Estimating Energy and Greenhouse Gas Impacts in All-Electric Residential New Construction

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ABSTRACT

New construction has always presented challenges for evaluators seeking to estimate the energy impacts associated with efficiency improvements. The lack of pre-construction data and/or a quality control group complicates the reconciliation of engineering estimates of savings with observed consumption. These challenges are augmented when the impacts result from the full electrification of the building and when greenhouse gas (GHG) and customer bills, which depend on hourly impacts, are the primary interest.

This paper presents the methodology and results from an evaluation of Sacramento Municipal Utility District's (SMUD) All-Electric Smart Homes Program, which incentivizes home builders to construct all-electric and all-electric-ready homes to take greater advantage of the renewable energy economy and reduce greenhouse gas emissions.

To overcome some of the evaluation challenges with new construction, the study employed a hybrid approach consisting of building simulations and the statistical modeling of participant AMI data. In this method, CBECC-Res Title 24 Energy Compliance Software generated simulated hourly end-use load profiles for participant homes under both the as built and counterfactual configurations. The team also used regression models with AMI data to develop load profiles of the actual consumption, disaggregated into base load and temperature-sensitive components. These simulated and actual load profiles were combined to create calibrated end-use profiles of both program and counterfactual homes. The comparison of these profiles was used to estimate the energy, GHG, and bill impacts for the program. Additionally, given the program timeframe, this paper discusses analysis conducted to account for the influence of COVID 19.

Introduction

SMUD's All-Electric Smart Homes Program incentivizes home builders to build new all-electric single family and multifamily homes. The program is available for production builders who build neighborhoods of homes with the same or similar floorplans. To receive the all-electric incentives, builders are required to construct homes with electric appliances and with a 240 volt/22 ampere plug adjacent to the parking area to enable the homeowner to install an electric vehicle (EV) charger. The new homeowners gain access to efficient electric technologies, including heat pumps, heat pump water heaters, and induction cooktops. By the end of 2021, there were approximately 420 program participants. Slightly fewer than 400 of these were single family homes built by 23 builders using 68 different floorplans. For this paper, the analysis focuses exclusively on single family homes.

Evaluation Objectives

The main objectives of the impact evaluation for this Program were to quantify the program impacts in terms of electric and gas consumption, greenhouse gases (GHG), and customer bills. These impacts are all derived from the substitution of gas end uses with electric equivalents, not any upgrades to the energy efficiency of the equipment, so the evaluation is looking at how the program has affected total electric and gas consumption in the household. Also, because the GHG and bill impacts are highly dependent on the time of day, the evaluation requires a comparison of energy consumption based on hourly load profiles.

COVID-19 and Analysis Cohorts

The evaluation plan was developed during the first waves of the COVID-19 pandemic, so significant emphasis was placed on those homes built early enough to have at least 10 months of consumption data before March 2020. The effects of COVID were considered too much of an unknown to base the impact evaluation on projects associated with homes built later in the Program. After data collection and some of the initial analysis, the evaluators came to consider questions about the persistence of COVID-19 effects and which period is a better representation of these households going forward. While the period of lockdowns is, one would hope, not what the future holds, there is some question about what amount of remote employment and other factors will be a permanent fixture in years to come. To the extent that the Post-COVID period might represent a “new normal,” it is important to consider the energy consumption from this period as well. Given these questions, the evaluators opted for grouping the participant homes into three cohorts:

1. Pre-COVID: All homes with enough data before March of 2020 to assess Pre-COVID consumption.
2. Post-COVID: All homes with enough data after March of 2020 to assess Post-COVID consumption.
3. Common Pre- and Post-COVID: Those homes common to the first two cohorts.

The motive for using these three cohorts is that the first two maximize the number of homes available for the analysis, ensuring that the portrayals of these two periods is based on as many projects and homes as possible, whereas the third allows for an “apples-to-apples” comparison of results from the first two groups. Note that the third cohort should consist of all the same homes as the first cohort, since any home with sufficient data before the pandemic would logically have data for period after the onset of COVID. However, due to data attrition this third cohort is a subset of the first.

Impact Methodology

The development of the necessary hourly load profiles to calculate the impacts presents two main challenges. The first is that new construction programs do not offer an easy counterfactual or baseline with which to compare Program participants. Whereas evaluations on existing homes can leverage data from before and after Program participation to employ any number of pre/post comparison methods, this approach clearly does not apply to new homes. For new construction, one of the main options is to identify a control group—a set of homes with similar attributes to the participant homes, but with both gas and electric as the sources of energy. The second challenge is identification of a reasonably equivalent control group, with similar attributes (home size and composition, HVAC equipment and efficiency, etc.) to the Program's homes. The necessary data are not readily available and collecting them is expensive and time consuming. But even if it were possible to identify such a control group efficiently and reliably, obtaining the PG&E gas records is another hurdle that makes this approach a fraught endeavor.

To overcome the challenges described above, the evaluation team developed an approach that combined building simulations, which were created by the project team, with statistical modeling of AMI data, which was provided by SMUD. A high-level visual portrayal of the main steps associated with this methodology is presented in Figure 1, followed by a more descriptive summary of the method.

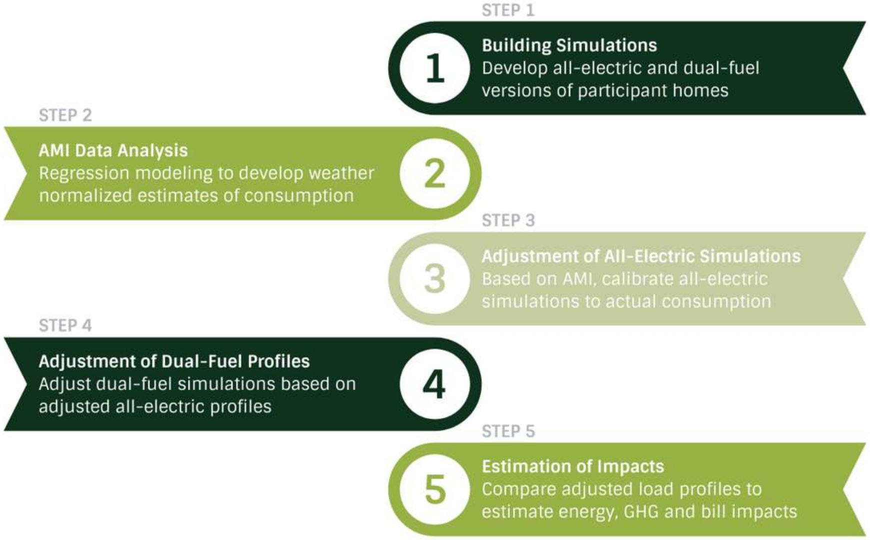

Figure 1. Main Steps in Impact Evaluation.

As seen in Figure 1, the impact approach started with building simulations, which provided hourly load profiles of simulated electricity consumption by end use in the Program all-electric homes. The simulation prototypes were then modified to represent the dual-fuel, or counterfactual, versions of these homes. If these all-electric and dual-fuel simulations were reliably representative of reality, all the impacts could be generated using their load profiles. However, actual consumption can vary substantially from building simulation estimates, so the profiles were calibrated to weather-normalized consumption developed from the AMI data for the participant homes. This calibration began by adjusting the all-electric simulation profiles to reflect actual consumption and later similar adjustments are applied to the dual-fuel simulations. The result is a series of load profiles for both all-electric and dual-fuel homes where both the magnitude and timing of electric and gas consumption are consistent with actual consumption. The electric and gas impacts are calculated by comparing the load profiles for the all-electric and dual-fuel homes, which are then used to determine the GHG and bill impacts.

Building Simulations

The evaluation used building simulation models based on Title 24 (Part 6) Building Energy Efficiency Standards to develop Title 24 compliant all-electric and dual-fuel energy use profiles for each home. The original simulations submitted for the all-electric homes as part of program enrollment were updated and corrected for errors. From these, the counterfactual models to estimate both electricity and natural gas usage were developed as if the home had been built as a Title 24 compliant dual-fuel home in the Sacramento area.

The counterfactual building simulations were intended to replicate the gas and electricity usage that each unique home would have used if it had not been built as part of the SMUD Smart Home Program. These models assume the homes would have included natural gas furnaces, water heaters, dryers, and cooktops. The counterfactual case was created with standardized inputs. The evaluation team based their assumptions for the choice of standardized inputs on their extensive experience with modern new single-family construction in California. Key inputs to the counterfactual included the use of a small instantaneous gas water heater with an Energy Factor (EF) of 82% (the 2016 Energy Code Prescriptive design for New Construction, NC), a central gas furnace with and Annualized Fuel Utilization Efficiency (AFUE) of 95%, and an air conditioning unit with SEER and EER efficiencies matching those of the heat pump in the all-electric model.

AMI Data Analysis

If the building simulations were accurate representations of actual consumption, the energy and GHG impacts could be derived directly by comparing the simulated load profiles from the all-electric homes with those from counterfactual dual-fuel homes. Actual consumption, however, varies considerably due to a variety of factors, such as the number of occupants, occupancy schedules, and behavioral factors, such as a preference for warmer or cooler temperatures.

How different, on average, are the estimates of consumption from the all-electric building simulations when compared with the AMI data? A comparison of the participant homes in the Pre-COVID cohort showed an average annual consumption of 7,241 kWh from the AMI data compared to 6,917 kWh for the simulations. This difference is less than 5%, but it does not account for differences in weather. The weather-normalized annual consumption of the AMI data, which is based on the same TMY weather as the building simulations, is 7,525 kWh for the Pre-COVID cohort. The discrepancy of 609 kWh represents a nearly a 9% difference consumption.

Even the 9% difference in annual weather-normalized consumption for this cohort is small, enough so that the simulations might seem to be a suitable representation of consumption. Total annual consumption, however, provides an incomplete picture of the equivalency of the two estimates. Extending the comparison further, separate summaries of the load profiles by month and hour reveal more relevant discrepancies. This is illustrated in Figure 2, which shows the total hourly consumption by month and hour for the same Pre-COVID cohort discussed above.

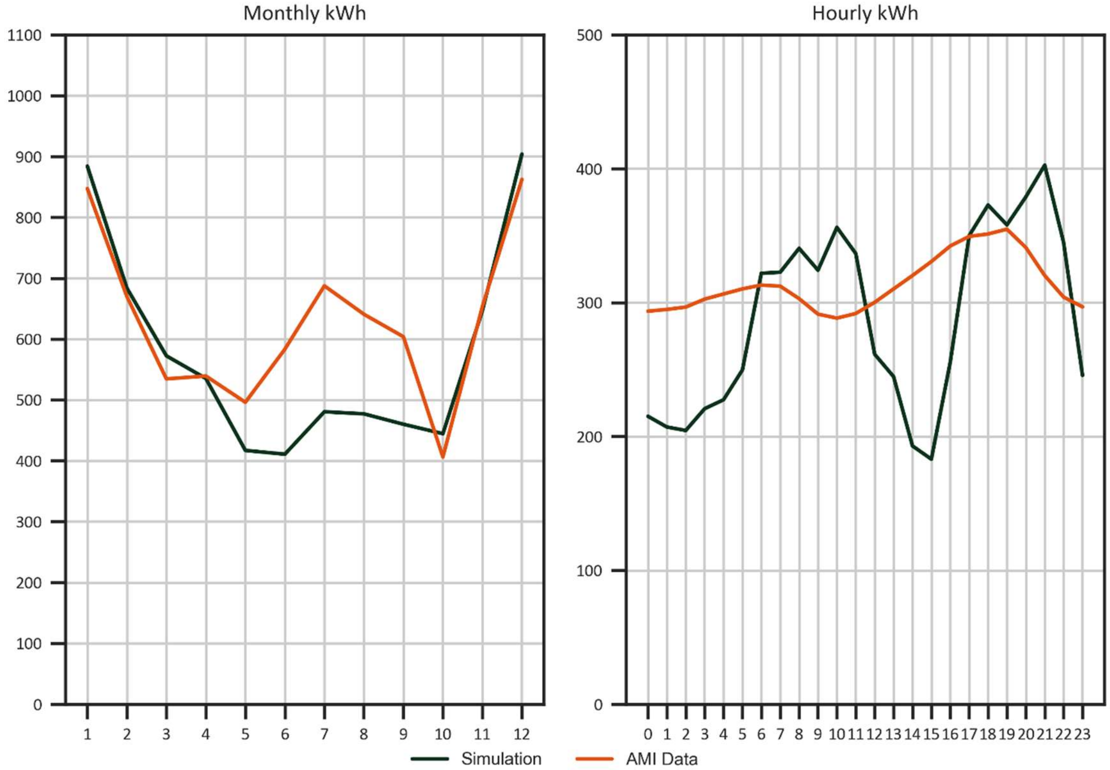

Figure 2: Monthly and hourly simulation and weather-normalized AMI profiles for Pre-COVID cohort

Based on the monthly profiles in Figure 2, the summer months are the clear source of differences between simulated and actual consumption, with load related to cooling the logical culprit. Given that heating is the primary driver behind differences in energy consumption and GHG between the all-electric and dual-fuel homes, it might be tempting to dismiss cooling differences in the AMI and building simulation models as not highly consequential. Yes, the total cooling will be incorrect, but it will be equivalently incorrect for both the all-electric and dual-fuel simulations, and therefore have less influence on the GHG and bill impacts. Before dismissing these monthly differences, however, it is important to consider the hourly profiles.

A comparison of the hourly profiles shows more marked differences. Whereas the simulations are indicative of a more distinct pattern for morning and evening occupancy, the AMI data indicate more consistent levels of consumption throughout the day. The AMI data do have higher levels of consumption in the morning and evening, but there is not the stark dip in the middle of the day that is seen in the building simulations. The monthly and hourly profiles in Figure 2 are based on averages of the total consumption for both the simulations and the weather-normalized AMI data, but the underlying variability is far less for the simulations. For the AMI data, there are some individual homes that have profiles that strongly resemble the simulation hourly profiles, but on average they do not. In contrast, all the simulations exhibit the same hourly profile with any variability due to home size, orientation, and other factors. Given the importance of the time of day for calculating the GHG impacts for electricity consumption, ignoring the differences in these profiles could result in misleading estimates of the Program impacts.

The differences between the simulations and actual consumption seen in the examples of monthly and hourly profiles mean that any analysis based solely on building simulations could misrepresent at least the seasonal and hourly timing of impacts. Given this, one might ask why not just use the weather normalized AMI data with some means of converting the electric heating to its gas equivalent. However, the AMI data is not suitable on its own because it would need to be disaggregated to end uses beyond heating, cooling, and base load. Specifically, the base load would need to be further disaggregated to identify the water heating, drying, and cooking end uses that are also associated with fuel switching. The shortcomings of both the simulations and the AMI data are what led to the development of the evaluation's impact methodology, which leverages both building simulations and AMI data.

Not only are the AMI data not sufficient to estimate the counterfactual usage estimates necessary to calculate Program GHG and bill impacts, but they are also not adequate in their raw form. First, as discussed previously, the underlying weather is an important factor. The observed consumption in the AMI data is based on actual atmospheric conditions while the simulations are based on a single typical meteorological year (TMY) profile of hourly temperatures (and other variables, such as humidity). Observed differences in usage could easily be attributed to hotter or cooler actual weather relative to the TMY data. The second issue is that even if the weather were very similar, adjusting the simulations based on total household consumption is insufficient to answer this evaluation's key research questions. Because the impacts are associated with fuel switching, the large majority of which is associated with heating, it is necessary to have some estimate how much of the AMI consumption comes from temperature sensitive end uses versus base load. The cooling load and base load components are not insignificant, but the heating consumption is critical to understand how the all-electric homes influence GHG impacts and energy costs.

All-Electric Home Simulation Adjustment

The tasks completed in steps one and two in Figure 1 (above) result in three different estimates of the consumption for the different cohorts of homes:

1. Building simulations hourly profiles for all-electric and dual fuel homes by end use, grouped into cooling, heating, and base load.
2. Weather normalized monthly AMI energy estimates for the all-electric homes by cooling, heating, and base load.
3. Weather normalized hourly AMI profiles for the all-electric homes by cooling, heating, and base load.

These three representations of consumption were the inputs used to develop the adjustments to calibrate the building simulations to the AMI for the all-electric homes. This paper does not allow for a detailed discussion, but in general the approach prioritized adjustments to cooling, which was based on analysis that showed this end use was the source of the largest discrepancies in the load profiles. The next adjustment was to heating load, with any remaining differences allocated to other end uses.

The most straightforward way to illustrate the effect of the adjustment is to compare visually the raw, or unadjusted, simulation profiles with final adjusted simulation profiles. This is presented in Figure 3, which shows the hourly base load, heating, and cooling load by quarter for the two versions. The difference in cooling load is among the most obvious adjustment, but more scrutiny shows how the overall profile more clearly matches the shapes seen in the AMI data.

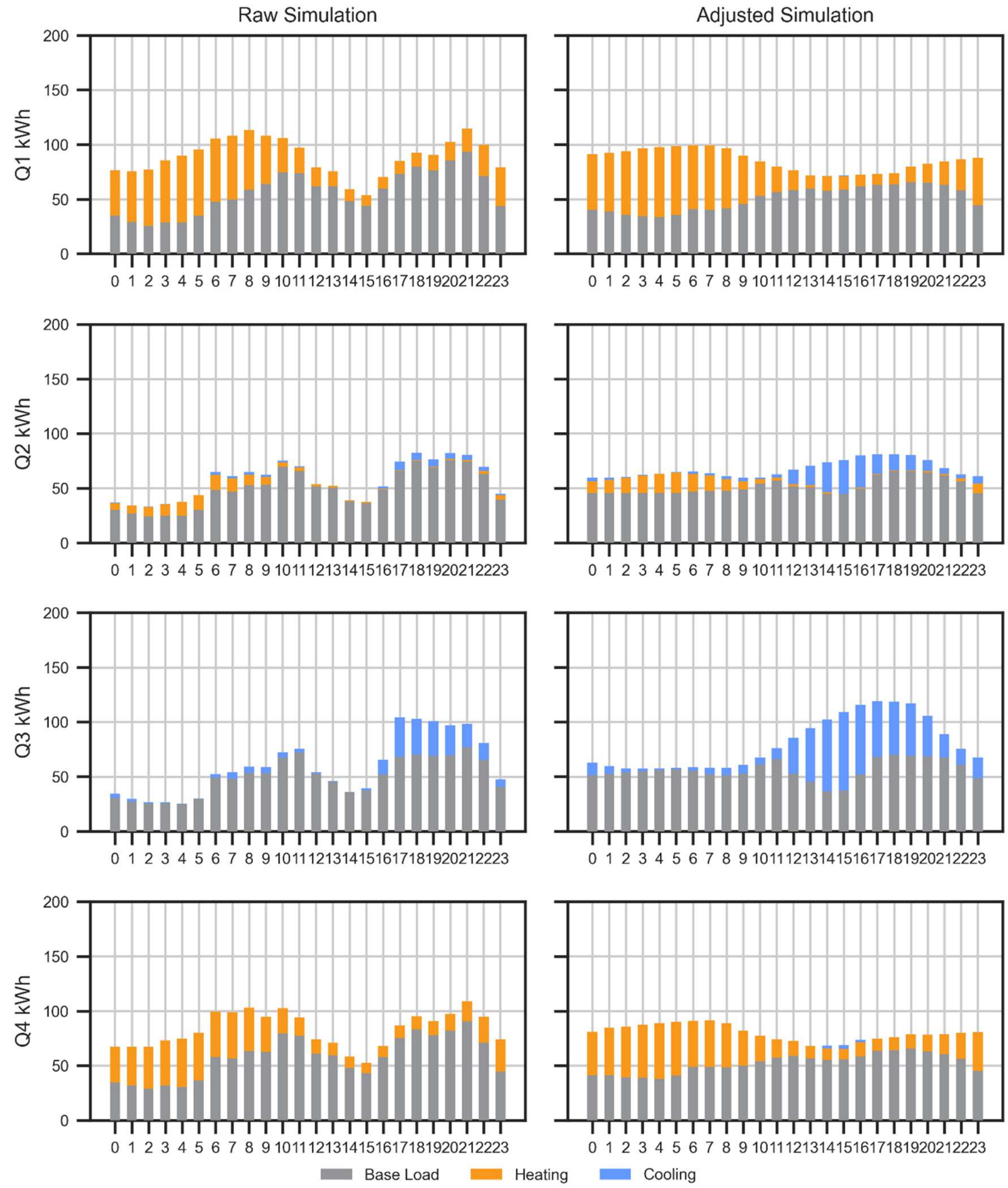

Figure 3: Unadjusted and adjusted simulation profiles by quarter for Pre-COVID cohort

Dual-Fuel Home Simulation Adjustment

Having developed adjusted simulation profiles for the all-electric homes in each cohort, the next step was to adjust the dual-fuel home building simulation estimates of usage to align with this more realistic usage profile. Based on the differences between the unadjusted and adjusted profiles, it is possible to perform similar adjustments for the dual-fuel home so that the simulated gas consumption reflects the changes made to the all-electric homes. This is essential to properly compare the corresponding energetic, greenhouse gas, and bill impacts.

Most of the gas consumption in the dual-fuel home is used for space heating, and thus should be adjusted to mirror the changes in heating energy use seen by the AMI adjusted all-electric home profile. The whole energy profile of the gas heating system, which includes gas consumption as well as a small amount of electric consumption to operate the equipment, was adjusted on a monthly basis corresponding to the change in the heating energy usage from the all-electric simulation data to the AMI adjusted all-electric data. On average, this incurs:

1. A 0.93% increase in the energy consumption of the gas heating system relative to the original simulation data for All Pre-COVID Premises,
2. A 3.64% increase in heating energy consumption for All Post-COVID Premises, and
3. A 0.34% increase in heating energy consumption for Common Pre- and Post-COVID Premises.

Additional gas consumption comes via other gas-driven base load appliances, which includes the stove/oven, water heater, and clothes dryer. The energy usage of these appliances, which consists of gas consumption as well as some electric consumption, was similarly adjusted on an hourly basis to match the base load adjustment for the all-electric home. On average, this incurs:

1. An 8.69% increase in overall energy consumption for the gas water heating, cooking, and drying relative to the original simulation data for All Pre-COVID Premises,
2. a 24.54% increase in gas appliance energy consumption for All-Post COVID Premises, and
3. a 15.14% increase in gas appliance energy consumption for Common Pre- and Post-COVID Premises.

Energy, Greenhouse Gas, and Bill Impacts

With the final adjusted simulation profiles for the all-electric and dual-fuel homes complete, the remaining task is to calculate the energy, GHG, and bill impacts associated with the Program homes. Before presenting these results, however, it is important to discuss one more important attribute of the program homes that plays an outsize role in the GHG and bill impacts.

Accounting for Solar

As shown in Table 1, most of the homes in the Program had solar panels, ranging from 75% to 84% depending on the cohort. The average system capacities ranged from 3.2 to 3.6 kW_{DC}. Per California state policy, solar systems should be sized based on the anticipated consumption of a home, so the system sizes for dual-fuel homes required a downward adjustment to account for the lack of electric consumption for heating and other end uses. Therefore, the evaluation team adjusted the dual-fuel counterfactual solar sizes down by the ratio of adjusted all-electric annual use to adjusted dual-fuel annual use.

Table 1. Homes with solar and system sizes for SMUD Smart Homes participants

Cohort	Number of Homes	Number of Homes with Solar	Mean Solar Capacity (kW_{DC})	Total Solar Capacity (kW_{DC})	Mean Solar Capacity across All Homes (kW_{DC})	Mean Solar Capacity (kW_{DC}) Applied to Dual-Fuel Homes
Common Pre- and Post-COVID Homes	69	58	3.2	185.2	2.7	1.8
Pre-COVID Homes	90	75	3.2	238.5	2.7	1.8
Post-COVID Homes	231	173	3.6	630.2	2.7	2.0

While metered solar generation was available in the historical data, these do not correspond to the TMY weather data used for simulation and weather normalization of the AMI data. To develop the solar profiles, we relied on the PVWatts® API to generate a simulated series based on a simplified one kW_{DC} system, which could be multiplied by the average system capacities for each cohort. The solar generation for each cohort is then subtracted from the total consumption to produce the net consumption. While our experience is that these simulated solar profiles are generally reliable, we do want to stress that they are not metered values and will not capture the site-specific conditions of the individual homes, so readers should consider this in interpretation of the results.

Energy Impacts

Energy impacts are based on comparing the electric consumption and gas consumption in the all-electric and dual-fuel profiles. Summaries of the annual energy impacts are presented in Table 3 and Table 4 for the adjusted and unadjusted profiles, respectively. While both versions have been presented for comparison, it is important to emphasize that the adjusted profiles reflect those aligned with the weather-normalized AMI, and therefore the most indicative of the actual Program impacts. Note also that the energy impacts in Table 3 and Table 4 are presented for three solar groups. An "All" group represents the average home, and therefore the average Program impacts, but because PV is so important to both greenhouse gas and bill impacts, "Solar" and "Non-Solar" groups have been included as well.

For the adjusted load profiles, the average all-electric home—as represented by the "All" group—resulted in an increase of 1,182 kWh for the Pre-COVID homes, or an increase in electricity consumption of 55% over a dual-fuel home. Without solar, this increase would have been 3,043 kWh, or 68%, as shown in the results for the "Non-Solar" group. For Post-COVID homes, the increase in electricity in all-electric homes is slightly higher at 57% due to the higher consumption, which was related more to cooling than those end uses associated with fuel switching.

The above comparison does not account for differences in homes in the Post-Covid period, which were substantially larger. The Common Pre- and Post-COVID group allows for a more meaningful comparison of the differences between these groups. With all things equal, the comparison of the all-electric with the dual-fuel homes illustrates what is driving the differences in consumption for the two periods. Whereas the total consumption for the all-electric home is 14% higher in the Post-COVID period, the gas consumption in the dual-fuel homes increased slightly under 7%, indicating that more of the increase in energy in the Post-COVID period is associated with electricity.

With respect to the unadjusted and adjusted profiles, the main difference is that the adjusted profiles include substantially higher levels of cooling (and possibly electric vehicles), which results in a lower increase in the electricity consumption as a percentage of consumption, since that end use is not affected by fuel switching. Note that for the Common Pre- and Post-COVID cohort, the unadjusted profiles are the same for both periods, which further bolsters the importance of reconciling the simulations with AMI data. The extent to which the Post-COVID consumption patterns are persistent is beyond the scope of this evaluation, but for at least the first couple of years after construction, the simulations are misrepresenting impacts substantially.

Table 3: Per-home energy impacts for all-electric and dual-fuel homes from adjusted simulations

		All-Electric			Dual-Fuel				Impacts	
		Electricity			Electricity			Gas	Electricity	
		kWh			kWh			kBtu	kWh	
Home Type	Solar Group	Total	Solar	Net	Total	Solar	Net	Total	Net kWh Increase	% Increase
Pre-COVID Homes	All	7,525	4,187	3,338	4,482	2,326	2,156	24,403	1,182	55%
	Solar		4,962	2,563		2,791	1,691		872	52%
	Non-Solar		0	7,525		0	4,482		3,043	68%
Post-COVID Homes	All	9,660	4,187	5,473	5,817	2,326	3,492	30,974	1,982	57%
	Solar		5,582	4,078		3,101	2,716		1,362	50%
	Non-Solar		0	9,660		0	5,817		3,842	66%
Common Homes, Pre-COVID	All	7,545	4,187	3,359	4,472	2,326	2,146	24,468	1,213	57%
	Solar		4,962	2,583		2,791	1,681		903	54%
	Non-Solar		0	7,545		0	4,472		3,073	69%
Common Homes, Post-COVID	All	8,623	4,187	4,437	5,426	2,326	3,100	26,245	1,337	43%
	Solar		4,962	3,661		2,791	2,635		1,027	39%
	Non-Solar		0	8,623		0	5,426		3,198	59%

Table 4: Per-home energy impacts for all-electric and dual-fuel homes from unadjusted simulations

		All-Electric			Dual-Fuel				Impacts	
		Electricity			Electricity			Gas	Electricity	
		kWh			kWh			kBtu	kWh	
Home Type	Solar Group	Total	Solar	Net	Total	Solar	Net	Total	Net kWh Increase	% Increase
Pre-COVID Homes	All	6,917	4,187	2,730	3,828	2,326	1,502	24,992	1,228	82%
	Solar		4,962	1,955		2,791	1,037		918	89%
	Non-Solar		0	6,917		0	3,828		3,089	81%
Post-COVID Homes	All	7,850	4,187	3,663	4,373	2,326	2,048	28,874	1,615	79%
	Solar		5,582	2,268		3,101	1,272		995	78%
	Non-Solar		0	7,850		0	4,373		3,476	79%
Common Homes	All	7,028	4,187	2,841	3,906	2,326	1,580	25,273	1,261	80%
	Solar		4,962	2,066		2,791	1,115		951	85%
	Non-Solar		0	7,028		0	3,906		3,122	80%

The increases in electricity consumption in all-electric homes presented above are to be expected. The replacement of a gas furnace and hot water heater with heat pump equivalents could have no other effect. The more relevant questions are what are the implications of these changes with respect to greenhouse gas emission and utility bills? These impacts are presented in the next two sections.

Greenhouse Gas Impacts

The evaluation calculated greenhouse gas emissions for both all-electric and dual-fuel homes based on the adjusted simulation profiles. The simulation data provided hourly electric energy usage for both the all-electric and dual-fuel homes, as well as gas usage for dual-fuel homes for the three solar groups: All Homes, Solar Homes, and Non-Solar Homes. Greenhouse gas emissions were calculated for the electric profiles (both for all-electric homes and dual-fuel homes), by multiplying the 8,760 hourly electric values by their respective short run hourly marginal emissions for 2021 (metric tons of CO_2 per MWh) and summing across the year. This calculation, which uses natural gas emission values from the statewide “GHG Calculator” developed by Energy & Environmental Economics, is shown in Equation 1.

Equation 1: Annual Electric Greenhouse Gas Emissions

$$\begin{aligned} &Annual\ GHG\ Natural\ Gas\ Emissions\ [Metric\ Tons\ of\ CO_2] \\ &\quad = \sum_{8760} Hourly\ MBtu \times \frac{Metric\ Tons\ of\ CO_2}{Mbtu} \times (1 + LUAF_{PG\&E} + ML_{upstream} \\ &\quad + ML_{ResBTM}) \end{aligned}$$

Where:

$\boldsymbol{Hourly\ MBtu}$**:** is hourly gas usage output from the adjusted simulations

$\frac{\boldsymbol{Metric\ Tons\ of\ CO_2}}{\boldsymbol{Mbtu}}$**:** is the Carbon Intensity, equal to 0.0000585 from the E3 calculator

$\boldsymbol{LUAF_{PG\&E}}$: is a compression factor and other unaccounted for losses, 2.41% from the E3 calculator

$\boldsymbol{ML_{upsteam}}$: is methane leakage upstream of natural gas power plants from the E3 calculator. This factor also applies to programs that change natural gas consumption only. Methane leakage avoided is this percentage times the GHG emissions, 5.57%

$\boldsymbol{ML_{ResBTM}}$: Residential behind-the-meter methane leakage, applicable to programs that eliminate natural gas appliances from a residential building, 3.78%

The GHG emissions from electricity generation (based on a SMUD model) and natural gas emissions for dual-fuel homes were summed to get an overall GHG emissions for the dual-fuel homes. As shown in Table 5, for homes with solar in all cohorts, the average GHG reduction across the all-electric Program homes was between 1.12 and nearly 1.19 metric tons of CO_2 annually. This is consistent with the SMUD Smart Home Program assumptions. As discussed in the section ‘Accounting for Solar’ above, the solar PV systems on dual-fuel homes were assumed to be smaller than those on all-electric homes due to the smaller electrical loads at dual-fuel homes. This assumption means that the same percentage of electricity is provided by solar for both all-electric and dual-fuel homes, but the energy (kWh) offset (and the emissions reduced) by solar are greater for all-electric than dual-fuel homes. This effect increased the net emissions reduction for all-electric solar homes, so the emissions reductions for non-solar homes are lower by approximately half compared to solar homes.

Table 5: Greenhouse gas impacts for 2021

Home Type	Solar Group	Metric Tons of CO_2 from Electricity Consumption		Metric Tons of CO_2 from Gas in Dual-Fuel Homes	Avoided GHG (Metric Tons of CO_2)
		All-Electric Homes	Dual-Fuel Homes		
Pre-COVID Homes	All	1.26	0.80	1.60	1.13
	Solar	0.98	0.63		1.24
	Non-Solar	2.79	1.64		0.45
Post-COVID Homes	All	2.05	1.28	2.03	1.26
	Solar	1.54	1.00		1.48
	Non-Solar	3.58	2.13		0.58
Common Homes, Pre-COVID	All	1.27	0.79	1.60	1.12
	Solar	0.99	0.62		1.23
	Non-Solar	2.80	1.64		0.44
	All	1.66	1.14	1.72	1.19

Common Homes, Post-COVID	Solar	1.38	0.97		1.30
	Non-Solar	3.19	1.98		0.51

One other way to understand the timing of the GHG impacts is with a heat map that shows the total avoided emissions by month and hour. This is depicted in Figure 4, which shows the heat map for both a program average home and a non-solar home. This juxtaposition is intended to illustrate the influence of solar, and though it is subtle, the program average home does have more avoided emissions during the hours of higher solar generation. The other finding to note is that there are hours where the all-electric home has higher emissions, as indicated by the orange shading. This a result of the distinct difference in the load profiles for the heating systems. The heat pump maintains a more consistent level of heating overnight while the gas furnace is off, only starting up in the early morning, which is where the most intense avoided emissions occur. For those overnight hours, however, the heat pump is generating emissions that the gas furnace does not.

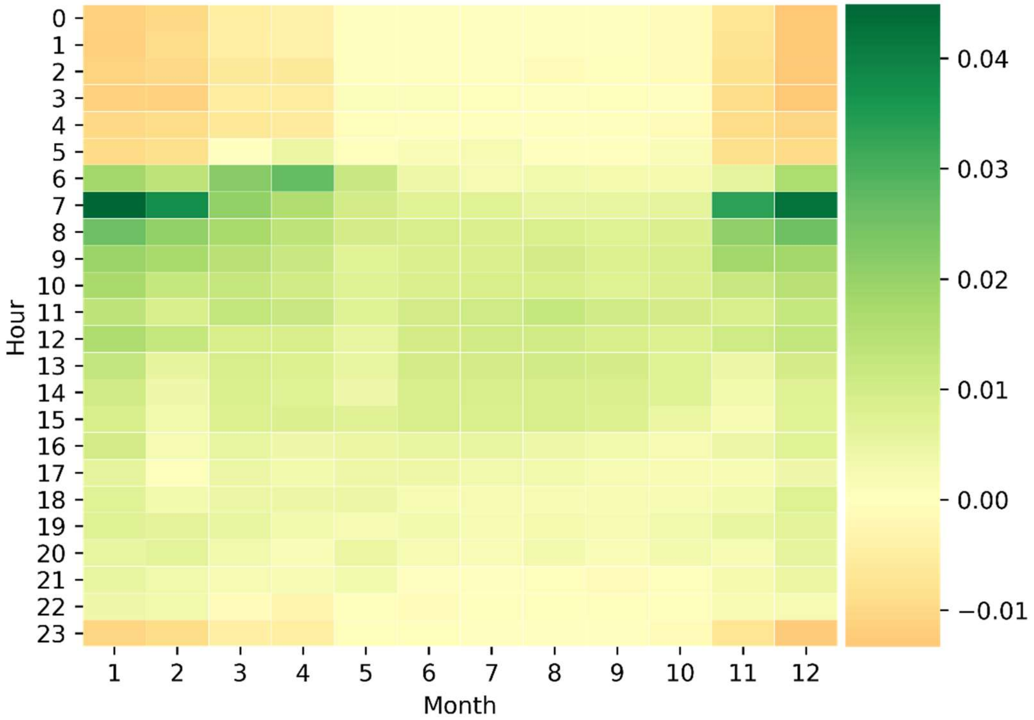

Figure 4: Heat map comparing 2021 total GHG emissions for Pre-COVID cohort homes

A caveat in the GHG emissions results is that they reflect current conditions. SMUD's projections are that the grid will continue to get cleaner over the next decade and achieve carbon neutrality in 2030. Currently the increase in GHG impacts is larger for non-solar homes, which use a greater share of electricity from the grid than solar homes. As the grid moves to zero carbon in 2030, the vast majority of program GHG savings will be from the conversion of gas end uses to electric, so the difference between solar and non-solar homes will become irrelevant.

Bill Impacts

The bill impacts are based on combining the adjusted load profiles for the all-electric and dual-fuel homes with their corresponding electric and gas rates to calculate the electric bills for both home types and the gas bills for the dual-fuel home. For this analysis, the evaluation team used:

- SMUD RTO2 for the electric rate since over 90% of premises were on this rate and this is the default Time-of-Day rate for all SMUD customers moving forward.
- For homes with solar, Net Energy Metering (NEM) credits we calculated at the full retail rate in compliance with SMUD NEM rules in place before March 2022.
- PG&E GS-R for the gas rate. This is one of the more prevalent gas rates for single-family residential customers in PG&E territory.

While the all-electric home electric bill will be substantially higher due to the additional electric usage, the question is whether this is less than the corresponding gas bill for the dual-fuel homes. The annual electric and gas bills for the three cohorts are presented in Table 6. Again, these results are shown separately for the three solar groups.

Table 6. Estimated annual average utility bill impacts

Home Type	Solar Group	Annual Electric Bill		Dual-Fuel Homes Annual Gas Bill	Savings from All-Electric vs Dual-Fuel	Percent Savings versus Dual-Fuel Bill
		All-Electric Homes	Dual-Fuel Homes			
Pre-COVID Homes	All	$1,093	$967	$486	$360	25%
	Solar	$994	$907	$486	$399	29%
	Non-Solar	$1,628	$1,264	$486	$122	7%
Post-COVID Homes	All	$1,373	$1,154	$623	$404	23%
	Solar	$1,195	$1,055	$623	$483	29%
	Non-Solar	$1,908	$1,451	$623	$166	8%
Common Homes, Pre-COVID	All	$1,095	$966	$487	$358	25%
	Solar	$997	$907	$487	$397	28%
	Non-Solar	$1,631	$1,264	$487	$120	7%
Common Homes, Post-COVID	All	$1,250	$1,104	$524	$378	23%
	Solar	$1,150	$1,045	$524	$419	27%
	Non-Solar	$1,785	$1,401	$524	$140	7%

For the average Program home, represented by the “All Homes” Solar Group, the annual bill savings are $360 and $404 for the Pre-COVID and Post-COVID cohorts, respectively. These represent savings of 25% and 23% of the bills for the dual-fuel homes. It is important to note the contribution of solar to these differences, as the compensation for exported surplus generation greatly reduces the total electric bills. Without solar, the annual bill savings amount to reductions of 7% and 8% for the Pre-COVID and Post-COVID homes respectively. While not insubstantial, these are far less than the bill impacts for homes that also have solar panels.

The influence of COVID-19 is also substantial. Whereas the Common Pre- and Post-COVID cohort had similar electric bills to the Pre-COVID cohort in Pre-COVID period ($1,095 versus $1,093), the electric bill for these homes increased 14% to $1,250 in the Post-COVID period. There are a lot of factors underlying this difference, but one major difference is the substantially higher cooling for these homes, which reduced the compensation for exported solar generation.

As a final note, at the time of submission, long-term gas prices are substantially higher than what was used in the original analysis, driven in large part by Russia's invasion of Ukraine. While the extent to which these increases will persist is uncertain, they would result in substantially higher customer bill savings than those presented in this paper.

Conclusions

The results of this evaluation showed the potential for electrification in new construction to reduce GHG impacts. However, as the comparison of simulations with AMI data show, the methods to estimate these impacts need to account for actual household consumption, both in terms of magnitude and timing. This finding was made even more clear through the comparison of pre- and post-COVID time periods. While it is not clear which set of analyses (Pre-COVID or Post-COVID) is most appropriate to assess the Program, since it is not entirely clear how many of the changes brought on by the pandemic will "go back to normal" as originally expected. More professionals are now working from home and therefore daytime occupancy will be higher now than in the Pre-COVID period. This higher occupancy often drives higher consumption and changes hourly profiles.

When using an appropriate method, however, for energy impacts, the evaluation showed the Pre-COVID cohort, the all-electric homes had an annual total consumption of 7,525 kWh (25,675 kBtu) compared to 4,482 kWh (15,239 kBtu) for the dual-fuel homes. This 72% increase in electricity consumption was offset by an avoided 24,403 kBtu (240 therms) in gas consumption. For the Post-COVID cohort, the all-electric homes had an annual total consumption of 9,660 kWh (32,960 kBtu) compared to 5,817 kWh (19,848 kBtu) for the dual-fuel homes. This 93% increase in electricity consumption was offset by an avoided 30,974 kBtu (306 therms) in gas consumption.

With respect to GHG emissions, the energy impacts result, on average, in a tonne less of CO_2 emissions per year compared to the traditional dual-fuel counterfactual homes in 2021. These emissions savings match SMUD's initial claims that a program home "saves over a ton of CO_2per year", as noted on the Smart Homes website. These savings are expected to grow in the coming years as SMUD's electricity generation mix becomes cleaner. All-electric homes without solar drove the generation of a half tonne less of CO_2 emissions per year than the dual-fuel counterfactual homes in 2021. Like solar homes, this also increases to approximately two metric tons of CO_2 per year in 2030.

For bill impacts, the evaluation estimated that, on average, in the Pre-COVID period, the all-electric homes saved homeowners $360 (nearly 25%) per year on their utility bills. In the Post-COVID period, the all-electric homes are estimated to save homeowners $404 (nearly 23%) per year on their utility bills. The results show that the solar panels are a key contribution to these bill savings.