PV Systems, Energy Efficiency, and Residential Electricity Consumption in California

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ABSTRACT

This paper presents the findings of an analysis of the electricity consumption of residential participants in the California Solar Initiative (CSI) program. This study assessed the effects—and possible interaction—of photovoltaic (PV) generation and energy efficiency on electricity consumption. It benefited from a wealth of data sources and offered an unprecedented opportunity to examine not only utility billing records and data on PV production, but also information on measure savings from utility tracking databases and telephone survey data. The study began with a detailed characterization of pre- and post-installation consumption and culminated in a statistically adjusted engineering (SAE) analysis to quantify the realization of rates of PV generation and measure savings.

An Unprecedented Opportunity

Energy efficiency and solar power have both been important components California's efforts to reduce the consumption of electricity, and there are numerous opportunities for customers of the state's three investor-owned utilities (IOUs) to take advantage of incentives for both. While their impacts have been evaluated separately, the intensive data requirements have meant there has never been a study that simultaneously looked at their impacts. With the benefit of an unprecedented array of data sources, this paper summarizes an analysis of 508[1] residential households in California that participated in the California Solar Initiative (CSI).

The sources of information available for this study included multiple years of monthly billing records, hourly metered data on photovoltaic (PV) production, utility program tracking data on the installation of energy efficiency measures, and information on household characteristics from a telephone survey. Additionally, data for all but PV production were available for a sample of non-participants. To take advantage of access to this broad variety of data, the major objectives of the analysis were to first characterize household consumption in homes with solar panels and then explore the possible interaction of PV production, energy efficiency savings, and total consumption.

PV Production and Household Consumption Patterns

There are multiple factors associated with solar power that influence its effect on overall consumption. The size of the installed system, the electric end uses in the household, and the behavior of the homeowner can all interact to produce very different consumption profiles. There are many hypothetical scenarios that could occur, such as the homeowner whose interest is in maximizing the

[1] The number of sites with billing and PV generation data was in the thousands. After limiting the sites to survey respondents and some attrition due to data issues, the final number of participants examined in the billing analysis was 508. Additionally, there were 595 nonparticipants included in the regression modeling to act as a control group.

export of solar energy. Alternately, there might be a homeowner for whom solar energy mitigates any conscience over running the air conditioning on high.

Given these and other possibilities, the initial phase of the analysis sought to identify patterns in the household consumption data. While there was a detailed exploration of the consumption profiles of all sites, for illustrative purposes only, the figures presented below show billing data and PV production data for three cases that exemplify the variability encountered throughout the data.

Figure 1: SDG&E Site—Stable Consumption and Net Exporter

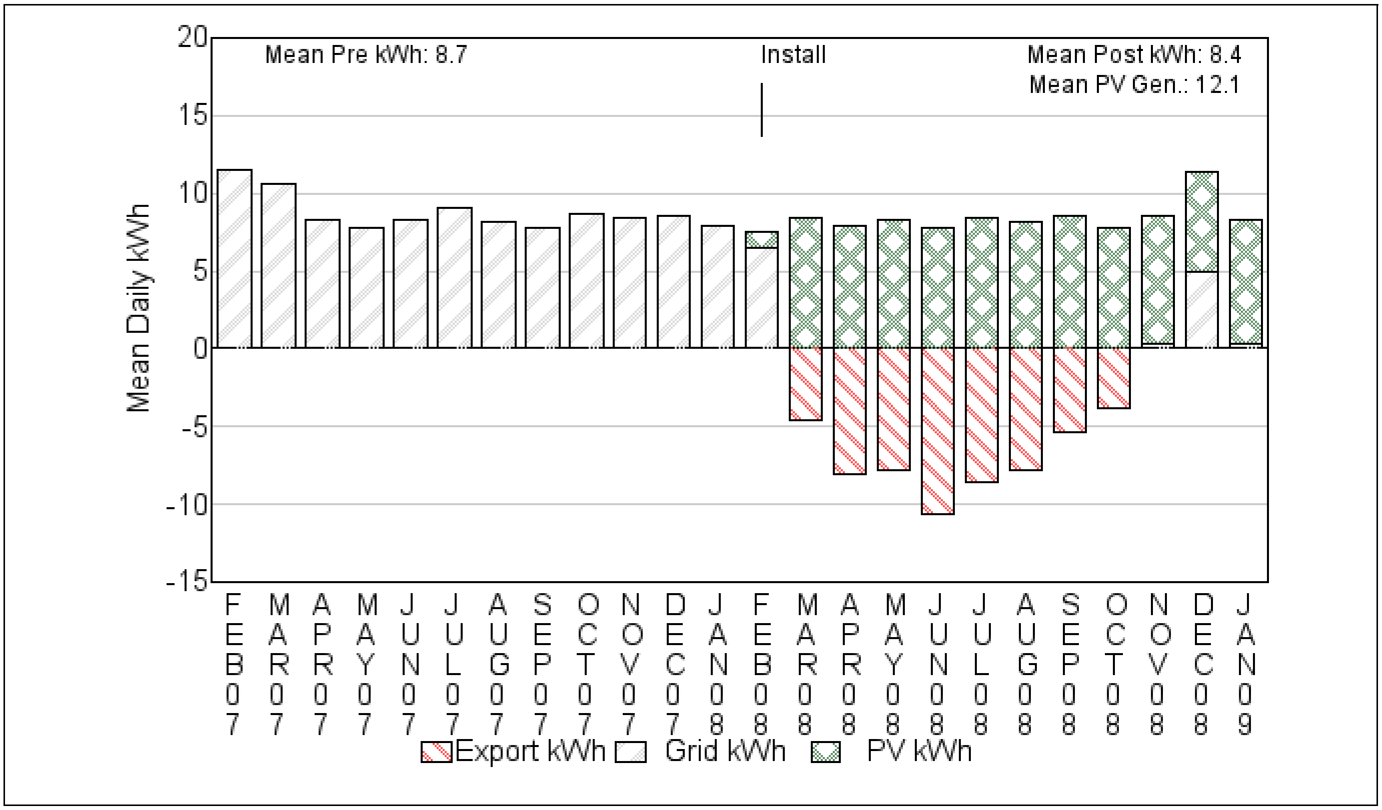
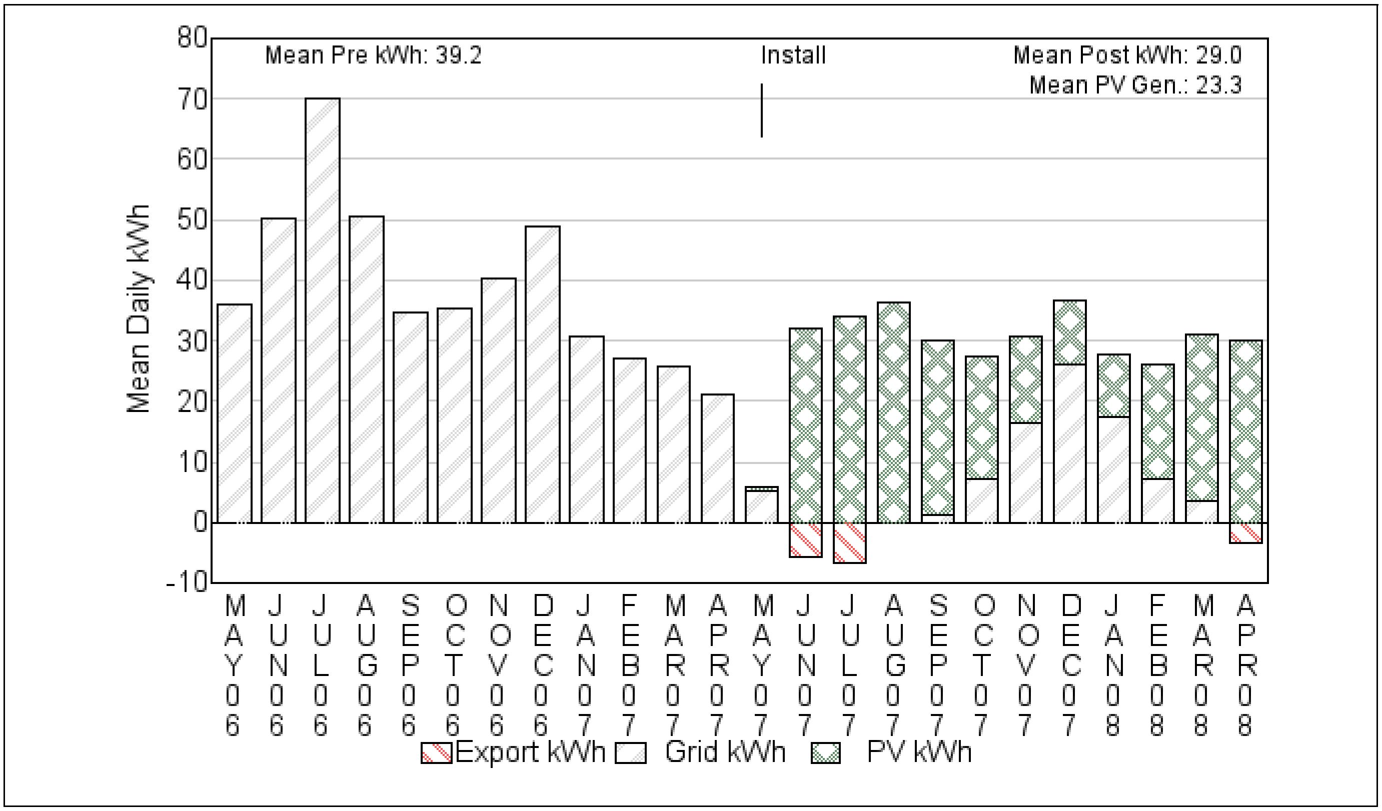


Figure 1 presents the household consumption profile for a site with stable consumption and production in excess of consumption. The graph series consist of three segments: Gray represents the electricity consumed off of the grid; red represents exported electricity generated by the PV system; and green represents PV generation consumed at the site. Both the gray and red segments come from the utility bill, where a negative bill indicates the export of electricity. Total PV production is the sum of the green segment and the absolute value of the red segment.

As the annotations on the graph show, for the site presented in Figure 1**Error! Reference source not found.**, the average daily consumption prior to PV installation is 8.7 kWh while the post-consumption is 8.4 kWh, showing relatively stable levels of consumption before and after installation of the PV system. The site represented in Figure 1Figure 1 is a net exporter site, with an average PV generation of 12.1 kWh that exceeds the average daily consumption of 8.4 kWh, leading to a net average daily export of 3.7 kWh. Additionally, the consumption of the site is low relative to most sites in San Diego and relative to most CSI participants. The low level of consumption could contribute to the site's production exceeding its consumption.

Figure 2: PG&E Site—Declining Consumption[2]



The site presented in Figure 2 has a decline in consumption, going from a mean daily pre-kWh of 39.2 kWh to 29.0 kWh per day. The PV production at this site satisfies 80 percent of the average daily consumption. Looking at the load shape for this site, there is a significant decline in electric usage in the summer following the installation of the PV system. Because it occurs during the summer months, the decline in the electric usage appears to be due to a reduced cooling load. The decline in the central air conditioning (CAC) load could be due to several factors, including behavioral changes, changes in weather, installation of energy efficiency measures, or a remodel at the time of the PV installation.[3]

The site presented in Figure 3 has an increase in consumption, going from 40.3 kWh before installation to 63.5 kWh per day. The PV production at the site satisfies 47 percent of the average daily post-consumption. The increase in the customer's load appears to be associated with an increase in the summer and winter consumption. The increase in the electric load could be due to several factors including: behavioral changes leading to increased CAC and electrical appliance usage; a warmer summer leading to increased CAC usage; increase in the number of people in the household; or a remodel at the time of the PV installation that added square footage to the house and perhaps a central air conditioner.

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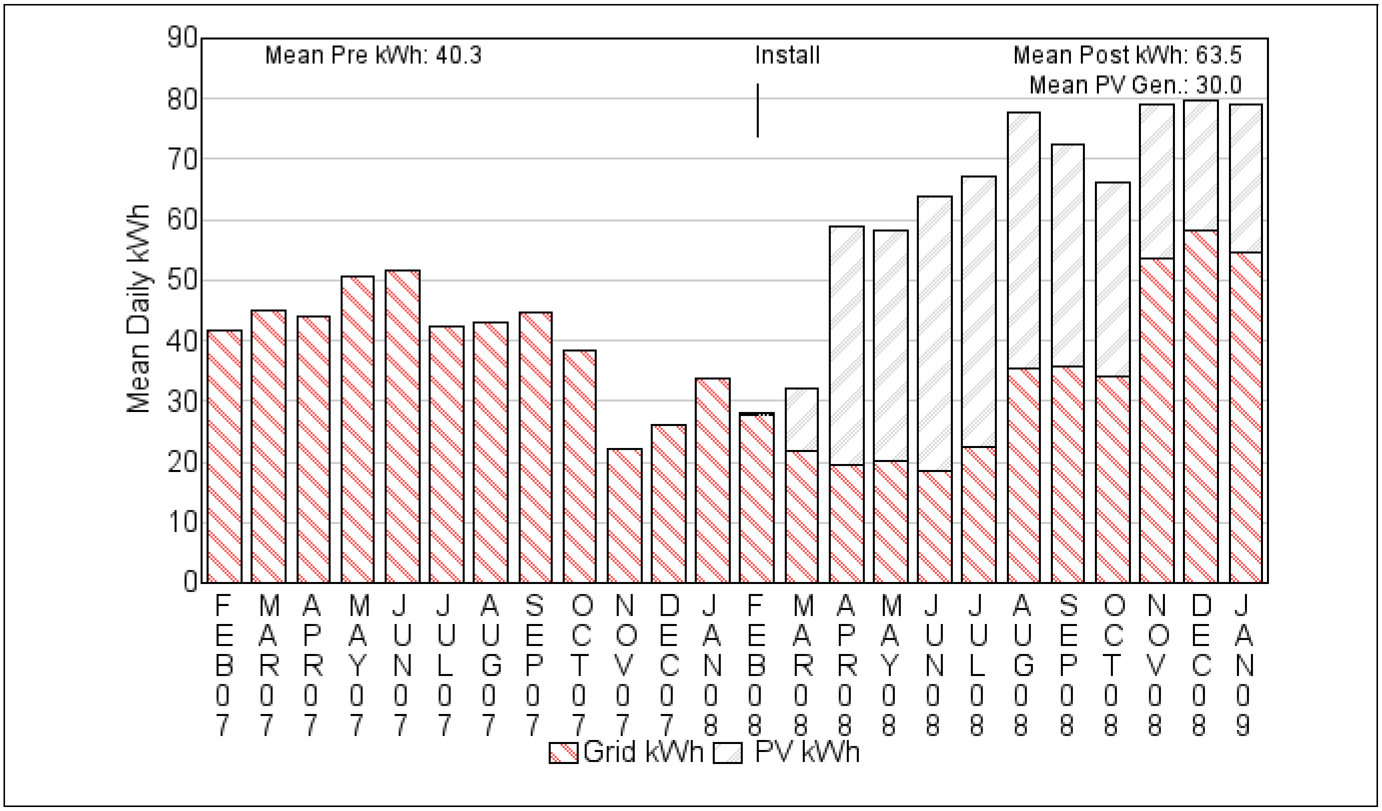
[2] The May total consumption is very small and may be due to an inaccurate date for the PV installation. During the analysis of billing and PV generation data it became apparent that the date the PV system begins producing electricity needs more careful attention by all three utilities. Future analyses would benefit from better information about the date the PV system is producing electricity.

[3] For sites included in the phone survey it is possible to determine if they have a central air conditioner. The phone survey, however, did not determine if households installed a new air conditioner, if they remodeled their homes, or if they changed the electricity consumption behavior at the time of PV installation. Future analyses should incorporate these types of changes.

Figure 3: SCE Site—Increasing Consumption



While the three examples shown above offer interesting demonstrations of the potential variability in consumption profiles, their value is primarily anecdotal. To understand what happens with the installation of PV systems across all participants, the analytical approach needs to examine all sites at the same time, which was the focus of the next stage of the analysis.

Modeling Changes in Energy Consumption

After limiting the subjects to 1,018 sites with 12 months of billing data for pre- and post-installation periods, a simple comparison shows that, on average, consumption after installation decreased for all three utilities. Table 1 shows the distribution of the change in consumption after installation by utility. The results indicated that for PG&E and SDG&E more than 40 percent of sites have pre- and post-PV electricity consumption that are within 10 percent of each other, while only approximately 27 percent of sites in SCE have pre-electricity consumption within 10 percent of post-consumption. Furthermore, the percentage of sites with a decrease of more than 10 percent was substantially higher than the percentage of sites that showed an increase of more than 10 percent.

Table 1: Pre- and Post-Electricity Consumption Distribution by Utility

Utility	PG&E Sites	PG&E % of Sites	SCE Sites	SCE % of Sites	SDG&E Sites	SDG&E % of Sites
Pre is less than 50% of Post	6	0.9%	11	4.6%	1	1.1%
Pre is 50% to 90% of Post	140	20.6%	76	31.4%	14	14.7%
Pre- and Post are within 10%	292	42.9%	66	27.3%	44	46.3%
Pre is 110% to 150% of Post	196	28.8%	73	30.1%	33	34.7%
Pre is more than 150% of Post	47	6.9%	16	6.6%	3	3.2%

Nevertheless, there are many reasons why pre- and post-installation consumption may differ, so merely comparing the pre- and post-installation consumption does not explain why the change occurred. To ascertain the underlying cause of the change, a statistically adjusted engineering (SAE) model was applied to both participant and non-participants to estimate energy consumption and develop gross realization rates for PV installation and the first-year energy impacts for energy efficiency measures.

The approach used to estimate realized savings for PV generation and energy efficiency measures was a monthly SAE framework that was estimated separately for each utility using the population of participants and nonparticipants with usable billing, tracking, and survey data. The model structure explains the household's monthly utility energy usage as a function of a site-specific and time-dependent fixed effect, weather, PV generation, ex post energy efficiency savings, and other characteristics of the household. The model controls for the impact of weather on energy consumption and the interaction of weather and major weather-sensitive household measures. The model includes variables that interact with multiple independent variables, including weather, weather-sensitive measures, and a binary variable designed to indicate that the household is a CSI participant and the PV system is installed.

Table 2 lists and describes the variables that were included in the model specification and the resulting parameters for each of the IOU-specific models, with single and double asterisks indicating statistical significance at the .01 and .05 levels, respectively. The model specification was first estimated using ordinary least squares (OLS) regression. After a review of the outputs showed evidence for heteroskedasticity, a correction was applied and the results in Table 2 reflect that modification.[4]

Table 2: SAE Model Specification and Results

Independent Variable	Description	PG&E		SCE		SDG&E	
		Coefficient Estimate	Standard Error	Coefficient Estimate	Standard Error	Coefficient Estimate	Standard Error
1. $PVGen_{it}$	Monthly PV generation for site *i* in month *t*	-0.987*	0.006	-0.974*	0.011	-1.001*	0.010
2. $EESavit \times PartPV_{it}$	Monthly energy efficiency savings for site *i* where site *i* is a CSI participant	-0.616*	0.123	-0.300*	0.097	-0.871*	0.213

[4] When using OLS, one of the assumptions is constant variance of the error terms. Heteroskedasticity occurs if the error terms exhibit non-constant or different variances. Heteroskedasticity does not bias the coefficient estimates but it does lead to an under estimation of the standard error if not corrected for during the modeling. The results presented here incorporate weighted least squares to correct for heteroskedasticity.

Independent Variable	Description	PG&E		SCE		SDG&E	
		Coefficient Estimate	Standard Error	Coefficient Estimate	Standard Error	Coefficient Estimate	Standard Error
3. $EESav_{it}$ x $NonPart_{it}$	Monthly energy efficiency savings for site *i* where site *i* is not a CSI participant	-0.575*	0.068	-0.153	0.086	-0.780*	0.176
4. HDD_{it}	Number of heating degree days in month *t* for site *i*[5]	-0.119*	0.021	-0.290*	0.039	-0.046	0.100
5. CDD_{it}	Number of cooling degree days in month *t* for site *i*	-0.611*	0.041	-0.113**	0.057	-0.540*	0.160
6. HDD_{it} x $People_i$	Number of heating degree days in month *t* for site *i* times the number of people in the household for site *i*	0.035*	0.004	-0.024*	0.009	-0.043*	0.015
7. CDD_{it} x $People_i$	Number of cooling degree days in month t for site i times the number of people in the household for site i	0.148*	0.009	-0.062*	0.011	0.008	0.022
8. HDD_{it} x $SQFT_i$	Number of heating degree days in month t for site i times the housing square footage for site i	0.00007*	0.000006	0.0002*	0.00001	0.00005**	0.00002
9. CDD_{it} x $SQFT_i$	Number of cooling degree days in month t for site i times the housing square footage for site i	0.0003*	0.00001	0.0003*	0.00002	0.00027*	0.00004
10. CDD_{it} x CAC_i	Number of cooling degree days in month t for site i times a binary variable (0, 1) indicating the presence of a central air conditioner at site i	0.844*	0.020	1.030*	0.032	1.111*	0.041
11. CDD_{it} x CAC_i x $PartPVPost_{it}$	Number of cooling degree days in month t for site i times a binary variable (0, 1) indicating the presence of a central air conditioner at site i times a binary variable (0, 1) indicating that site i is a CSI participant site and the PV system is installed	0.027	0.040	-0.106**	0.056	-0.501*	0.190
12. CAC_i x $PartPVPost_{it}$	Binary variable (0, 1) indicating the presence of a central air conditioner at site i times a binary variable (0, 1) indicating that site i is a CSI participant site and the PV system is installed and it is summer time (June, July, August, or September)	5.687	10.208	42.765*	16.423	76.906**	35.304
13. HDD_{it} x $EHeat_i$	Number of heating degree days in month *t* for site *i* times a binary variable (0, 1) indicating the presence of a non-natural gas heater at site *i*	0.132*	0.009	0.057**	0.029	0.475*	0.034
14. HDD_{it} x $EHeat_i$ x $PartPVPost_{it}$	Number of heating degree days in month *t* for site *i* times a binary variable (0, 1) indicating the presence of a non-natural gas heater at site *i* times a binary variable (0, 1) indicating that site *i* is a CSI participant site and the PV system is installed	-0.146*	0.033	-0.209**	0.106	-0.125	0.149
15. $EHeat_i$ x $PartPVPost_{it}$	Binary variable (0, 1) indicating the presence of a non-natural gas heater at site *i* times a binary variable (0, 1) indicating that site *i* is a CSI participant site and the PV system is installed and it is winter time (November, December, January, or February)	67.839*	14.776	-29.340	33.908	19.130	27.828
16. HDD_{it} x $ESpa_i$	Number of heating degree days in month *t* for site *i* times a binary variable (0, 1) indicating the presence of an electric heated spa at site *i*	0.082*	0.017	0.126*	0.026	0.123*	0.046

[5] The HDD and CDD are calculated using a 65 degree basis. All temperatures cooler than 65 lead to additional heating degree days while temperatures warmer than 65 lead to additional cooling degree days.

Independent Variable	Description	PG&E		SCE		SDG&E	
		Coefficient Estimate	Standard Error	Coefficient Estimate	Standard Error	Coefficient Estimate	Standard Error
17. HDD_{it} x $ESpa_i$ x $PartPVPost_{it}$	Number of heating degree days in month *t* for site *i* times a binary variable (0, 1) indicating the presence of an electric heated spa at site *i* times a binary variable (0, 1) indicating that site *i* is a CSI participant site and the PV system is installed	0.191*	0.046	-0.151	0.085	-0.220	0.179
18. $ESpa_i$ x $PartPVPost_{it}$	Binary variable (0, 1) indicating the presence of an electric heated spa at site *i* times a binary variable (0, 1) indicating that site *i* is a CSI participant site and the PV system is installed	-32.180**	15.078	17.853	17.395	5.230	31.437
19. CDD_{it} x $ESpa_i$	Number of cooling degree days in month *t* for site *i* times a binary variable (0, 1) indicating the presence of an electric heated spa at site *i*	-0.109*	0.039	0.062	0.042	-0.216*	0.066
20. CDD_{it} x $ESpa_i$ x $PartPVPost_{it}$	Number of cooling degree days in month *t* for site *i* times a binary variable (0, 1) indicating the presence of an electric heated spa at site *i* times a binary variable (0, 1) indicating that site *i* is a CSI participant site and the PV system is installed	0.105	0.117	-0.029	0.093	0.736*	0.221
21. HDD_{it} x $EPool_i$	Number of heating degree days in month *t* for site *i* times a binary variable (0, 1) indicating the presence of an electric heated pool at site *i*	-0.127*	0.049	0.266*	0.076	-0.132	0.096
22. HDD_{it} x $EPool_i$ x $PartPVPost_{it}$	Number of heating degree days in month *t* for site *i* times a binary variable (0, 1) indicating the presence of an electric heated pool at site *i* times a binary variable (0, 1) indicating that site *i* is a CSI participant site and the PV system is installed	0.025	0.115	0.149	0.155	-0.497	0.469
23. $EPool_i$ x $PartPVPost_{it}$	Binary variable (0, 1) indicating the presence of an electric heated pool at site *i* times a binary variable (0, 1) indicating that site *i* is a CSI participant site and the PV system is installed	-118.815*	34.387	52.304	36.922	109.849	78.176
24. CDD_{it} x $EPool_i$	Number of cooling degree days in month *t* for site *i* times a binary variable (0, 1) indicating the presence of an electric heated pool at site *i*	-0.559*	0.128	-0.320*	0.077	-0.491*	0.164
25. CDD_{it} x $EPool_i$ x $PartPVPost_{it}$	Number of cooling degree days in month *t* for site *i* times a binary variable (0, 1) indicating the presence of an electric heated pool at site *i* times a binary variable (0, 1) indicating that site *i* is a CSI participant site and the PV system is installed	1.148	0.257	0.237**	0.111	0.667	0.491
		R Squared	0.979	R Squared	0.978	R Squared	0.978

* represents statistical significance at the 1% level
** represents statistical significance at the 5% level

The first result of note is that the R-squared values for all three utilities are approximately 98 percent, indicating that the model explains nearly all of the variability in utility consumption. Having established a reasonable goodness of fit for the models, the attention now turns to the parameter estimates for the independent variables.

The coefficients in Table 2 represent each independent variable's impact on the household's consumption. For each one-unit change in the explanatory variable, the coefficient represents the kWh change in energy consumption. The parameters of most interest are the estimated coefficients for the PV production and energy efficiency savings variables (variable numbers 1, 2, and 3). The parameters for these variables represent the SAE realization rates that show the share of each of those variables that are observed in household billing data. A coefficient of negative one (-1.00) would indicate that 100 percent of the estimated values for those variables was observable in the data. Note that the realization rate for energy efficiency measures is estimated separately for CSI participants and nonparticipants. These realization rates help to determine if the PV generation data and the ex post energy efficiency savings values need to be further adjusted due to savings realized in the site level bills.

Based on the SAE models, the realization rate of PV systems installed in SDG&E's, PG&E's, and SCE's service territories is approximately 100, 98.7, and 97.4 percent, respectively. The realization rates are precisely estimated and provide strong support for accuracy of the PV production estimates in the model. The estimated realization rates are interpreted to mean that 97.4 to 100 percent of the PV generation is observable in the bills.

The estimated coefficients for all energy efficiency variables—based on the reported ERT[6] savings for the measures installed in each household—are negative and statistically significant. The realization rates for the energy efficiency measures installed in SDG&E's territory are 0.87 for CSI participants (EESave * PartPV) and 0.78 for nonparticipants (EESave * Nonpart). These estimated coefficients indicate that the model finds or realizes 87 percent and 78 percent of the estimated savings from energy efficiency measures in the customers' billing data. In PG&E's territory, the energy efficiency realization rates are 62 percent for CSI participant and 58 percent for nonparticipants. In SCE's service territory, the energy efficiency realization rates are only 30 percent for CSI participants and 15 percent for nonparticipants. The energy efficiency realization rates are statistically significant for participants in all three IOUs. The energy efficiency realization rates are statistically significant for non-participants in SDG&E and PG&E and are marginally significant for nonparticipants in SCE's service territory.

The realization rates imply that for SDG&E, 87 percent of each household's energy efficiency savings were observed in the CSI participant bills and 78 percent of the reported savings were observed for nonparticipants. The lower realization rates for PG&E and SCE relative to SDG&E may be a function of the distribution of measures installed, as SDG&E had far fewer participants with refrigerator recycling and pool pumps, which might have different realization rates compared to most measures.[7] Regardless, the finding that all six realization rates are less than 100 percent should be viewed with caution given that the ratio of energy efficiency savings to consumption was less than 5 percent for all three utilities and that energy efficiency was not the focus of this analysis.

The model also included independent variables to control for the influence of weather (variables 4 and 5); the interaction of weather and the number of people in the household (variables 6 and 7); the interaction of weather and square footage (variables 8 and 9); and the interaction of weather with major electrical measures in the household (variables 10 through 25). Participation and post-installation dummy variables are also included in most of the interaction terms.

The estimated coefficients on the non-interactive weather variables are counter-intuitive, as one would typically expect hotter or cooler temperatures to increase consumption. This is due to the inclusion of many interactive variables for weather, which are more informative. For example, the estimated coefficient for cooling degree days (CDD) interacted with the presence of a central air

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[6] The ERT is the 2006-2008 evaluation reporting tool. The ERT includes the gross ex post per unit energy savings values incorporated into this analysis.

[7] A review of the end use level saving per application by utility revealed that PG&E and SCE have many more households that recycled refrigerators and installed pool pumps than occurred in SDG&E participant and nonparticipant samples. If the recycled refrigerator savings are based on the assumption that the refrigerator is not replaced, but many households replace the refrigerator, the ERT savings would be high relative to the reduction in household electricity usage. The replacement of recycled refrigerators with new refrigerators would contribute to a lower realization rate. Similarly, if the pool pump savings assume a reduction in pool pump run times that were not actually undertaken in this sample of participants, the ERT savings would not be observable in the billing data.

conditioner finds that participant and nonparticipant households with air conditioners use statistically significantly more electricity on hot summer days than households without air conditioners.[8]

As an illustration of what these parameters mean, an increase in the day's average temperature from 65 to 66 degrees would cause a household with CAC to use 1.11 kWh more energy than a household without an air conditioner for the day in SDG&E's territory. If the one-degree increase in the daily average temperature occurs for each day of the month, the household with CAC would use 33.3 kWh more in a 30-day month than the household without air conditioning. For SCE households, a one-degree increase in the daily average temperature increases the daily usage for a home with air conditioning by 1.03 kWh or 30.9 kWh per month relative to a SCE household without air conditioning. In PG&E's service territory, a one-degree increase in temperature increases the daily usage for a home with air conditioning by 0.84 kWh or 25.2 kWh per month relative to a household without air conditioning.

The estimated coefficients on the weather interaction terms are interpreted as the energy consumption from a one-unit change in heating or cooling degree days for participant households, with the household appliance, following the installation of PV. These variables are designed to capture changes in the use of weather-sensitive household measures following the installation of PV systems. Positive, statistically significant coefficients on these measures would indicate that CSI participants are more sensitive to weather, increasing their usage of energy-intensive measures following the installation of their PV systems. If these coefficients are insignificant, CSI participants do not modify their usage of energy-intensive weather sensitive measures relative to nonparticipants following the installation of their PV systems. If the coefficients on these variables are statistically significant and negative, the model results would imply that CSI participants are decreasing their usage of energy-intensive weather-sensitive measures relative to nonparticipants after their PV systems were installed. Weather may also influence electricity usage through its interactive effect with square footage and the number of people in the household.

The model includes two variables with interaction between PV participation and presence of a central air conditioner. The first PV/CAC interaction term is a binary variable (0/1) indicating that it is summer time, the household has a central air conditioner, and the household has installed a PV system. The coefficient on this variable will show if the household increases or decreases their CAC consumption of electricity after the PV system is installed apart from the influence of weather on CAC consumption. The second variable interacts with PV, CAC, and CDD. The coefficient on this variable will show the influence of a one-degree increase in the cooling degree days on the CAC electricity consumption for a household with a PV system.[9]

The positive, statistically significant estimated coefficient on the interaction of CAC with post-CSI participation (variable 12) indicates that households with air conditioners use their CAC more in the summer, following the installation of their PV systems, than nonparticipant and pre-PV participant households, regardless of the weather. For households with CAC in SDG&E's territory, following the installation of solar, their monthly kWh usage increased by approximately 77 kWh during the summer months.[10] This increase in usage was independent of the temperature. For households with CAC in

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[8] The CDD are calculated on a 65 degree basis. If a day's average temperature is higher than 65 degrees, the day's CDD are augmented by the number of degrees the average temperature exceeds 65. The monthly CDD is the sum of the daily CDD.

[9] The influence of CDD on CAC consumption for a nonparticipant household or for a participant household prior to the installation of their PV system is measured by the coefficient on the CDD/CAC interaction term. The influence of CDD on CAC consumption for a participant household following the installation of their PV system is measured by the sum of the coefficients on CDD/CAC and CDD/CAC/PVPart.

[10] For SDG&E, the summer months are July, August, and September. The summer months were chosen looking at the monthly distribution of CDD.

SCE's territory, following the installation of their PV system, their monthly electricity consumption increased by approximately 43 kWh during the summer months.[11]

The estimated increase in CAC usage following PV installation, however, is counter balanced in SDG&E's and SCE's territories by the estimated coefficient on the interaction of central air with post-CSI participation and cooling degree days. For SDG&E and SCE the models find a statistically significant negative relationship between weather and CAC electricity usage for CSI participant households following the installation of their PV systems. The estimated coefficient on the interaction of weather, CAC, and the post-CSI participant dummy variable implies a one-degree increase in daily average temperature in SDG&E territory causes post-PV households with air conditioning to use 0.501 kWh less per day and 15.03 kWh less per month than a household with air conditioning that does not have PV installed. In SCE's territory, a one-degree increase in average daily temperature is associated with 0.106 kWh less per day or 3.18 kWh less per month for households with CAC and PV systems relative to SCE households with CAC and no PV system. In PG&E's territory, the model did not find a statistically significant relationship between weather, CAC usage, and post PV installation.

In summary, following the installation of their PV system, households generally appear to use their air conditioners more, but their usage is less sensitive to increases in temperature. For CSI participant households in SDG&E's territory, the reduced weather sensitivity in CAC usage counteracts the general increased CAC usage if the average cooling degree days of the month is higher than 5.2; that is, if the average temperature is 70.2 ^{o}F. Therefore, if the average cooling degree days were 5.3, a nonparticipant household with CAC will, on average, use more electricity than a similar CSI participant household. For SCE households, the critical CDD value is 13.5.

The model's findings show that CAC usage for CSI households is less sensitive to the weather than CAC usage for nonparticipant households. On very hot days, CSI participants increase their air conditioning consumption less than is observed in the nonparticipant sample. The CAC interactive terms for SDG&E and SCE support the hypothesis that CSI households increase their general usage of air conditioning following the installation of the PV systems. Perhaps because CSI households have increased their general usage of air conditioning following PV installation they increase their usage less as the temperature increases relative to nonparticipants with CAC.

As an illustration of what these findings mean, Figure 4 and Figure 5 show the impact of PV installation and extreme weather on the estimated loads for two households with CAC in SDG&E's service territory. Both graphs show simulated load profiles derived from applying the SAE coefficients to a participant and nonparticipant household in SDG&E's territory. The participant load profiles are represented by the bars while the nonparticipant consumption is represented by the single line. Figure 4 is simulated under actual weather for 2007 and 2008. Figure 5 is simulated under extreme summer weather for 2007 and 2008.

[11] For SCE, the summer months are June, July, August, and September. The summer months were chosen looking at the monthly distribution of CDD.

Figure 4: SDG&E Simulated Loads for Participant and Nonparticipant Sites with Actual Summer Weather

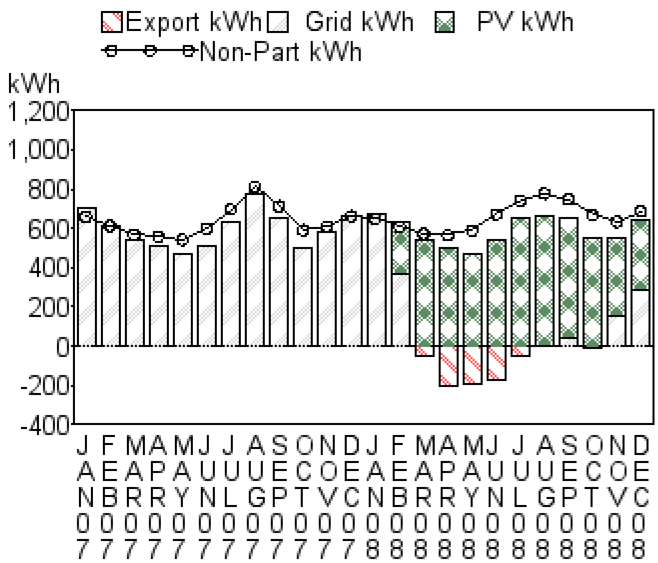
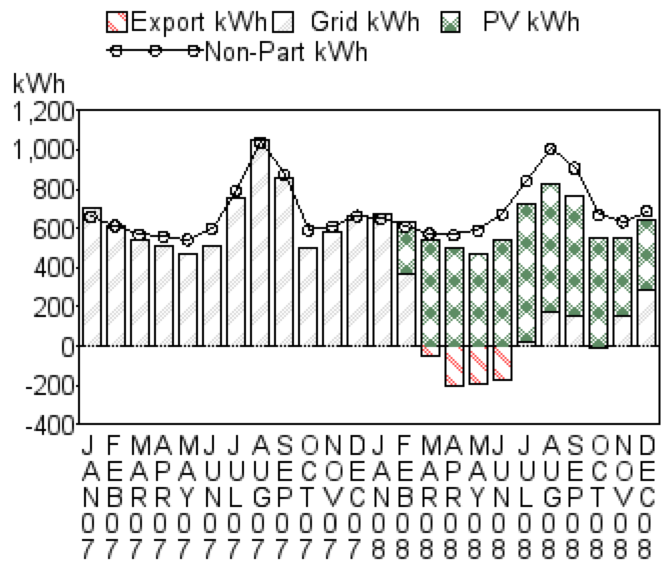


Figure 5: SDG&E Simulated Loads for Participant and Nonparticipant Sites with Extreme Summer Weather



In both figures, the load profiles of the two households look similar prior to the installation of the PV system. Following the installation of the PV system, the illustrations show that the usage for the two households (CSI participant and nonparticipant) diverges during the summer months. For the summer months in Figure 4 (July, August, and September), after the PV system is installed the CSI participant's electricity consumption is approximately 120 kWh less in each month than the monthly consumption for the nonparticipant.[12] During the post installation summer of 2008, the CSI participant's reduced CAC weather sensitivity more than offsets the general increase in CAC usage.

To highlight the influence of the CSI participants' reduced CAC weather sensitivity on the relative load profiles of the two households, the graph in Figure 5 illustrates the same two households' simulated loads under extreme weather. In this figure, the average daily temperature in July is five degrees higher than in Figure 4, seven degrees higher in August, and three degrees higher in September. The electricity consumption for both households rises in the summer months relative to the load profiles in Figure 4. Under the extreme summer conditions prior to the installation of the system, both households increase their loads by a similar amount. Following the installation of the system, however, the extreme weather causes the load of the PV household to increase by less than of the load for the nonparticipant household. Under the extreme weather simulation, the CSI participant's monthly consumption is 175 kWh less than the nonparticipant's consumption in August 2008.

Overall Conclusions and Key Findings

The billing data and the billing analysis model illustrate that there is a sizeable influence of PV systems on residential utility energy consumption. In reviewing and comparing the billing and PV system data, it is clear that individual household energy consumption can rise, fall, or remain unchanged following the installation of PV systems. While the simple pre- and post-installation comparison does

[12] Under actual weather, the model predicts that the participant's electricity consumption will be 661 kWh while the nonparticipant's consumption is forecast to be 779 kWh during August 2008.

not provide an explanation of why or how consumption changes, the SAE billing model demonstrated that there are numerous factors that influence consumption following the installation of PV systems.

Among the key findings from the billing model were the estimated realization rates for the quantity of energy generated by PV systems and the savings for energy efficiency measures. The generation estimates were largely supported by the estimated coefficients, with approximately 97-100 percent of the ex ante generation realized in the billing analysis. For energy efficiency savings, the realization rates were both lower and less consistent, ranging from 15 percent for SCE non-participants to 87 percent for SDG&E participants.

Other key findings of interest include the various interaction terms involving weather, major appliances, and program participation. For example, the analysis finds that after the installation of PV systems, household energy demand associated with CAC usage increases while the weather sensitivity of CAC usage falls for CSI households in SCE's and SDG&E's territory. This means that households with PV systems are using more air conditioning, but they are less inclined to use more during uncharacteristically hot periods than non-participants.

The implications of these findings are many, but they all lend support to the single idea that electricity generated by PV systems does not simply replace electricity consumed off the grid. The underlying behavioral factors are varied, complex, and difficult to measure. Nevertheless, they do manifest themselves in household characteristics (presence of CAC, for example) that can be measured, which has promise for offering program designers and implementers some means for using the information to improve program design.

The use of billing analysis to investigate the influence of PV and possible behavioral post-PV influences on energy consumption is groundbreaking and important. Future analyses, however, would benefit from additional information on other changes that may be occurring in the household simultaneously with the installation of the PV system. For example, while the phone survey for this study included information on CAC, pools, spas, and electric heating, participants and nonparticipants were not questioned about possible changes in these electric measures or changes in the household's usage of the measures.