measures from multiple measure categories, which would logically feature more variation in measure costs.

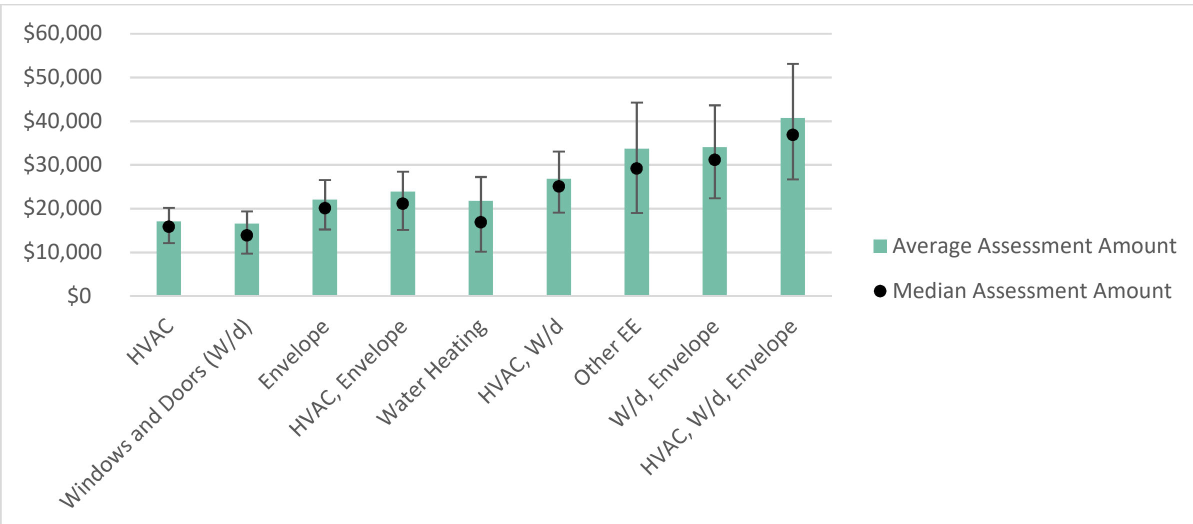

Figure 6. Average, median and interquartile range of assessment amounts for households in electricity savings analysis

Note: The brackets denote the interquartile ranges.

2.2 Utility electricity and gas usage data for R-PACE households

We received data on electricity and gas usage for R-PACE households from the four large California investor-owned utilities (IOU): Pacific Gas & Electric Company (PG&E), San Diego Gas & Electric (SDG&E), Southern California Edison (SCE), and Southern California Gas Company (SCG). PG&E and SDG&E are dual-fuel utilities from which we received both electric and gas data; SCE is electric-only; and SCG is gas-only.

In each case we gathered all data that the utility in question was able to provide on the list of R-PACE households that were submitted. We were not able to obtain data on every R-PACE household and fuel, for several reasons. First, some R-PACE households are not served by one of the four IOUs. This is most notably the case for households served by municipal electric utilities. For example, the Los Angeles Department of Water and Power provides electricity service to many households in Los Angeles County, while SCG supplies their gas service. As such, we could estimate gas usage impacts but not electricity usage impacts for most R-PACE households in Los Angeles County. A number of other cities in California also receive electric service from municipal utilities (e.g., Sacramento), and a few parts of the state have municipal gas service.[27] Second, the four IOUs were not able to match every requested address of a household that participated in a PACE program with its electricity and gas usage data. See Appendix A for more details on the number of households matched for each utility.

The energy usage data that we received differed in a number of respects across utilities and fuels:

- The temporal resolution of the data ranged from every 15 minutes (SCE) to hourly (PG&E electric, SDG&E electric, SCG) to daily (PG&E gas) to monthly (SDG&E gas).[28]
- We received account-level data from some utilities and premise-level data from others. In principle, accounts identify the customer paying for a given fuel at a given premise, while the premise identifies the location where accounts exist. We chose to conduct a premise-level analysis. As houses change occupancy, so do utility accounts, so an account-level analysis would have introduced breaks in metering time series and further restricted the number of households in our analysis. Moreover, the installed measures may influence energy usage even after a change in occupancy. Our use of a comparison group also helps guard against misinterpreting occupancy effects as project effects: comparison households may also have experienced occupancy-related impacts, and we would expect such occupancy-related impacts in the R-PACE group to be offset by similar impacts in the comparison group.
- Daily gas data collected from PG&E strongly suggest that their meters only log usage in increments of approximately one therm (e.g., 1.03 therm). During periods of limited gas use—for example, in the summer for many households—it was common to observe several days of zero consumption in the daily gas usage data, followed by a day of, for example, 1.03 therms, followed by several days with more zeros, followed by another 1.03 therms. This surely reflects the utility's data collection process rather than actual customer usage. This pattern in PG&E gas usage has implications for the quality of our weather model fits, as discussed in Section 3.6 and Appendix D. We did not observe this pattern in any of the electric data, nor in the hourly SCG or monthly SDG&E gas data.
- All utilities' data contained occasional data gaps, where no usage was recorded for a given time period. In some cases, consecutive days or weeks of the metering time series were missing entirely. These gaps occur at differing frequency across utilities, meaning that the proportion of accounts failing our data sufficiency checks (see section 3.2 and Appendix A) varied by utility. We address this differential attrition across utilities when aggregating our results (see section 4.4).
- Some premises, particularly those at the beginning or end of our study period, did not have the full year of pre-project or post-project energy usage data from utilities necessary to estimate savings, which led us to drop those premises from the analysis (see section 3.2). The share of premises affected by this issue varied across utilities. In

[27] See https://ww2.energy.ca.gov/maps/serviceareas/natural_gas_service_areas.pdf for natural gas utility service areas and https://ww2.energy.ca.gov/maps/serviceareas/Electric_Service_Areas_Detail.pdf for electric utility service areas.
[28] We received some daily gas data from SDG&E, but enough daily data was missing that virtually none of the households passed our data sufficiency checks. We relied on monthly data for SDG&E gas, which is collected via a different process.

particular, we could not estimate impacts for many of the earliest R-PACE assessments, which were concentrated in PG&E service territory. However, as project volumes were much lower in the early years, this represents only a small fraction of all R-PACE projects.

- The electric IOUs provided solar generation in different formats. PG&E provided hourly customer load, net of PV generation, whereas SCE and SDG&E provided hourly solar generation and customer consumption as separate readings. We collapsed these generation and delivery readings into a net consumption value that mirrored the PG&E structure and met the data requirements of our energy usage analysis model.

3. Approach to estimating changes in household energy usage

Section 3 describes our approach to modeling energy usage impacts for PACE households, including screens for data adequacy and model performance. Figure 7 summarizes our process at a high level. Appendix A details the evolution of our sample as we apply these screens.

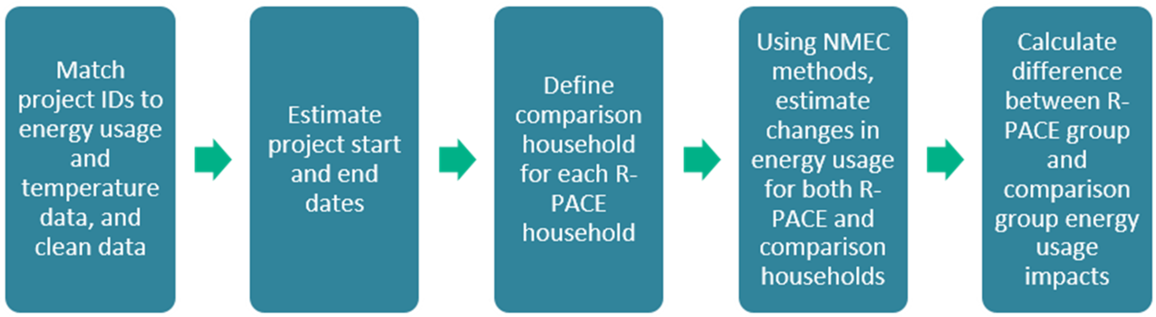

Figure 7. Overview of estimation approach

We estimate the energy impacts of R-PACE projects using normalized metered energy consumption methods (sometimes known as NMEC). These methods leverage household-level energy usage data, comparing energy usage before and after projects were implemented. They adjust usage to remove the effects of actual weather on energy consumption, and then project post-project usage into a "typical" weather year. Both models used for our calculations –the Princeton Scorekeeping Method (PRISM) and the Time-of-Week and Temperature (TOWT) model – are NMEC models.

We employ NMEC models in a manner largely consistent with emerging methodological consensus in California and elsewhere. The CalTRACK working group[29] has been developing standardized methods and software for using NMEC methods in California, driven largely by the usage of these models to estimate savings for pay-for-performance energy efficiency programs. We employ this software (as maintained by Recurve[30]) and generally implement our models (both PRISM and TOWT) in a manner consistent with CalTRACK recommendations. This approach also facilitates comparison with NMEC-based project impacts calculated for other California efficiency programs (see section 5.2).

3.1 Modeling of energy usage impacts

To estimate gas usage impacts, we employ the PRISM model (Fels 1986). The model leverages temperature and gas usage data in the year prior to the beginning of the project (the "baseline

[29] See https://www.caltrack.org/.
[30] See https://github.com/openeemeter/eemeter for Python code implementing the models.

period") and the year following completion of the project (the "reporting period"). Estimation of the model proceeds at the household level in four steps:

- First, we fit a regression of gas usage on historical heating degree days in the baseline period to estimate the pre-project temperature dependency of the household's gas usage.
- Second, we fit a regression of observed gas usage on historical heating degree days in the reporting period to estimate the post-project temperature dependency of the household's gas usage.
- Third, we use the reporting period normal-year heating degree days as inputs into the models produced in the first two steps. The model then estimates post-project usage in a normal weather year and estimates what usage would have been had the project not occurred, using heating degree days in a normal year.
- Fourth, we subtract weather-normalized gas usage during the reporting period from the baseline period to estimate changes in gas usage because of the R-PACE project.

We use a floating balance point method at the household level for choosing the base temperature for defining heating degree days, in keeping with PRISM model best practices (Fels 1986). Consistent with CalTRACK methodology, we also fit intercept-only weather models for each period and use whichever model has the higher adjusted r^2 for each household.[31]

Our method for estimating electricity usage changes employs a different statistical model, but follows a similar process of generating and differencing weather-adjusted baseline and reporting period usage. To estimate electricity impacts, we employ the time-of-week-and-temperature (TOWT) model (Price et al. 2011). TOWT leverages hourly (or more disaggregated) usage data to enrich the PRISM approach to weather-normalization. TOWT uses baseline usage patterns to define each hour of the week as "occupied" or "unoccupied" and employs this occupancy variable as an additional explanatory variable in its weather regressions. TOWT removes weather effects via a piecewise linear regression model, allowing the relationship between weather and temperature to be somewhat non-linear. Finally, following the CalTRACK implementation of TOWT, we estimate weather-dependency separately for each calendar month, rather than for the entire period.[32]

We use the TOWT model to analyze electricity usage over time because we have hourly electricity usage data from the three California electric IOUs (see section 2.2). We do not have hourly data from two of the three gas IOUs, so we use the PRISM model to analyze changes in gas usage over time. In order to test whether results between the two models are consistent

[31] Since the adjusted r^2 of an intercept-only model is zero, this model is only chosen if the adjusted r^2 of the HDD model is negative. This might be the case for non-gas-heated households.

[32] Specifically, we model weather-dependence using data from the month in question as well as the month immediately preceding and following that month, again per CalTRACK methods. Data from both shoulder months receive a weight of 0.5 in the regressions, while data from the month in question receive a full weight of 1.

and comparable, we also ran the PRISM model on a sub-sample of our electricity meters (see Appendix B).

3.2 Energy data cleaning prior to model estimation

We took steps to ensure that we had a robust time series of energy usage data to use in model estimation. We followed energy data cleaning recommendations made by CalTRACK, and also consulted Uniform Methods Project recommendations (Agnew and Goldberg 2017).

- *Checking for energy data sufficiency*. We excluded from the analysis any meter that was missing 10% or more of the meter data in any month of the analysis period. We also removed meters whose metering data did not span the baseline and reporting periods. For most utilities and fuels, relatively few meters failed this check. However, in two cases (PG&E electric and SCG gas), we lost substantial shares of our meters. Fortunately, we were still left with at least several thousand meters that passed these checks for each utility and fuel. See Appendix A for details by utility and fuel.
- *Removing projects with multiple reads*. We removed any household that had meter reads with the same time stamp but different usage readings. This affected fewer than 500 meters (0.3% of the full dataset), almost all of them electric.
- *Removing duplicated data*. Some meter data contained duplicated readings – the same usage and time stamp appearing multiple times in the usage time series. We removed the duplicated readings so that a premise only had one reading per time stamp (e.g. each hour or day, depending on the dataset).

3.3 Temperature data

We associated each of our households with a weather station that had both sufficient historical and typical weather year data. For each R-PACE household, we identified the closest station within 200km that was in the same climate zone as the household and met a data sufficiency screen. The screen that we implemented excluded any station for which 10% or more of the hourly readings in a month were missing for either the historical or typical weather year datasets. If the chosen station's temperature data fails those sufficiency screens, we move on to the next closest station. If there was no station within 200km of the R-PACE household that has sufficient data, we discarded the household.

Hourly temperature data for each weather station are from the National Oceanic and Atmospheric Administration (NOAA). As noted above, we use TMY3 for typical weather year data.

3.4 Defining project installation dates

To estimate pre-and post-retrofit energy usage in our models, we must define project start and end dates. Some energy efficiency projects might take a number of days or weeks to complete, and their impacts might begin to take effect before project completion. We assume that the impact of solar projects on household electricity usage takes effect on the date of system interconnection.

As discussed in section 2.1, we received project funding dates from CAEATFA, and in some cases received other dates from R-PACE program providers that more closely correspond to actual project completion dates. We were not able to obtain project-specific start dates. Through discussion of the project implementation, completion, and funding process with each provider, we defined program-specific time windows that we believe encompass and reflect the vast majority of project installations. For energy efficiency projects, these project installation time windows are generally two to four weeks in duration, meaning that we defined the project start date to be two to four weeks prior to the best project completion end date that we received. We do not consider the dates within these project installation time windows when estimating energy usage impacts: the baseline period is the year prior to the start date of the time window and the reporting period is the year following the end date of the time window.

Some solar projects in California were subject to interconnection delays during the time period studied, meaning that they would not have begun to generate electricity until well after their installation. Thus, in these cases, the project funding dates would not be meaningful. To address this issue, we used project interconnection dates from Berkeley Lab's Tracking the Sun dataset (see section 2.1). If these interconnection dates were too distant from our R-PACE project dates (more than 60 days before or 120 days after), we discarded the household out of concern that the installed solar PV system might not have been the same system financed through R-PACE.

3.5 Selection of comparison households

To account for non-weather factors that might influence energy usage over time, we select a comparison group of households. As our usage dataset contains only R-PACE households, we employ the rolling specification of the prior and future participants method to select our comparison households (Agnew and Goldberg 2017). Our selection algorithm proceeds at the meter level as follows:

1. For each R-PACE household, we identify other R-PACE households that meet all of the following criteria:
    a. Their project start and end dates are outside the baseline and reporting periods of the household being matched (such that their usage was not affected by projects installed during the time period of comparison);
    b. They are in the same zip code and utility jurisdiction at the household being matched (and therefore may be subject to similar factors affecting energy usage, including prices and economic factors);
    c. Their usage (for the fuel in question) and weather data pass our data quality and sufficiency checks (see section 3.2); and

d. They did not have solar PV installed before or during the baseline and reporting periods of the household being matched (because the presence of PV significantly alters the level and pattern of electricity usage in households).

2. Of these candidates, we selected the household that had the most similar usage (electricity or gas, as appropriate) during the matched project's baseline period as measured by the minimum sum of absolute differences in monthly consumption of that fuel over the R-PACE household's baseline period. This prioritizes comparison households with similar monthly consumption to the matched household.

We ran the selected comparison meters through the appropriate model (i.e., TOWT for electricity, PRISM for gas) using the project dates of the matched household. The change in grid electricity or gas use calculated represent how consumption in the comparison household changed over the same time period due to non-project factors. The subtraction of the comparison household's change in usage from the matched household's change in usage, therefore, results in an estimate of the reduction in grid electricity or gas use attributable to the R-PACE project.

For some meters, no candidate comparison meters meet all the criteria in step 1 above. We exclude these unmatched meters from our results. We are able to identify comparison meters for about two-thirds of our electric accounts and more than 80% of our gas accounts. Appendix A details how this and other exclusions affect our sample size.

3.6 Goodness-of-fit screens for household energy usage

Given that weather adjustment is core to the PRISM and TOWT modeling methodology, we implement a screen for the quality of that fit. We base that screen on the coefficient of variation of the root mean squared error (CVRMSE) of the baseline model weather fit for each household. Unfortunately, there is no hard-and-fast guidance as to an appropriate CVRMSE screen for a portfolio-level study such as ours. Moreover, using data with higher temporal frequency, as we do where possible, results in higher CVRMSE. We reviewed discussion of this issue during the CalTRACK methods development,[33] and follow the recommendation for a "permissive" CVRMSE value of between 0 and 1 in a portfolio setting. In our main results, we exclude all meters whose baseline CVRMSE is outside this range. This restriction excludes about 1% of households, relative to the full dataset. It has very little impact on our electricity estimates, but has a somewhat larger effect on our gas estimates. Appendix C details the sensitivity of our results to this goodness-of-fit screen. Appendix D presents goodness-of-fit statistics, including CVRMSE, from our weather model fits.

[33] See https://www.caltrack.org/project-updates/archives/03-2018

4. Results: Estimates of energy usage impacts for R-PACE households

This section summarizes the energy usage impacts that we calculated, disaggregated by utility service territory (Section 4.1), California climate zone (Section 4.2), and measure category (Section 4.3). In Section 4.4 we aggregate our results to estimate energy use impacts across all California R-PACE projects in the study period.

These energy use impacts reflect the difference in usage changes between the matched R-PACE and comparison group households (sometimes known as a "difference in differences" approach). In aggregate, the average change in electricity usage for comparison group households was less than 1.5% for each measure category (see Appendix F for separate estimates of energy impacts for R-PACE and comparison households).

4.1 Usage impacts by utility

Table 1 shows our estimates of the average reduction in grid electricity[34] and gas use for R-PACE households in each measure category for each California IOU.

Table 1. Average R-PACE project impacts by California IOU

			Electric		Gas	
Utility	Measure category	Fuel	Reduction in grid electricity use (%)	Sample size	Reduction in gas use (%)	Sample size
PGE	EE	Electric	4.8%	2,491	7.2%	3,447
SCE			2.7%	12,668	N/A	N/A
SCG			N/A	N/A	2.1%	4,471
SDGE			-0.4%	3,085	3.0%	2,090
PGE	Solar	Electric	68.7%	1,313	2.0%	2,321
SCE			66.0%	1,574	N/A	N/A
SCG			N/A	N/A	-2.9%	831
SDGE			83.1%	2,211	-3.1%	1,391
PGE	Solar and EE	Electric	67.5%	125	2.6%	176
SCE			57.1%	368	N/A	N/A
SCG			N/A	N/A	5.3%	154
SDGE			83.3%	494	3.0%	323

34 We use the term "reduction in grid electricity use" here because it includes both electricity savings from energy efficiency measures and avoided grid electricity consumption due to on-site PV generation. We study the change in household load net of PV generation, and (for PV homes) cannot separate avoided grid consumption from efficiency savings, since both reduce net load.

We would highlight key results as follows:

- For R-PACE households that installed solar PV, reductions in grid electricity use ranged between 66-83% of electricity usage across the three IOUs. Not surprisingly, average reductions in grid electricity use were quite high for these households (7300-8800 kWh per year). SDG&E solar projects generate more electricity on a household percentage basis than those in the other utilities, likely due to a combination of high insolation and lower average pre-project household usage due to low cooling loads. For these homes that installed solar PV, gas usage increased modestly (3%) for homes located in SoCal Gas and SDG&E service territory after installation and declined modestly (2%) for homes located in PG&E service territory. In general, solar projects have little impact on gas consumption, though the impacts vary across utilities in a manner for which we have no immediate explanation.
- In PG&E and SDG&E service territories, R-PACE households that installed both solar PV and energy efficiency measures saw larger average reductions in grid electricity use that exceeded those homes that just installed solar PV. However, in SCE territory, reductions in grid electricity use were about 10% lower in homes that installed solar PV and efficiency measures compared to PV-only households (57% vs. 66% savings). This result is counter-intuitive and surprising. Given that we find this result only in SCE territory, it may be explained by particular characteristics of these projects. All the joint EE/PV projects in SCE territory were installed by a single R-PACE program. While we cannot test this given our data, it is possible that many of these 368 projects were done by a single R-PACE contractor that may have installed smaller-than-typical PV systems. For this group of homes that installed both solar PV and efficiency measures, we observe average reductions in gas use at households in all three service territories, ranging from 2.6% at PG&E to 3% at SDG&E and 5.3% at SoCal Gas.
- In analyzing savings for households that installed energy efficiency measures, it is important to note that the vast majority of R-PACE energy efficiency projects affect only space conditioning energy usage (see Section 2.1), and that the majority of California households are heated by natural gas.[35] For R-PACE households that only installed efficiency measures, electricity savings ranged between 3 to 5% for households located in SCE and PG&E service territory while average electricity usage increased slightly for SDG&E R-PACE customers (0.4%). Many homes in coastal areas of California enjoy very mild summers and do not have air conditioning. In particular, SDG&E's service territory is largely coastal, making it difficult to save electricity via upgrades to space conditioning equipment. The negative electricity savings in SDG&E territory may also reflect installation of air conditioning equipment in households that previously did not have air

[35] Most R-PACE participating households are single-family (Deason et al. 2020). In 2009 (the most recent data available), 86% of California single-family homes used natural gas as the main source of space heating and only 2% used electricity (Palmgren et al. 2010). 8% used other fuels and 4% were not heated. In 2009 40% of California households were not air-conditioned (see https://www.eia.gov/consumption/residential/reports/2009/state_briefs/pdf/ca.pdf and https://www.eia.gov/consumption/residential/data/2009/hc/hc1.11.xls). Air conditioning saturation varied dramatically by climate zone, from less than 20% in the San Francisco Bay Area, to around 50% in coastal urban areas in southern California, to over 90% in many inland areas (Palmgren et al. 2010). These air-conditioning numbers describe all households, not single-family households; saturation levels are likely slightly higher in single-family households.

conditioning (see section 4.3.1). Average gas usage declined by 2%, 3% and 7% at R-PACE households that are located in SoCal Gas, SDG&E and PG&E respectively. PG&E's service territory is in northern and central California, where winters – while still mild by national standards – are cooler. Consistent with this, R-PACE energy efficiency projects save more gas usage on average in PG&E territory (7%; 42 therms).

Understanding energy impacts of energy efficiency relative to solar PV

Our metered data analysis shows much larger reductions in grid electricity use from solar PV than energy efficiency projects. Solar PV projects also cost more, but the cost difference is nowhere near as large as the difference in our energy results. It might seem tempting to conclude that solar PV offers greater return on the dollar than energy efficiency. We caution against this oversimplified conclusion.

It is not appropriate to compare the total cost of energy efficiency improvements to the cost of solar PV. Households need building envelopes and HVAC technologies to meet basic thermal needs, and will not go without these products when they are needed. For example, data show that the majority of R-PACE HVAC projects occur at or near the end of the useful life of the equipment being replaced (Research Into Action 2017). (This is very likely true for other EE programs as well.) These homeowners will spend money on a new HVAC unit irrespective of R-PACE; the question is whether they spend more money and get a more efficient system than they would otherwise, thereby saving on energy use. It is common to only consider the *incremental* cost of a more efficient measure (above a code-minimum unit) relative to the incremental savings that measure generates. We do not have the data to support this calculation, which is why we declare it to be out of scope. For solar PV, considering reductions in grid electricity demand relative to the full system cost is sensible.

One might also want to consider differing levels of incentives available for different technologies. Most residential solar PV systems qualify for the Investment Tax Credit, which reduces system costs by 30% if the household can fully monetize the credit. While energy efficiency measures often qualify for incentives, those incentives rarely cover such a large fraction of project costs. Determining the appropriate level of such incentives for different technologies is beyond the scope of this report, but we note that total project costs borne by other parties (and therefore not included in R-PACE assessments) are likely somewhat higher for solar PV.

4.2 Usage impacts by California climate zone

Figure 13 maps climate zones as defined by the state of California.

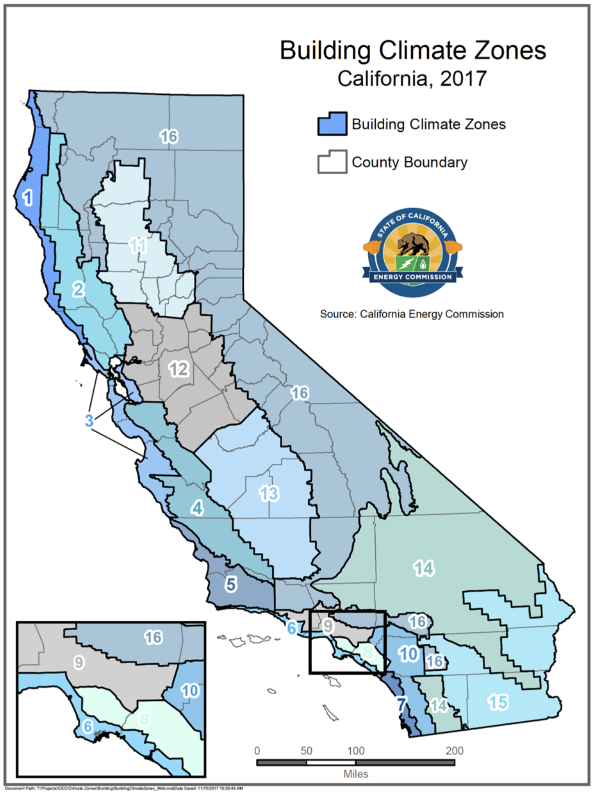

Figure 8. California climate zones

Figure 9 shows our estimates of the average R-PACE project impacts by California climate zone for households that installed various types of energy efficiency measures. Percentage electric savings from energy efficiency projects are highest (4 to 13%) in non-coastal climate zones (e.g., 4, 12, 13, 14, and 15–Central Valley, Sierra Nevada region, and inland desert areas) which experience warmer summers and therefore higher cooling loads.[36] Gas savings are highest in more northern or more inland zones (e.g., 3, 4, 12, 13, and 14—the greater Bay Area, northern Central Valley, and Sierras). Zone 3 is coastal but far enough north to require more significant space heating in the winter (4% savings); zones 4, 12, 13, and 14 are far enough inland that they also have significant heating demand (6 to 11% average gas savings). (Zone 15 is essentially a desert environment, warm enough to not require much space heating despite being inland.)

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[36] Note that the savings for projects in various climate zones include some projects that installed new central AC in households that had previously lacked such units, or installed a gas furnace in a home that had previously used an electric space heater or wood stove. We might expect that a greater share of R-PACE projects would include installation of new HVAC technologies, rather than replacement of existing units, in climates where heating or cooling demand is low and therefore many homes would not have previously had these technologies. Such effects likely explain the negative savings for electricity in climate zone 7 (a temperate coastal Southern California climate zone where air conditioning penetration is low) and for gas in climate zone 15 (a hot desert climate where minimal heating is necessary). We discuss this issue in greater depth in section 4.3.1 below.

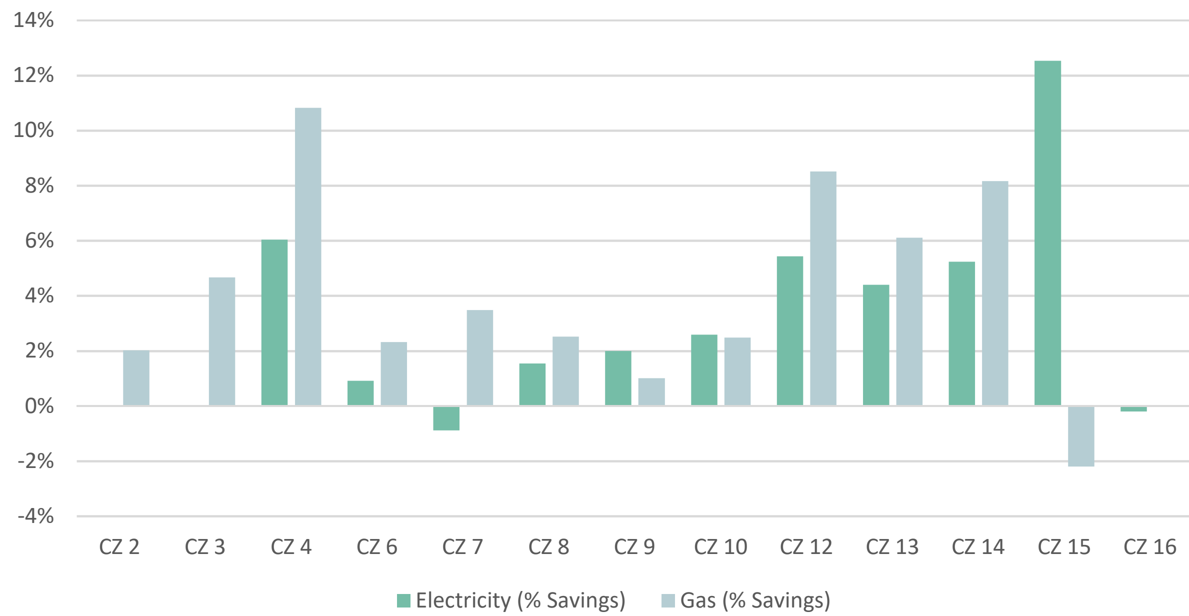

Figure 9. Energy efficiency project impacts by California climate zone

Note: We do not include results in climate zones where we had results for less than 100 households for a given fuel. This includes climate zones 2 and 3 for electricity, and climate zone 16 for gas. Climate zone 1 did not have enough households with results for either fuel.

In Figure 10, we show reductions in grid electricity and gas use for households that installed solar PV. Electric impacts for homes that installed solar PV differ somewhat in percentage terms by climate zone (64 to 87% reduction in consumption of off-site utility-generated electricity per household). This is likely due to both variation in insolation and cooling-related differences in baseline consumption. For example, San Diego (zone 7) has high insolation and relatively low cooling demand, and has the highest percentage reductions in grid electric use (87%). Solar PV gas impacts are near zero.

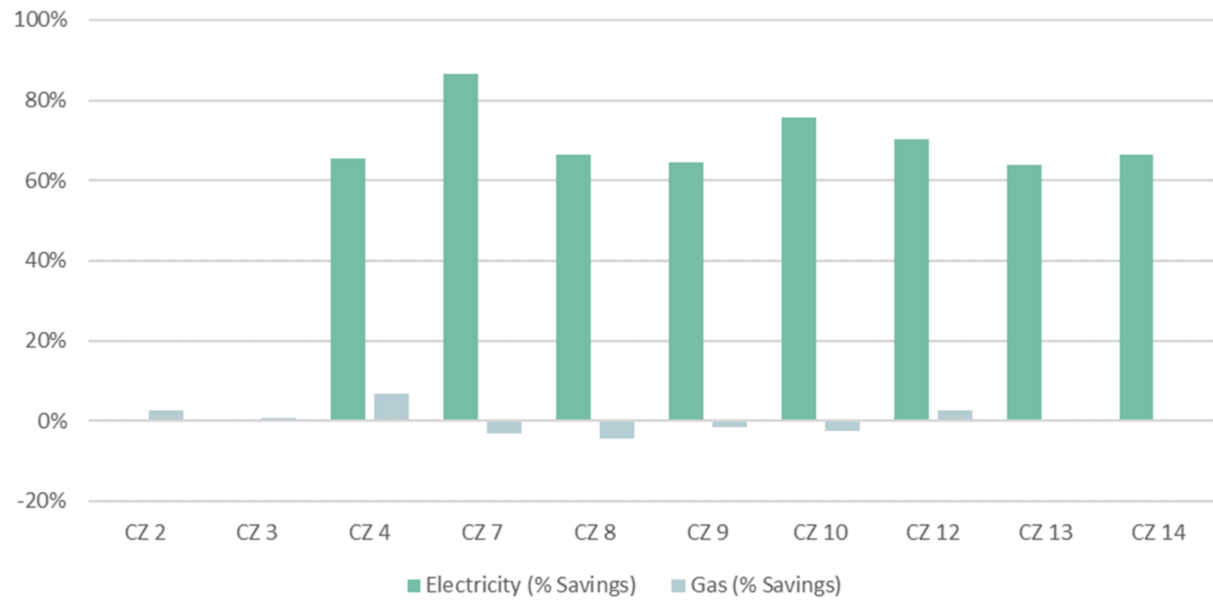

Figure 10. Solar PV project impacts by climate zone

Note: We do not include results where fewer than 100 meters were successfully run in a given climate zone for a given fuel. This includes climate zones 2 and 3 for electricity and climate zones 13 and 14 for gas. Climate zones 1, 5, 6, 11, 15, and 16 did not have enough households with results for either fuel.

4.3 Usage impacts by energy efficiency measure category

Figure 11 shows average usage impacts by energy efficiency measure category. We would highlight key results as follows:

- Measure categories relating to the building shell (envelope, windows and doors) save on both gas and electricity, as would be expected. Average electricity savings range between 3-5%, with gas savings ranging between 3-6%.
- Most water heaters in California use natural gas, so water heater savings are on the gas side.[37] Average gas usage declined by about 12% for customers that installed more efficient water heaters or other related measures.
- In general, multi-category projects have higher savings, especially for gas. For example, households that installed HVAC, envelope measures, and new windows/doors reduced average electricity usage by 6% and average gas usage by 10%.
- Results for HVAC-only projects require careful interpretation and thus we have done a deeper dive in section 4.3.1.

[37] Per KEMA Inc. (2010), 88% of California single-family households had gas water heaters in 2009 and only 5% had electric water heaters. The increase in electricity usage from water heater projects that we estimate might reflect some switching from gas to electric water heaters, which we cannot directly observe in the data.

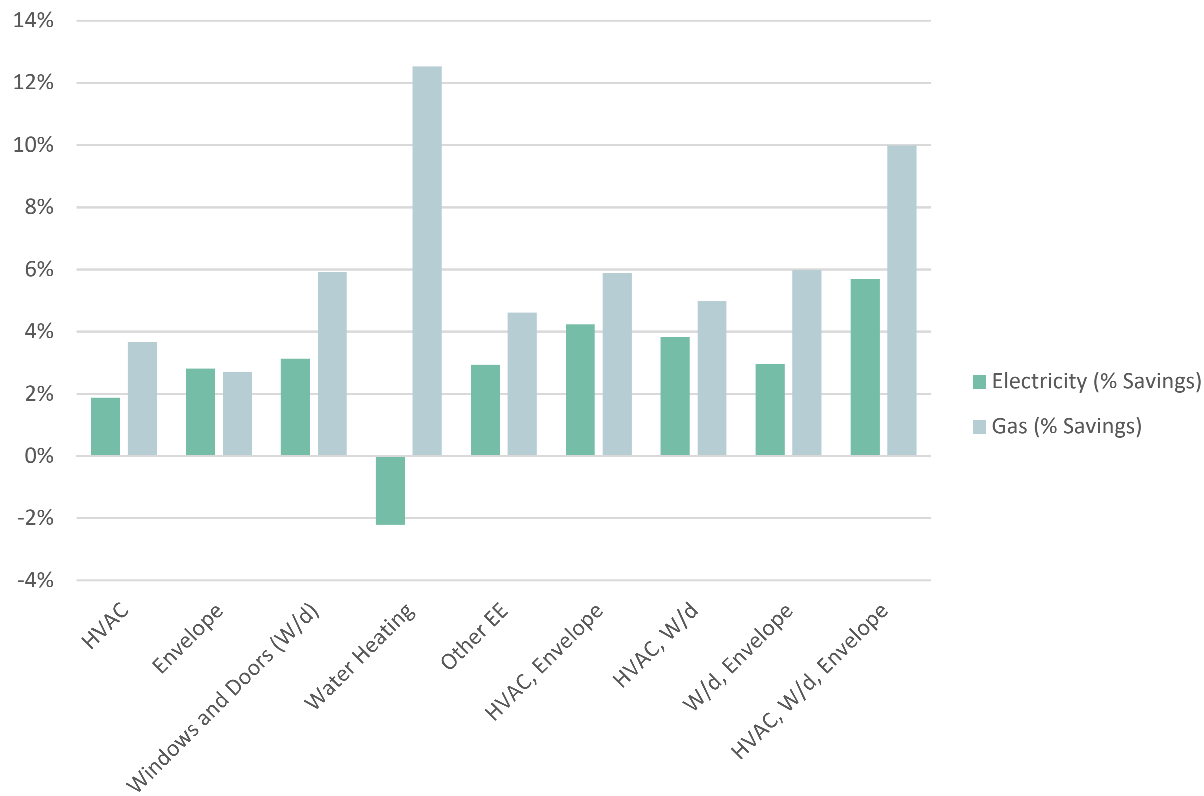

Figure 11. Energy efficiency project impacts by measure category

4.3.1 HVAC project savings

In the vast majority of cases, the measure data we received from PACE providers (see section 2.1) do not establish whether the HVAC projects in our data installed new heating or air conditioning equipment, both, or neither (e.g., household installed new duct sealing or new whole house fans). Moreover, an unknown fraction of projects that installed HVAC equipment represent households that did not have space cooling equipment (A/C) or central heating systems prior to installation. The baseline condition of some R-PACE households may have been far different than households served by utility efficiency programs that typically replace existing HVAC equipment (e.g., changing out existing A/C equipment for new higher efficiency equipment). This may be a larger issue in California's mild climate than in most parts of the U.S.[38] In the case of heating, some R-PACE households may be installing new gas- or electric-heating equipment that is replacing or supplementing wood or propane heating.

[38] As of 2009, about 40% of California single-family households did not have air conditioning and about 14% did not have heating systems, leaving room for penetration of new systems. Nationwide, only 4% of households are not heated and only 17% lack air conditioning. See https://www.eia.gov/consumption/residential/reports/2009/state_briefs/pdf/ca.pdf and https://www.eia.gov/consumption/residential/data/2009/hc/hc1.11.xls. The rates of unheated homes are lower among single-family homes in California (KEMA Inc. 2010) and quite possibly nationwide as well.

As such, the average result for each fuel is based on an agglomeration of projects expected to reduce usage of that fuel (e.g., a furnace replacement's impact on gas usage); projects expected to have little impact on that fuel (e.g., an air conditioning project's impact on gas usage[39]); and projects expected to increase usage of that fuel (e.g., a new gas-fired furnace installed in a house that did not have gas heating equipment). Thus, our HVAC results should not be interpreted to mean that the average air conditioning replacement reduced electricity use by only 4%, or that the average gas furnace replacement reduced gas usage by only 2% (see Figure 11).

Figure 12 and Figure 13 show distributions of impact estimates for electricity and gas usage for R-PACE project and comparison households that installed HVAC only measures. Note that households with negative savings in Figure 12 or Figure 13 *increased* electricity or gas usage respectively after the R-PACE project was installed. Households with positive savings *decreased* their electricity or gas usage. The distribution of "impacts" for comparison households (shown in gray shading)—which did not implement projects in the time window analyzed—gives a sense of the natural variability of year-on-year household energy usage due to non-project factors, even after we have normalized for the effects of weather.

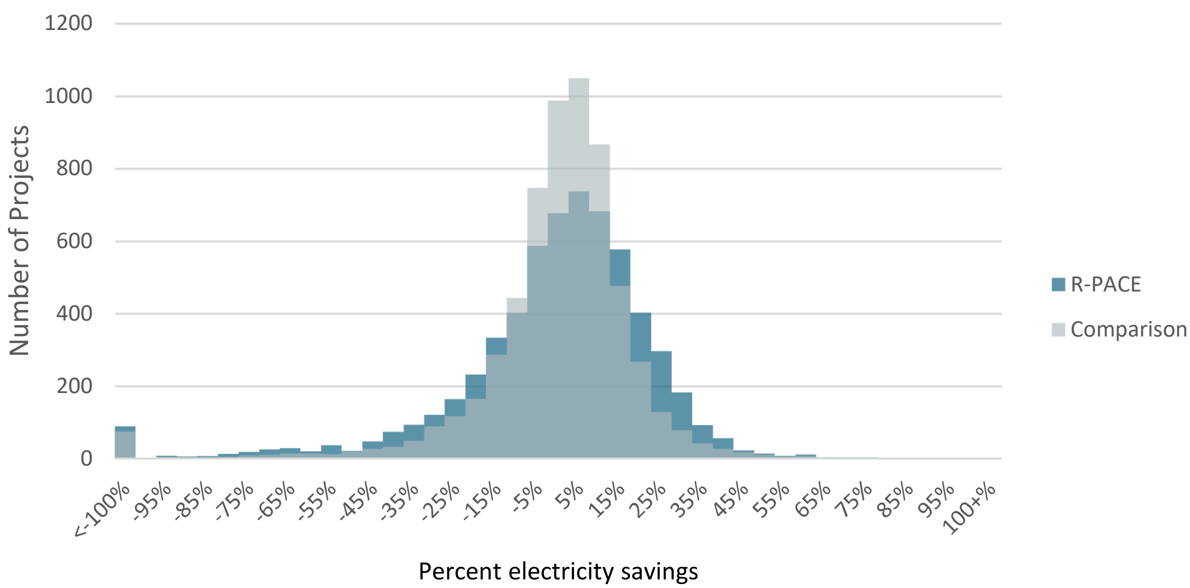

Figure 12. Distribution of household electricity savings from HVAC projects

Note that positive numbers represent savings (reductions in electricity use); negative numbers are negative savings (increases in electricity use).

Figure 12 and Figure 13 show that a greater share of comparison HVAC households than R-PACE HVAC households had energy impacts that were within 10% of baseline usage than project households, which is the expected finding. Specifically, in our electricity impacts analysis of

[39] It is plausible that AC projects, especially installations, increase gas use, as they would be expected to raise heating demand on days when both heating and AC are in use at different times. The same might be true of gas furnace projects and electricity use. On the other hand, gas furnaces may decrease electricity use in the form of secondary space heating.

HVAC-only households, 67% of comparison households had changes in usage between -10% and 10% of baseline usage, whereas only 50% of R-PACE households had usage changes in that range. Note also that a greater share of R-PACE HVAC households had positive savings (to the right of zero reflecting *decreased* usage after the R-PACE project was installed). 27% of R-PACE households saved more than 10% of baseline usage as compared to 18% of comparison households. However, a higher percentage of R-PACE households also have "negative savings" (energy impacts to the left of zero, which means that energy usage *increased* after the R-PACE project). 22% of R-PACE households increased usage by 15% relative to their baseline usage ("negative savings") compared to only 15% of comparison households. We find similar patterns among HVAC-only households in our gas analysis.

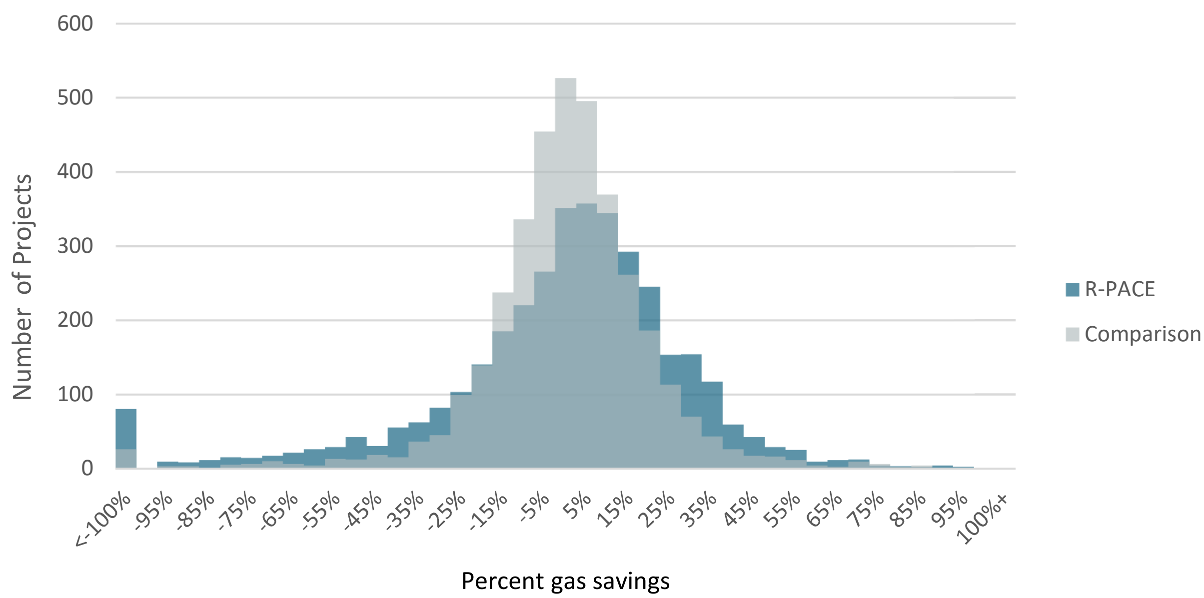

Figure 13. Distribution of household gas savings from HVAC projects

Note that positive numbers represent savings (reductions in gas use); negative numbers are negative savings (increases in gas use).

The greater share of project households on the far left side of the distribution (e.g., negative savings exceed 15%) suggests that these projects include installation of a new furnace or air conditioning equipment in households that did not have this type of equipment prior to the R-PACE project. Similar histograms for other measures, such as envelope measures, do not show higher shares of project households on the left-hand side of the distribution. We were not surprised by this finding, as R-PACE providers had flagged HVAC installations as a potential issue when furnishing the data for this study.

To gain greater clarity on HVAC impacts, we take two approaches. First, we have enough confirmed gas furnace projects to calculate results from them. This subset of projects may include both gas furnace installations and replacements, but excludes projects that are electricity-focused and would therefore have little impact on gas usage. Second, we use algorithmic method to infer which HVAC projects may be installations, then exclude them from our results to assess their impact. We discuss each approach below.

For the first approach, we were able to identify over 300 confirmed gas furnace projects in our dataset, enough to provide a reasonable estimate of impacts.[40] These gas furnace projects may include new installations as well as replacements of existing furnaces. Estimated impacts from this set of gas furnace/HVAC projects are different than from the estimated impacts of the average HVAC-only project (where we do not know what type of HVAC equipment or controls or measures were installed). On average, the gas furnace projects reduced natural gas use by 10% while electricity use decreased by 7%. These electric savings might result from reductions in electric space heating, either due to a switch from electric to gas heat or reductions in the usage of secondary electric heat in gas-heated homes. These gas furnace projects demonstrate savings that are larger than those from HVAC projects in general, despite potentially including some furnace installation projects. We cannot be sure, however, whether the share of furnace installations (as opposed to furnace replacements) among these projects is similar to that in the full dataset.

For the second approach, in an attempt to parse installations of new HVAC units from replacements of existing units with new units, we focus on seasons and times of day that are most likely to reveal the actual context and baseline conditions underlying installation of HVAC projects. We examine estimated electricity and gas use impacts at those times. Specifically, we examine each HVAC-only project's electricity usage impact from noon to midnight in the summer months of July through September. If weather-normalized electricity use *increases* by more than 15% during these hours, we infer that the project includes a new air conditioning installation. If weather-normalized electricity use *decreases* by more than 10% during these hours, we infer that the project includes a replacement of existing air conditioning equipment. Projects with usage changes that fall between these values are ambiguous or may not have included a cooling-related efficiency measure at all (e.g., only measures affecting gas usage were installed). For natural gas, we apply similar logic to all usage during the winter months of December to February. An *increase* in gas consumption of 25% after the R-PACE project was completed is our threshold for inferring installation of a new gas furnace in a household that previously did not have gas central heating equipment. If gas usage for HVAC-only projects *decreased* by at least 10%, then we assume that a new gas furnace replaced existing gas-fired equipment.[41]

[40] While we would have liked to undertake a similar analysis of confirmed air conditioning projects, we could not affirmatively identify enough air conditioning projects to provide an estimate of their impacts.

[41] We define these cutoffs from the data underlying Figure 12 and Figure 13. We choose cutpoints near the parts of the savings distributions where the share of project households begins to be greater than the share of comparison households, suggesting that values at and beyond these cutpoints are more likely to reflect project effects than other factors. Figures 12 and 13 show full-year results. By focusing on seasonal time periods where HVAC effects ought to be more pronounced, we are more confident that the observed effects are related to installed measures in projects. For example, we guard against mis-identifying electric heat impacts as air conditioning impacts. Note that we restrict our inquiry to air conditioning and gas heat, so are not considering electric heat (such as via an air-source heat pump).

Figure 14 shows annual savings estimates for HVAC-only projects categorized in this manner, along with the sample sizes of each inferred category. The data suggest that many R-PACE HVAC-only projects may be installations of new equipment rather than one-for-one replacement of existing types of HVAC equipment. For example, among HVAC-only households for which we estimate electricity savings, 37% (2253) of projects are categorized as new AC installations and 37% of projects (2233) as AC replacements, while 26% of projects (1589) are categorized as unknown. Among HVAC-only households for which we estimate gas savings, 22% (786) of projects are categorized as new gas furnace installations and 33% of projects (1217) as gas furnace replacements, while 45% of projects (1630) are categorized as unknown. Our assumption is that non-classified projects for heating are cooling projects, and vice versa. We view this effort to characterize the underlying baseline condition of HVAC projects as exploratory, yielding approximate distributions, because our algorithm likely mischaracterizes some projects.

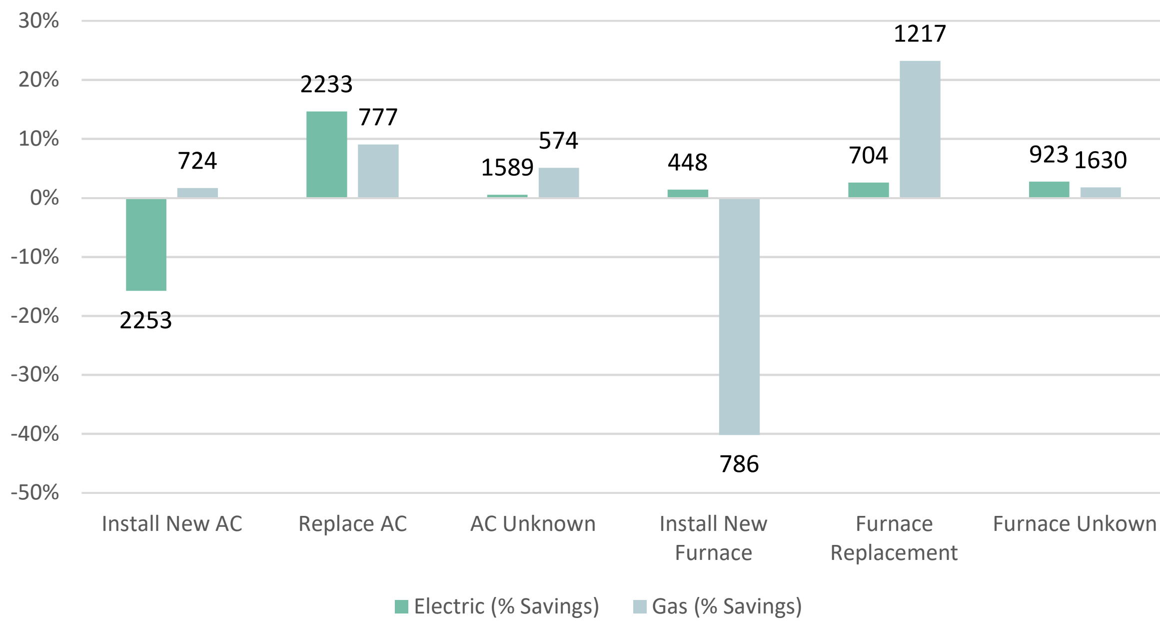

Figure 14. Distribution of percent household gas savings from HVAC-only projects

Note: Numbers above or below each bar show the sample of households inferred to be in that category. Sample sizes for the "other fuel"—gas in the case of the cooling classifications, electricity in the case of the heating classifications—are smaller because some "other fuel" meters failed one of our checks or were missing data altogether.

Among projects we classify as A/C equipment replacement, average annual electric savings are 15% (see Figure 14). Among projects we classify as heating equipment replacement (e.g. furnaces), average annual gas savings are 23%. For the projects that we classify as having installed new equipment in households that did not previously have that equipment, usage *increased* significantly—by 16% on average for inferred cooling equipment installs and by 40% on average for inferred heating equipment installs (e.g. furnaces). In general, the impact of inferred new cooling equipment projects on gas use and of inferred gas heating projects on electricity use are small (1-2%), as would be expected.

4.4 Usage impacts across the R-PACE portfolio

In order to estimate average usage impacts from all R-PACE projects, we calculate a weighted average of the estimated impacts by utility. Weighting by the sample size of R-PACE projects installed in each utility service territory is important because we lose more meters due to data sufficiency issues from some utilities than others (see section 3.2 and Appendix A). Table 2 summarizes the average energy impacts by type of project.

Table 2. Average reductions in grid electricity and gas use by type of project in California R-PACE programs

Measure category	% reduction in grid electricity use	% reduction in gas use
Efficiency	2.9%	3.5%
Efficiency without inferred new HVAC installations	4.9%	6.0%
Solar	68.9%	-1.7%
Solar and EE	63.6%	4.3%

Our results suggest that, on average, an R-PACE-financed energy efficiency project reduces a household's electricity usage by about 3% and gas usage by about 4%. If we exclude those energy efficiency projects that we infer to be installations of new HVAC equipment (rather than replacement upgrades of existing equipment), then average household savings increase slightly, to 5% for electricity and 6% for gas. For those projects that installed solar PV only, the reduction in grid electricity usage averaged 69% across households while average gas usage increased slightly (1.7%).

We can provide a rough estimate of the impact of all residential projects that have utilized PACE in California since its inception.[42] Through December 31, 2019, CAEATFA data show 215,522 R-PACE financings.[43] Using the weighted-average savings per project from Table 2, as well as the split between energy efficiency, solar PV, water, and joint EE/PV projects from our full dataset (Figure 1), we estimate that these projects would generate reductions in grid-tied electricity consumption of 506 GWh (506 million kWh) in a normal weather year.[44] These

[42] To provide this estimate of energy impacts from all R-PACE projects in California, we assume that savings in our sample of projects are representative of R-PACE projects that were implemented in service territories served by municipal utilities, and of R-PACE projects that were implemented at later dates.

[43] This number is a slight undercount of the true total of all PACE financings for at least two reasons. First, CAEATFA does show some data on financings in place prior to July 2014, but does not track them in detail, and a financing that was prepaid prior to July 2014 would likely not be reflected in the data. Second, some providers did not enroll early projects in the CAEATFA loss reserve, and they are therefore not included in CAEATFA's totals.

[44] We assume that the distribution of projects by retrofit strategy (e.g. solar, efficiency, solar+efficiency) for the full dataset is representative and that these savings estimates by type of measure can be applied to the entire population of R-PACE financings (~203,000 households).

reductions in electricity use are mostly attributable to projects that installed solar PV; non-PV projects collectively reduce electricity consumption by 33 GWh in a normal weather year. We estimate that R-PACE projects would generate total first-year gas consumption reductions of 2 million therms. Total program reductions in grid electric use are equivalent to the electricity consumption of about 74,000 California households (including both efficiency and PV generation) and the gas consumption of about 4700 California households.

To develop an estimate for savings over the expected lifetime of measures installed in residential PACE projects in California, we used project lifetimes derived from our Cost of Saving Energy database (Hoffman et al. 2018). We calculate an average project lifetime for various types of efficiency measures and solar PV installations using information provided by program administrators on lifetime and first-year savings. We estimate an average R-PACE project lifetime of 19 years.[45] We then multiply the average first-year reductions in grid electricity and gas use for each of the project measure categories by measure lifetimes for all R-PACE households in California, which yields our estimate of 9.6 TWh in lifetime avoided consumption of grid electricity from R-PACE projects through the end of 2019. PACE households that installed energy efficiency measures account for about 0.7 TWh of these savings. Total lifetime gas savings from R-PACE projects are about 37 million therms through the end of 2019. These estimates of lifetime electricity and gas savings provide a first-order sense of total R-PACE program impacts in California.[46]

[45] New A/C equipment units typically have shorter lives than gas furnaces, while other efficiency measure categories (generally envelope-related such as windows, doors, insulation) are common across both fuels. Solar PV systems typically have lifetimes of 20 years or more, making the average measure lifetime across the two fuels comparable.
[46] These measure lifetime calculations are approximate as we do not account for any degradation in measure performance over the economic lifetime of the measures, nor for variance in individual project lifetimes.

5. Discussion: Contextualizing our findings

5.1 The California context

Much of California, especially the heavily-populated coastal part of the state where most R-PACE projects are located, has a much milder climate than most other parts of the country. As a result, space conditioning accounts for a relatively small share of California's energy use. According to the U.S. Energy Information Administration (EIA),[47] in 2009, gas space heating accounted for 39% of California's household gas use, while space cooling accounted for 11% of household electricity use. For comparison, these values are 63% and 19% for the U.S. as a whole. Per Figure 2, the vast majority of R-PACE energy efficiency projects affect space conditioning energy use only. Therefore, potential savings from space conditioning-related energy efficiency measures are lower in California, both in absolute and percentage terms, than they would be in the country as a whole.

Per EIA, 14% of California households were not heated and over 40% did not use air conditioning in 2009. Air conditioning penetration in particular has been increasing in California (Palmgren et al. 2010). Unlike some other energy efficiency programs, R-PACE programs can finance air conditioner and heating unit installations. Per section 4.3.1, our data suggest substantial installation of both new air conditioning and heating units in California households that may not have had this type of equipment previously. Installation of these measures tends to result in increased energy use, but would not likely be as common for R-PACE programs implemented in parts of the country where heating and cooling units are more ubiquitous.

Due to the combination of these two factors, similar R-PACE programs in other parts of the country might be expected to achieve greater energy efficiency savings, both in percentage and absolute terms.

5.2 Comparison to Home Upgrade Program and Advanced Home Upgrade Program impacts

To put our results in context, we compare them to a recent evaluation of California's Home Upgrade Program (HUP) and Advanced Home Upgrade Program (AHUP). HUP and AHUP are whole home retrofit programs that provide incentives for the installation of multiple measures. The programs focus on similar efficiency end uses to R-PACE and are available statewide in IOU service territories. HUP projects consist of at least three measures, including at least one of the following measures: air sealing (an envelope measure in our rubric), attic insulation (an envelope measure), or duct sealing (an HVAC measure). Other potential measures are envelope, HVAC, and water heating-related. AHUP projects consist of at least four (in some places at least five) measures, and also includes windows. Both programs offer incentives – up to $1300 for HUP depending on measures installed, and up to $5500 for AHUP depending on modeled savings. Costs for these programs include incentives (rebates) paid to customers after

[47] https://www.eia.gov/consumption/residential/reports/2009/state_briefs/pdf/CA.pdf

installation of these measures plus the costs incurred by the utility to administer the program (e.g. marketing, education, QA/QC, monitoring/verification of savings).

These programs address similar end uses to R-PACE, although HUP and AHUP projects are likely to be more comprehensive than R-PACE projects on average, especially in the case of AHUP. R-PACE projects do not have a minimum number of measures. As shown in Figure 2, most R-PACE energy efficiency projects' measures fall into a single measure category (though they may include multiple measures within that measure category – our data are not granular enough to reveal this). Moreover, HUP and AHUP do not allow installation of new HVAC equipment in homes that do not have air conditioning; they only support HVAC projects that replace an existing unit with higher efficiency equipment.

DNV GL (2019) evaluated electricity and gas savings in households participating in HUP and AHUP from mid-2016 through mid-2017 and used similar energy analysis methods, which facilitates a comparison that is relatively unconfounded by methodological differences.[48] Table 3 shows HUP, AHUP, and our R-PACE results by utility.

Table 3. Average electricity and gas savings of HUP, AHUP, and R-PACE projects

Electric utility	**HUP average savings**	**AHUP average savings**	**R-PACE average savings, energy efficiency projects**	**R-PACE average savings, inferred new installations excluded**
PG&E	8%	5%	4.8%	6.1%
SCE	2%	6%	2.7%	4.7%
SDG&E	0%	*	-0.4%	2.7%
Gas utility				
PG&E	10%	11%	7.2%	9.3%
SCG	5%	15%	2.1%	4.8%
SDG&E	8%	*	3.0%	4.9%

On average, per-household electric savings were slightly higher for HUP and AHUP participants (2 to 8% for SCE and PG&E customers respectively) compared to R-PACE households that implemented efficiency measures (3 to 5% for PACE customers in SCE and PG&E respectively). Average gas savings were significantly higher for HUP and AHUP participants (5 to 15%) compared to R-PACE households (2 to 7%). When considering our R-PACE estimates with inferred installations removed, both gaps close somewhat, with R-PACE electric savings in particular appearing to be similar to HUP/AHUP savings. In our view, given the likely differences

[48] DNV GL employed the PRISM model using daily data for both electricity and gas and employed a floating balance point, as we did when running our daily models (see section 3.2). They also produce results for a normal weather year using TMY3 weather data. And they employ a comparison group, chosen based on pre-project consumption and climate zone, which is broadly similar to how we define our comparison group households.

in the mix and frequency of measures installed in typical projects for each program, our energy impact results for R-PACE appear to be reasonable.

During this time period, R-PACE participation rates were considerably higher than HUP and AHUP. HUP had about 5700 participants in these 12 months and AHUP had about 3500. In contrast, R-PACE had about 60,000 participants, of which we estimate that about 43,000 installed energy efficiency measures. Therefore, in aggregate, total energy efficiency savings from R-PACE households in California are higher than from HUP and AHUP programs.

5.3 Issues not addressed by our methods

We do not have data on the existing building and equipment stock or the condition of existing equipment in R-PACE households prior to the R-PACE projects. The likely presence of many installations of new equipment (rather than replacement of existing equipment), discussed extensively in section 4.3.1, is one clear case where the nature of the equipment prior to the project makes a critical difference in our interpretation of the savings results. Another example could be an HVAC unit that failed some time prior to the R-PACE project, meaning that baseline usage would be artificially suppressed for at least part of the baseline period, resulting in an underestimate of savings.

We also cannot account for other changes in the household that occur in the baseline or reporting periods. For example, we cannot account for changes in occupancy; if one or more people move into or out of the household during the period of observation, we would attribute some of this change to the project. In another case, if a homeowner puts on an addition at the same time as a small R-PACE energy efficiency project, we will likely estimate an increase in usage even if the project reduced usage on its own.

Finally, we do not address whether the presence of R-PACE financing caused the projects to happen (e.g. what share of the savings might have occurred absent R-PACE). Our use of a comparison group does remove certain non-program factors, but only those common to other similar households. Our methods do not address what a household would have done in the absence of R-PACE. For example, the household may have pursued the same project with alternative capital sources; might have installed a somewhat different, and possibly less energy efficient, project; or might not have done a project at all. As noted in Section 1, several analyses of R-PACE and solar PV have shown that the presence of R-PACE has been associated with greater PV deployment. Deason and Murphy (2018) discuss this issue further, including considerations for extending this result to energy efficiency.

6. Conclusions

R-PACE programs in California have achieved notable participation volume relative to other residential energy efficiency financing programs. Per Deason et al. (2016), in 2014 R-PACE programs accounted for nearly half the capital that flowed through energy efficiency financing programs nationwide, despite operating in only two states at the time. R-PACE volumes grew significantly after that time through 2017, though they declined somewhat in 2018 and 2019. R-PACE volumes are also large compared with comprehensive whole-home retrofit programs in California. From July 2016 through June 2017, California R-PACE programs served about 60,000 households, of which about 43,000 conducted energy efficiency projects, while California's Home Upgrade (HUP) and Advanced Home Upgrade (AHUP) energy efficiency programs served about 9000.

Table 4 summarizes our estimates of R-PACE program impacts.[49] We find that R-PACE-financed energy efficiency projects have reduced electricity usage by about 3% on average and natural gas usage by about 4% in participating households. We estimate normal year savings of 35 GWh and 2.3 million therms, and total savings of 0.7 TWh and 44 million therms over the full lifetimes of these projects. Savings are greater for projects with measures in multiple measure categories and in areas of the state with high space conditioning demand. Our data suggest that a substantial share of R-PACE HVAC measures may be installations in households that did not previously have this type of equipment, rather than replacement of existing, similar HVAC equipment. Removing inferred HVAC installations yields an estimate of about 5% electricity and 6% gas savings on average from projects properly understood as energy efficiency improvements.

Table 4. Estimated R-PACE program first-year and lifetime savings

Project category	Average relative household first-year electricity savings	Average absolute household first-year electricity savings (kwh)	Total first-year electricity savings (GWh)	Total lifetime electricity savings (TWh)	Average relative household first-year gas savings	Average absolute household first-year gas savings	Total first-year gas savings (million therms)	Total lifetime gas savings (million therms)
Energy efficiency	2.9%	245	35	0.7	3.5%	16	2.3	44
Solar PV	68.9%	7,937	414	7.9	-1.7%	-9	-0.5	-9
EE + PV	63.6%	6,542	59	1.1	4.3%	21	0.2	4
Water-only	-2.4%	-209	-2	0.0	-2.8%	-13	-0.1	-3
Total	25%	2,352	506	9.6	1.9%	9	2.0	37

[49] To generate this table, we multiplied average impact in each measure category and utility by the total number of projects in that utility-measure category, assuming that projects for which we observe measure information are representative of those we do not. This ensures that our program-wide estimates are not distorted by different rates of attrition across measure categories – see Figure 1.

R-PACE-financed projects that include solar PV (and occasionally also include efficiency measures) have reduced household grid electricity usage by about 68% on average. We estimate total first-year avoided grid electricity consumption of 473 MWh, and total avoided grid electricity consumption of 9.0 TWh over the full lifetimes of these projects. We estimate that these projects increase gas consumption slightly on average.

Across all R-PACE projects implemented through the end of 2019, we estimate first year reductions of 506 GWh of grid electricity consumption and 2 million therms of gas consumption, and lifetime reductions of 9.6 TWh and 37 million therms respectively.

As a percentage of household energy usage, savings from R-PACE energy efficiency projects are not large. However, given the California climate and the measures supported by R-PACE, we would not necessarily expect large percentage savings. Most California households experience very mild climates and the vast majority of R-PACE projects are space conditioning-only. These factors combine to limit the level of savings these projects can attain. In other climates, savings from projects that installed similar types of efficiency measures would likely be larger in both absolute and percentage terms.

When compared with projects implemented under California's whole-home energy efficiency retrofitting programs supported by utility customers, R-PACE energy efficiency projects save slightly less energy per project. This is not surprising given that R-PACE projects are likely less comprehensive: the whole-home programs require installation of multiple measures, while some R-PACE projects installed single measures. R-PACE programs have more participating households than the whole-home programs, however, so energy efficiency projects supported by California R-PACE programs have saved considerably more energy in total than projects supported by California's whole-home programs.

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Appendix A. Residential PACE households in California: Attrition analysis and impact of data quality screening

In Appendix A, we describe data on the population of PACE households based on data received from CAEATFA and discuss the evolution of the sample of PACE households included in this study as we dealt with attrition of households and data quality screens.

Figure A-1 andFigure A-2 present our treatment of R-PACE households through various stages of dataset merges and data quality screens for electric and gas meters, respectively. We began with assessment information on more than 120,000 PACE projects obtained from CAEATFA. Of those, we were able to connect 66% to project measures provided to us by PACE program administrators and to addresses accessed through a dataset from Zillow (see second column in Figure A-1 andFigure A-2: CAEATFA, addresses and measures). Our sample of projects was then reduced by about 10% (see third column in Figure A-1 andFigure A-2: Date Assignment and Screen) because some solar PV installations had no interconnection dates in Tracking the Sun, a database of PV installations developed by Berkeley Lab (Barbose and Darghouth 2019). We dropped these solar PV projects out of concern that their measure mix may have been mischaracterized.

Our electric and gas samples then diverged as we connected the project data to utility account datasets, leaving us with about 52,000 electric meters and 59,000 gas meters for analysis (see fourth column in Figure A-1 andFigure A-2: Sample for Analysis). We lose more electric meters than gas meters because a number of R-PACE project households are served by utilities whose energy usage data we were not able to access–largely municipal electric utilities. Data quality screens on temperature (see section 3.3) and meter data sufficiency (see section 3.2) caused us to remove more than a quarter of remaining electric meters and more than 60% of remaining gas meters (see columns 5 through 7 in Figure A-1 andFigure A-2).

Our assignment of meters for comparison households reduced the sample size for R-PACE households further, as some R-PACE households lacked a suitable comparison household that passed these same data screens (see column 9 in Figure A-1 andFigure A-2: No Matching Comparison Household). Of these matched pairs, we then excluded any meter from a household that had pre-existing solar or baseline period CVRMSE less than 0 or greater than 1 (see column 10 in Figure A-1 andFigure A-2: Baseline CVRMSE or Pre-existing Solar). We exclude households with pre-existing solar because the presence of solar greatly distorts the relationship of electricity usage with temperature (see Appendix E). We exclude households with baseline period CVRMSE greater than one out of concern that the model may not give reasonable values for these households (see discussion in section 3.6).

Our final sample includes about 25,500 electric meters and nearly 16,000 gas meters (see column 11, labeled Energy Analysis Results, in Figure A-1 andFigure A-2).

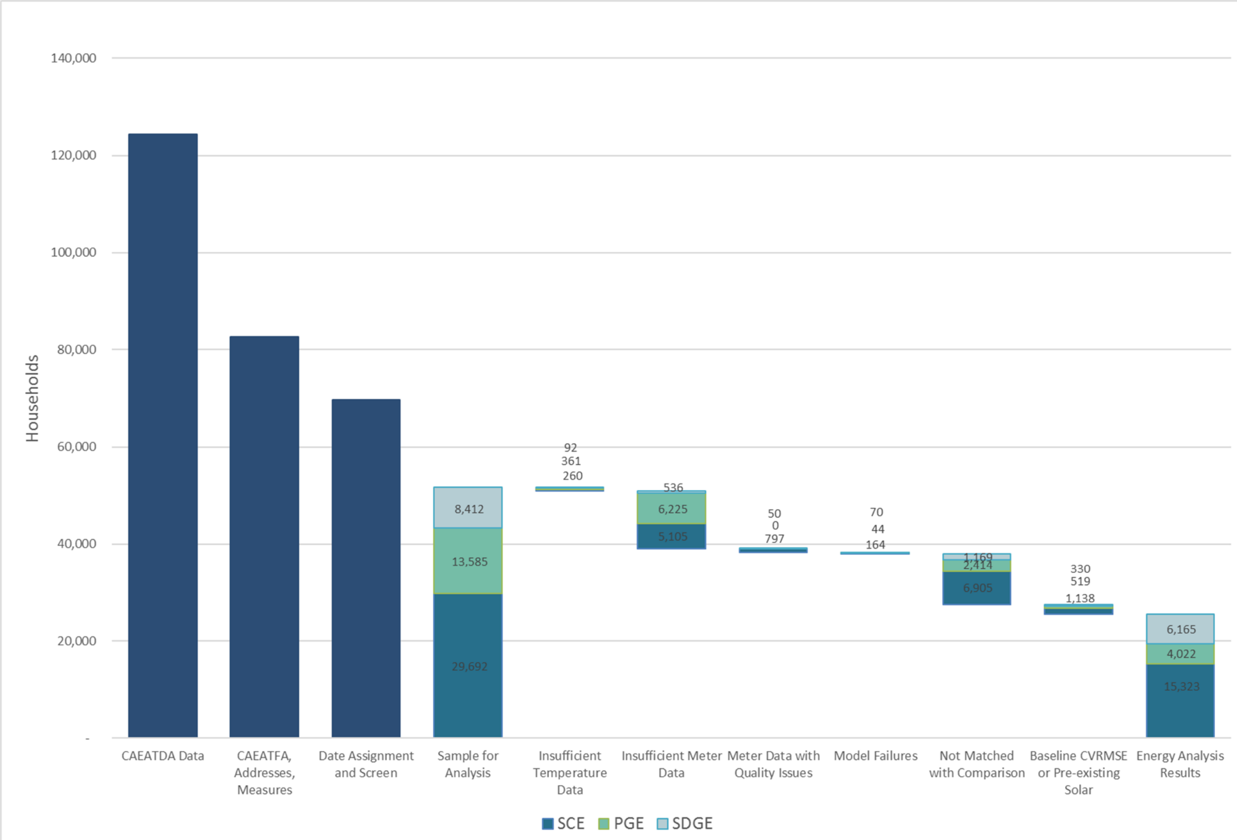

Figure A-1. Electric sample attrition

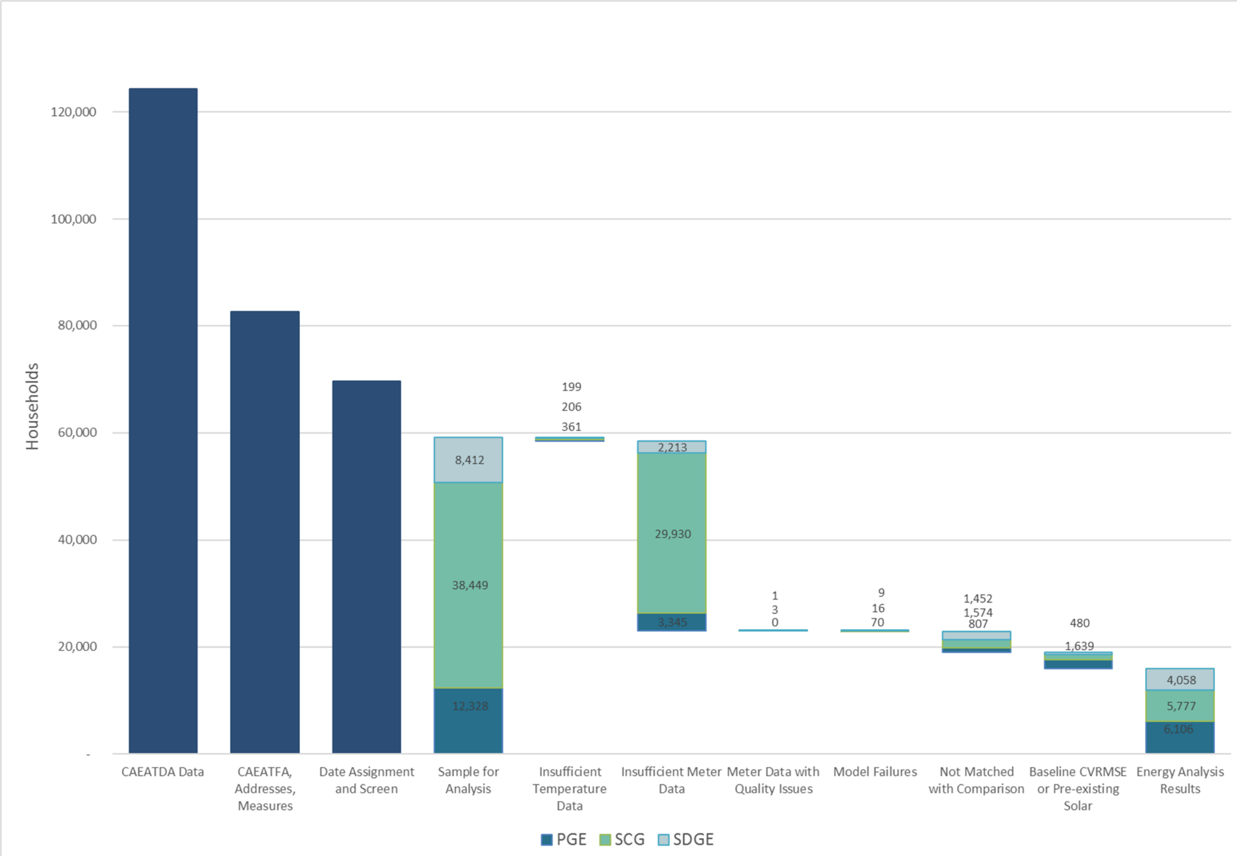

Figure A-2. Gas sample attrition

Appendix B. Energy impacts of water-only projects

California R-PACE programs allow the installation of measures that address water use, including low flow toilets, hardscaping, irrigation, and rainwater catchment systems. While toilets and hardscaping likely have minimal energy usage impacts, irrigation systems (for example) may require pumps that increase electric load. Overall, we find that for R-PACE projects that only included water measures, household electricity and gas consumption increased on average 2.4% and 2.8% (see Table F-1). These increases did vary by utility, with grid electricity usage increasing from 0.9% in SCE territory to 5.5% in PG&E territory. We used the same methodology to produce the statewide numbers as we did for Table 2, weighting by the number of R-PACE projects installed in each utility service territory to account for the attrition of projects through the steps of our energy analysis. Because there are few water-only projects, they have a small impact on R-PACE's statewide impact on gas and grid electricity use (see Table 4).

Table B-1. Average R-PACE project impacts by California IOU, including water-only measures

		Electric		Gas	
Utility	Measure category	Reduction in grid electricity use (%)	Sample size	Reduction in energy use (%)	Sample size
PGE	EE	4.8%	2,491	7.2%	3,447
SCE		2.7%	12,668	N/A	N/A
SCG		N/A	N/A	2.1%	4,471
SDGE		-0.4%	3,085	3.0%	2,090
Statewide		**2.9%**	**18,244**	**3.5%**	**10,008**
PGE	Solar	68.7%	1,313	2.0%	2,321
SCE		66.0%	1,574	N/A	N/A
SCG		N/A	N/A	-2.9%	831
SDGE		83.1%	2,211	-3.1%	1,391
Statewide		**68.9%**	**5,098**	**-1.7%**	**4,543**
PGE	Solar and EE	67.5%	125	2.6%	176
SCE		57.1%	368	N/A	N/A
SCG		N/A	N/A	5.3%	154
SDGE		83.3%	494	3.0%	323
Statewide		**63.6%**	**988**	**4.3%**	**653**
PGE	Water-Only	-5.5%	93	-6.0%	162
SCE		-0.9%	713	N/A	N/A
SCG		N/A	N/A	-1.4%	321
SDGE		-2.2%	375	-3.5%	254
Statewide		**-2.4%**	**1,181**	**-2.8%**	**737**

Appendix C. Energy usage analysis: Hourly vs. daily usage model results and uncertainty analysis of savings estimates

In Appendix C, we discuss the impact of varying granularity in the energy usage data (e.g. hourly vs. daily energy use) on energy impacts for R-PACE households. We also estimate confidence intervals for the energy usage impacts for R-PACE households, and find that our confidence intervals are consistently very small compared to our estimates of energy usage impact.

The electric results presented in section 4 are all products of the TOWT model, which estimates hourly energy usage and savings. We also ran an alternative model (PRISM) to estimate impacts using daily electricity usage rather than hourly usage data. Table C-1 compares results from the two models.

The savings estimates from the two models are similar across utilities and measures for energy efficiency projects, although we do find that the daily model estimates slightly higher electric efficiency savings. Reductions in grid electricity use for projects that installed solar PV diverge more notably, with the daily model (PRISM) showing substantially lower reductions in grid electricity use. The PRISM and TOWT models were not designed to estimate solar PV impacts, and there may be more accurate ways to do so. Regardless, issues affecting PV electricity impacts are unlikely to be relevant to assessing impacts on gas usage.

We take these results as evidence that our electric savings (from TOWT) and our gas savings (from PRISM) are broadly comparable and not confounded by the use of different models.

We also present confidence intervals in Table C-1. We calculate confidence intervals using the following method:

1. Calculate a confidence interval for each R-PACE household using the method specified in ASHRAE Guideline 14 (Reddy and Claridge 2000)
2. Calculate a confidence interval for that R-PACE household's comparison household using the same method
3. Calculate a confidence interval for the difference in savings between the R-PACE and comparison household, assuming independence in the errors from each household (Granderson et al. 2018)
4. Roll up the confidence intervals from step 3 to the full portfolio (e.g., energy efficiency projects in PG&E households) again assuming independence of errors

Empirically, the literature establishes that our confidence intervals for our electricity results are somewhat underestimated, but does not provide a tractable alternative. The formula used in ASHRAE Guideline 14 contains an empirically estimated factor of 1.26 to make the calculation more tractable. Sun and Baltazar (2013) derive improved factors for monthly and daily data that are somewhat larger. In our context (i.e., 12 months of reporting period data), these factors are 1.31 and 1.39, respectively. All of these factors carry through our set of equations multiplicatively—for example, using the Sun and Baltazar daily factor of 1.39 would result in aggregated estimated confidence intervals that are 10% larger (1.39/1.26) than those using the ASHRAE 14 factor. However, Sun and Baltazar do not provide values for hourly data. Similarly, Touzani et al. (2019) demonstrate that the ASHRAE 14 formula underestimates errors using both daily and hourly data, most likely due to insufficiently correcting for autocorrelation in the errors in hourly data. It is beyond the scope of this report to find and propose a correction for this technical problem.

However, given the size of our (underestimated) confidence intervals, we are confident that model error at the portfolio level is small relative to our estimated impacts, due to the very large number of meters in our dataset. Even if our estimated electric errors were low by an order of magnitude—which is very unlikely—our results in our large samples would still generally be quite reliable. And Sun and Baltazar suggests that our gas errors are likely only underestimated by about 10%.

Table C-1. Hourly and daily model savings by utility and measure

		Hourly Model		Daily Model	
Utility	Measure	% savings	90% confidence interval (+/-)	% savings	90% confidence interval (+/-)
PGE	EE	4.8%	0.1%	5.2%	0.4%
SCE		2.7%	0.0%	3.2%	0.0%
SDGE		-0.4%	0.1%	1.2%	0.0%
PGE	Solar	68.7%	0.1%	56.9%	0.6%
SCE		66.0%	0.1%	55.7%	0.0%
SDGE		83.1%	0.1%	69.3%	0.0%
PGE	EE and solar	67.5%	0.3%	48.6%	1.9%
SCE		57.1%	0.2%	48.2%	0.0%
SDGE		83.3%	0.2%	69.2%	0.0%
PGE	Water-only	-5.5%	0.3%	2.1%	1.6%
SCE		-0.9%	0.1%	1.0%	0.0%
SDGE		-2.2%	0.2%	-2.2%	0.0%

Appendix D. Alternate filters on eligible meters

In Appendix D, we examine the impact of various data quality filters that could have been applied to household energy model results for PACE participants. The goal here was to identify and set aside meters that the energy analysis model cannot handle well.

In Table D-1, we present percentage reductions in grid electricity and gas use for non-solar and solar PV projects in each utility jurisdiction under three different data filters. Data Filter 1 makes no exclusions. Data Filter 2 (Baseline CVRMSE Filter) is the one we use to produce estimates of reductions in grid electricity and gas use throughout this study. This data filter excludes all accounts that have baseline CVRMSE estimates less than zero[50] or greater than one, meaning that our weather model was not predicting consumption accurately. CVRMSE (coefficient of variation of the root mean square error) is a measurement of model accuracy, with a value of zero indicating a perfect fit. This screen raises gas savings estimates considerably in PG&E households, as many of the gas accounts in our PG&E data showed lumpy gas consumption in the summer—likely due to meters registering gas consumption in approximately one therm increments—that made daily gas consumption difficult for the model to predict.

Next, Data Filter 3 (High Usage Filter) screens for high-usage households by excluding any project whose baseline usage is greater than three interquartile ranges above the median usage of all projects. The Uniform Methods Protocol (UMP) recommends review and potential removal of these households. In our dataset, the bottom of this range is below zero for both electricity and gas, so the impact of this screen is confined to high-using households. This screen eliminates about 1% of the meters.

We manually examined a subset of the households that would be subject to this screen, per the Uniform Methods Project recommendations. With only a handful of exceptions, the high usage appeared to be genuine, rather than a result of data anomalies. Moreover, we believe our goodness-of-fit screen should catch the data anomalies. As a result, we elected to not remove these high-usage households from our results as presented in the body of the paper.

As Table D-1 shows, all of these screens deliver very similar results for electricity, and largely for gas as well, although a few of the gas results are somewhat sensitive to the choice of screen.

[50] CVRMSE values below zero stem from weather-normalized predictions of negative usage in the baseline period, which is not sensible. This occurs in only a handful of cases.

Table D-1. Net percentage reductions in grid electricity and gas use by utility, measure, and fuel under different data quality screens

Utility	Measure	Fuel	% savings: 1) No filter	% savings: 2) Baseline CVRMSE filter	% savings: 3) High usage filter
PGE	Efficiency	Electric	4.7%	4.8%	4.6%
SCE			2.6%	2.7%	2.5%
SDGE			-0.2%	-0.4%	-0.3%
PGE		Gas	3.4%	7.2%	1.8%
SCG			2.1%	2.1%	1.6%
SDGE			3.2%	3.0%	1.4%
PGE	Solar	Electric	68.8%	68.7%	68.8%
SCE			66.2%	66.0%	67.0%
SDGE			83.2%	83.1%	83.9%
PGE		Gas	1.5%	2.0%	1.8%
SCG			-2.2%	-2.9%	-2.1%
SDGE			-3.3%	-3.1%	-4.0%
PGE	EE and solar	Electric	67.8%	67.5%	67.3%
SCE			57.0%	57.1%	58.2%
SDGE			83.5%	83.3%	84.0%
PGE		Gas	2.4%	2.6%	2.2%
SCG			5.1%	5.3%	5.1%
SDGE			3.0%	3.0%	-2.1%
PGE	Water-only	Electric	-6.2%	-5.5%	-7.7%
SCE			-0.7%	-0.9%	-0.9%
SDGE			-1.5%	-2.2%	-1.2%
PGE		Gas	1.0%	-6.0%	-5.1%
SCG			0.6%	-1.4%	-1.3%
SDGE			-2.9%	-3.5%	-5.7%

Table D-2 contains the utility account-weighted averages for electric and gas projects. We find that the contribution to overall energy efficiency savings from high usage households is more pronounced for gas meters than for electric meters, with Data Filter 3 resulting in efficiency savings of 1.6% compared to 3.5% with Data Filter 2. Otherwise, results are very similar regardless of screen applied.

Table D-2. Net percentage reductions in grid electricity and gas use by measure and fuel under different data quality screens, weighted by utility accounts

Fuel	Measure	1) No filter	2) Baseline CVRMSE filter	3) High usage filter
Electric	EE	2.9%	2.9%	2.7%
	Solar	69.1%	68.9%	69.6%
	EE and solar	63.6%	63.6%	64.2%
	Water-only	-2.3%	-2.4%	-2.6%
Gas	EE	2.5%	3.5%	1.6%
	Solar	-1.5%	-1.7%	-1.4%
	EE and solar	4.2%	4.3%	3.6%
	Water-only	0.3%	-2.8%	-2.6%

Appendix E. Model goodness-of-fit statistics

In Appendix E, we provide statistics on the goodness-of-fit of our energy (electricity and gas) model for households in each IOU and by type of measure.

Table E-1 and Table E-2 contain average baseline and reporting model statistics by utility and type of measure for electric and gas households. The baseline and reporting model statistics indicate how well the model describes pre-retrofit and post-retrofit consumption, respectively. CVRMSE (coefficient of variation of the root mean square error) is a measurement of model accuracy, with a value of 0 indicating a perfect fit. R-squared measures how well variation in usage is explained by weather alone and has a maximum value of one. In mild climates, such as California, R-squared values are often much less than one, especially for electricity. NMBE (normalized mean bias error) represents the average bias in the modeled usage as a share of total observed usage; a value of zero shows no bias.

Note that CVRMSE and R-squared values are not comparable across model types. More temporally granular data have higher CVRMSE and lower r-squared values. This is most notably reflected in the SDG&E statistics in Table E-2, which are based on monthly data rather than daily data for PG&E and SCG. Moreover, our electric results are based on hourly data, and model fits exhibit higher CVRMSE and lower r-squared than they would using daily data.

The reporting period values for solar homes change dramatically, as the presence of solar greatly changes the timing of net electricity usage. Generally, R-squared values go up, as solar generation is determined by insolation, which is fairly well correlated with temperature. However, CVRMSE values also go up as insolation distorts the pattern of the relationship between temperature and electricity usage. These models were not designed to estimate solar impacts, and more thought should be given to the ramifications of these model fit issues for estimates of solar PV savings. In a few cases, the model generates very strange predictions for these households, which are reflected for example in the NMBE values for PG&E and SDG&E solar homes in the reporting period. We include median values for the goodness-of-fit electricity statistics in Table E-3 to demonstrate that these issues are the product of a relatively small number of accounts, rather than a systematic issue.

Table E-1. Mean goodness-of-fit statistics, electricity meters

Fuel	Measure	Utility	Period	CVRMSE		R-Squared		NMBE	
				Treatment	Control	Treatment	Control	Treatment	Control
Electric	EE	PGE	Baseline	0.67	0.58	0.56	0.57	0.01	0.01
		PGE	Reporting	0.61	0.56	0.57	0.58	0.01	0.01
		SCE	Baseline	0.55	0.50	0.57	0.58	0.01	0.01
		SCE	Reporting	0.50	0.50	0.58	0.58	0.01	0.01
		SDGE	Baseline	0.55	0.51	0.51	0.51	0.01	0.01
		SDGE	Reporting	0.17	0.52	0.51	0.51	0.00	0.01
	Solar	PGE	Baseline	0.55	0.54	0.58	0.58	0.01	0.01
		PGE	Reporting	20.62	0.55	0.76	0.59	0.32	0.01
		SCE	Baseline	0.50	0.46	0.59	0.62	0.01	0.01
		SCE	Reporting	-0.80	0.46	0.77	0.63	0.01	0.01
		SDGE	Baseline	0.53	0.49	0.54	0.55	0.01	0.01
		SDGE	Reporting	-7.78	0.50	0.78	0.54	-0.07	0.01
	EE and solar	PGE	Baseline	0.55	0.55	0.57	0.59	0.01	0.01
		PGE	Reporting	2.42	0.56	0.74	0.59	0.02	0.01
		SCE	Baseline	0.50	0.47	0.59	0.60	0.01	0.01
		SCE	Reporting	1.19	0.48	0.72	0.59	0.01	0.01
		SDGE	Baseline	0.52	0.49	0.54	0.54	0.01	0.01
		SDGE	Reporting	2.86	0.51	0.77	0.53	0.01	0.01
	Water-only	PGE	Baseline	0.61	0.55	0.57	0.58	0.01	0.01
		PGE	Reporting	0.59	0.55	0.58	0.59	0.01	0.01
		SCE	Baseline	0.54	0.50	0.57	0.59	0.01	0.01
		SCE	Reporting	0.57	0.50	0.58	0.60	0.01	0.01
		SDGE	Baseline	0.58	0.52	0.52	0.52	0.01	0.01
		SDGE	Reporting	0.58	0.52	0.51	0.51	0.01	0.01

Table E-2. Mean goodness-of-fit statistics, gas meters

				CVRMSE		R-Squared		NMBE	
Fuel	Measure	Utility	Period	Treatment	Control	Treatment	Control	Treatment	Control
Electric	EE	PGE	Baseline	0.70	0.62	0.57	0.60	0.00	0.00
		PGE	Reporting	0.66	0.64	0.59	0.62	0.00	0.00
		SCE	Baseline	0.53	0.47	0.52	0.57	0.00	0.00
		SCE	Reporting	0.51	0.48	0.55	0.55	0.00	0.00
		SDGE	Baseline	0.23	0.21	0.76	0.78	-0.01	-0.01
		SDGE	Reporting	0.20	0.18	0.81	0.82	0.00	0.00
	Solar	PGE	Baseline	0.66	0.61	0.55	0.60	0.00	0.00
		PGE	Reporting	0.63	0.64	0.58	0.61	0.00	0.00
		SCE	Baseline	0.56	0.46	0.52	0.61	0.00	0.00
		SCE	Reporting	0.55	0.47	0.50	0.57	0.00	0.00
		SDGE	Baseline	0.24	0.22	0.73	0.77	-0.01	-0.01
		SDGE	Reporting	0.20	0.19	0.80	0.82	0.00	0.00
	EE and solar	PGE	Baseline	0.65	0.63	0.57	0.61	0.00	0.00
		PGE	Reporting	0.66	0.64	0.60	0.60	0.00	0.00
		SCE	Baseline	0.53	0.46	0.52	0.56	0.00	0.00
		SCE	Reporting	0.50	0.46	0.53	0.53	0.00	0.00
		SDGE	Baseline	0.25	0.21	0.74	0.78	-0.01	-0.01
		SDGE	Reporting	0.21	0.18	0.79	0.83	0.00	0.00
	Water-only	PGE	Baseline	0.82	0.63	0.56	0.60	0.00	0.00
		PGE	Reporting	0.76	0.59	0.57	0.63	0.00	0.00
		SCE	Baseline	0.56	0.50	0.57	0.61	0.00	0.00
		SCE	Reporting	0.58	0.50	0.55	0.58	0.00	0.00
		SDGE	Baseline	0.24	0.23	0.75	0.79	-0.01	-0.01
		SDGE	Reporting	0.20	0.19	0.81	0.82	0.00	0.00

Table E-3. Median goodness-of-fit statistics, electric meters

Fuel	Measure	Utility	Period	CVRMSE Treatment	CVRMSE Control	R-Squared Treatment	R-Squared Control	NMBE Treatment	NMBE Control
Electric	EE	PGE	Baseline	0.59	0.55	0.56	0.57	0.01	0.01
		PGE	Reporting	0.56	0.55	0.57	0.58	0.01	0.01
		SCE	Baseline	0.50	0.47	0.56	0.58	0.01	0.01
		SCE	Reporting	0.48	0.47	0.58	0.59	0.01	0.01
		SDGE	Baseline	0.51	0.48	0.50	0.51	0.01	0.01
		SDGE	Reporting	0.51	0.49	0.51	0.50	0.01	0.01
	Solar	PGE	Baseline	0.54	0.52	0.59	0.59	0.01	0.01
		PGE	Reporting	1.67	0.53	0.78	0.60	0.02	0.01
		SCE	Baseline	0.48	0.43	0.60	0.63	0.01	0.01
		SCE	Reporting	1.45	0.43	0.79	0.64	0.02	0.01
		SDGE	Baseline	0.50	0.47	0.53	0.54	0.01	0.01
		SDGE	Reporting	1.84	0.48	0.80	0.54	0.01	0.01
	EE and solar	PGE	Baseline	0.54	0.52	0.58	0.60	0.01	0.01
		PGE	Reporting	1.46	0.53	0.76	0.60	0.02	0.01
		SCE	Baseline	0.48	0.44	0.59	0.60	0.01	0.01
		SCE	Reporting	1.13	0.45	0.74	0.60	0.01	0.01
		SDGE	Baseline	0.50	0.47	0.54	0.53	0.01	0.01
		SDGE	Reporting	1.64	0.50	0.79	0.53	0.01	0.01
	Water-only	PGE	Baseline	0.59	0.53	0.57	0.57	0.01	0.01
		PGE	Reporting	0.58	0.54	0.59	0.59	0.01	0.01
		SCE	Baseline	0.52	0.47	0.57	0.59	0.01	0.01
		SCE	Reporting	0.52	0.47	0.58	0.61	0.01	0.01
		SDGE	Baseline	0.55	0.50	0.52	0.52	0.01	0.01
		SDGE	Reporting	0.55	0.51	0.50	0.51	0.01	0.01

Table E-4. Median goodness-of-fit statistics, gas meters

				CVRMSE		R-Squared		NMBE	
Fuel	Measure	Utility	Period	Treatment	Control	Treatment	Control	Treatment	Control
Electric	EE	PGE	Baseline	0.62	0.56	0.62	0.65	0.00	0.00
		PGE	Reporting	0.59	0.54	0.65	0.67	0.00	0.00
		SCE	Baseline	0.46	0.44	0.58	0.63	0.00	0.00
		SCE	Reporting	0.44	0.44	0.61	0.62	0.00	0.00
		SDGE	Baseline	0.19	0.18	0.83	0.84	0.00	0.00
		SDGE	Reporting	0.17	0.16	0.88	0.88	0.00	0.00
	Solar	PGE	Baseline	0.60	0.56	0.60	0.64	0.00	0.00
		PGE	Reporting	0.58	0.54	0.63	0.66	0.00	0.00
		SCE	Baseline	0.46	0.42	0.58	0.67	0.00	0.00
		SCE	Reporting	0.45	0.43	0.55	0.64	0.00	0.00
		SDGE	Baseline	0.20	0.19	0.81	0.84	0.00	0.00
		SDGE	Reporting	0.17	0.16	0.87	0.88	0.00	0.00
	EE and solar	PGE	Baseline	0.59	0.57	0.64	0.65	0.00	0.00
		PGE	Reporting	0.56	0.54	0.66	0.68	0.00	0.00
		SCE	Baseline	0.46	0.44	0.59	0.62	0.00	0.00
		SCE	Reporting	0.43	0.43	0.57	0.58	0.00	0.00
		SDGE	Baseline	0.20	0.19	0.81	0.83	0.00	0.00
		SDGE	Reporting	0.17	0.16	0.87	0.89	0.00	0.00
	Water-only	PGE	Baseline	0.64	0.56	0.59	0.64	0.00	0.00
		PGE	Reporting	0.61	0.54	0.61	0.68	0.00	0.00
		SCE	Baseline	0.49	0.45	0.64	0.65	0.00	0.00
		SCE	Reporting	0.48	0.45	0.62	0.64	0.00	0.00
		SDGE	Baseline	0.20	0.20	0.82	0.85	0.00	0.00
		SDGE	Reporting	0.17	0.17	0.88	0.88	0.00	0.00

Appendix F. R-PACE and comparison household impacts

In Appendix F, we present estimates of reductions in grid electricity and gas use by fuel, type of measure and utility separately for R-PACE households and our comparison group of households (see Table F-1).

Note that the subtraction of comparison savings from R-PACE savings may not total to percent savings values presented in the main report due to rounding. We also present the utility-weighted percent savings separately in Table F-2.

Table F-1. R-PACE and comparison household % savings by utility, measure, and fuel

			R-PACE households		Comparison households	
	Measure	Fuel	% savings	Confidence interval (+/-)	% savings	Confidence interval (+/-)
PGE	Non-solar	Electricity	4.37%	0.06%	-0.41%	0.05%
SCE			0.54%	0.03%	-2.14%	0.02%
SDGE			0.00%	0.05%	0.36%	0.05%
PGE		Gas	4.02%	0.22%	-3.23%	0.11%
SCG			1.44%	0.16%	-0.64%	0.11%
SDGE			6.04%	0.52%	3.03%	0.48%
PGE	Solar	Electricity	69.05%	0.08%	0.33%	0.07%
SCE			66.29%	0.07%	0.32%	0.06%
SDGE			84.85%	0.06%	1.77%	0.05%
PGE		Gas	-1.47%	0.16%	-3.43%	0.13%
SCG			-1.91%	0.38%	0.96%	0.61%
SDGE			0.23%	0.85%	3.36%	0.60%
PGE	EE and solar	Electricity	67.81%	0.2%	0.26%	0.22%
SCE			55.86%	0.14%	-1.21%	0.12%
SDGE			85.41%	0.12%	2.10%	0.11%
PGE		Gas	-0.51%	0.49%	-3.11%	0.47%
SCG			4.66%	0.76%	-0.68%	0.60%
SDGE			5.61%	1.57%	2.65%	0.93%
PGE	Water-only	Electricity	-5.23%	0.26%	0.31%	0.24%
SCE			-3.11%	0.11%	-2.17%	0.10%
SDGE			-0.84%	0.15%	1.40%	0.14%
PGE		Gas	-8.02%	0.58%	-2.04%	0.51%
SCG			0.36%	0.49%	1.77%	0.46%
SDGE			-0.87%	1.60%	2.65%	1.38%

Table F-2. R-PACE and comparison % Savings by Fuel and Measure, Weighted by Utility Accounts

Fuel	Measure	R-PACE households (% savings)	Comparison households (% savings)
Electricity	EE	1.6%	-1.4%
	Solar	69.4%	0.5%
	EE and solar	63.2%	-0.3%
	Water-only	-3.4%	-1.1%
Gas	EE	2.6%	-0.9%
	Solar	-1.5%	0.2%
	EE and solar	3.5%	-0.9%
	Water-only	-1.8%	0.9%