Memorandum

To: Travis Holtby and Eric Johnson, California Public Utilities Commission

From: Opinion Dynamics and Guidehouse

Date: March 19, 2024

Re: CPUC Fuel Substitution Infrastructure Market Study – Data Tool Methodology

Introduction

This document accompanies the Excel-based workbook provided to the California Public Utilities Commission (CPUC) in February 2024 for the Fuel Substitution Infrastructure Market Study. Opinion Dynamics developed the data tool to help review the fuel substitution scenario outputs and pricing analyses completed in this study. The study included a residential participant survey, a commercial business survey, and an electrician survey covering residential and commercial elements. Below, we provide a brief overview of the various tabs included in the workbook and the critical analyses used to generate fuel substitution scenario results and associated infrastructure costs. The overall draft report will provide additional details about the analyses and results.

Overview of Workbook

Below is a description for each of the tabs included in the workbook. The workbook contains a data dictionary tab describing the variable definitions associated with each scenario tab.

- Scenario_Results_Summary: This tab summarizes the key findings from each sector and each scenario considered in our analyses.
- Residential_CR-BldgType: This tab presents the residential scenario and pricing results by fuel substitution scenario, climate region, and building type.
- Residential_BV-BldgType: This tab presents the residential scenario and pricing results by fuel substitution scenario, building vintage, and building type.
- Nonres_CR: This tab presents the nonresidential scenario and pricing results by fuel substitution scenario and climate region.
- Nonres_BldgType: This tab presents the nonresidential scenario and pricing results by fuel substitution scenario and building type.
- Statewide Weighted Results: This tab presents the overall statewide weighted results associated with residential and nonresidential fuel substitution scenarios and building types.
- Res_CostSummary: This tab summarizes the electrician pricing for various fuel substitution scenarios from the residential electrician survey.

- Nonres_CostSummary: This tab summarizes the electrician pricing for various fuel substitution scenarios from the commercial electrician survey.
- Summary-Multivariate-Res: This tab provides the results of a multivariate analysis for the residential fuel substitution scenarios. The team provides an overview of the regression analyses at the end of this document.
- Summary-Multivariate-NonRes: This tab provides the results of a multivariate analysis for the nonresidential fuel substitution scenarios. The team provides an overview of the regression analyses at the end of this document.
- ResRawDictionary: This tab presents a data dictionary for the ResRawOutputs dataset.
- ResRawOutputs: This tab presents the raw output data associated with the residential scenario analysis.
- NonResRawDictionary: This tab presents a data dictionary for the NonResRawOutputs dataset.
- NonResRawOutputs: This tab presents the raw output data associated with the nonresidential scenario analysis.
- ElectricianRawOutputs: This tab presents the raw output data from the electrician survey for residential and commercial electricians. Please see the electrician survey at the end of this document for the variable labels associated with specific question outputs.

Key Analyses and Assumptions

The team used the residential occupant and commercial customer surveys to understand the infrastructure upgrades needed to support fuel substitution measures in these markets. The surveys gathered information on the existing electrical panel size and the number, type, and fuel for key equipment types. The team used this information to assess which projects are likely to need infrastructure upgrades due to electrical panel capacity constraints or space constraints. The overall report will discuss the analyses and the scenario results in detail.

Below, we detail the critical analyses and assumptions the team used to develop some of the main inputs for the workbook.

Adjusted Workforce Implementation Likelihood Results

The FS Infra MS Data Tool includes two types of results related to customers' infrastructure upgrade needs: (1) Technical Engineering Needs Assessment results and (2) Workforce Implementation Likelihood results. The Technical Engineering Needs Assessment results detail customers' infrastructure needs based solely on our engineering-based analysis of whether a given fuel substitution scenario would necessitate additional panel capacity and/or breaker slots, the methods of which are described in detail in the full report. The Technical Engineering Needs Assessment results closely align with infrastructure need results from TECH Clean California program data.

The Workforce Implementation Likelihood results were an added exercise that attempted to account for the fact that, in the field, electricians may do or recommend something different based on their own practices that may not follow the method we used to determine technical needs. Specifically, surveyed electricians reported not always using panel optimization when technically feasible to create space in a panel with no open breaker slots but remaining capacity, instead electing to do a full panel upgrade regardless in some cases.

The electrician survey asked residential and commercial electricians how often it is possible to optimize space in an electric panel (i.e., create space in a panel with no open breaker slots but excess capacity) instead of upgrading the panel to a higher amperage (questions Q15c and Q26a). For each sector, the survey presented respondents with the following response options: Always, Often, Sometimes, Rarely, Never, and Don't Know. The team assigned the following weights to these responses to develop a weighted average representing the frequency with which optimization strategies are used.

- Always – 100%
- Often – 75%
- Sometimes – 50%
- Rarely – 25%
- Never – 0%

Nonresidential electricians answered this question separately for the different business types they worked on (up to three). The team averaged the distribution of responses across business types to calculate a single distribution for nonresidential electricians.

The team multiplied these survey response weights by the percentage of respondents within each category to calculate the percentage of projects likely to receive panel optimization for a space-constrained panel with available remaining capacity, given current electrician practices. Interestingly, the results for residential and commercial electricians were very similar. Our calculations estimated that residential electricians use optimization approaches 52% of the time and commercial electricians use optimization approaches 53% of the time. In the data tool, this adjustment factor is labeled the "Electrician Survey Panel Optimization Adjustment Factor."

The team applied these values to adjust the Technical Engineering Needs Assessment results to attempt to estimate the proportion of respondents likely to receive panel optimization versus a panel upgrade given the frequency with which electricians use optimization. An example of how we applied the adjustment factor is shown below. As seen in Table 1, the original Technical Engineering Need Assessment that 15% of customers need panel optimization is multiplied by the 52% adjustment factor, resulting in a Workforce Implementation Likelihood that indicates 8% of customers are likely to receive panel optimization services. The remaining 7% of the original 15% optimization need is reallocated to the panel upgrade bucket, shifting the percentage of customers receiving a panel upgrade from 3% according to the Technical Engineering Needs Assessment to 10% according to Workforce Implementation Likelihood. The percentage of customers who only need a simple connection does not change, only the distribution of infrastructure needs among optimization and upgrades.

Table 1. Market Rate Residential Heating Only Scenario (Multifamily Homes) - Electrician Survey Panel Optimization Adjustment Factor Application

Panel Optimization - Technical Engineering Needs Assessment	Panel Upgrade - Technical Engineering Needs Assessment	Simple Connection - Technical Engineering Needs Assessment	Electrician Survey Panel Optimization Adjustment Factor	Panel Optimization - Workforce Implementation Likelihood	Panel Upgrade - Workforce Implementation Likelihood	Simple Connection - Workforce Implementation Likelihood
15%	3%	82%	52%	15% * 52% = 8%	3% + (15% - 8%) = 10%	82%

As previously mentioned, these adjustment factors and the resulting Workforce Implementation Likelihood results were an added exercise to this study that attempted to account for the nuances in workforce practices and experiences in the field. As such, these results should be interpreted as the range of possible infrastructure need outcomes in relation to the Technical Engineering Needs Assessment results.

Typical Panel Optimization Cost

The survey asked residential and commercial electricians a) how frequently they use different panel optimization strategies and b) what the typical cost is associated with the different optimization strategies they have used. Specifically, the survey asked about the following optimization strategies:

- Smart circuit breakers
- Smart panel
- Circuit pausers
- Load-sharing
- Sub-panel
- Meter collars
- Other

While it is mechanically possible to develop a weighted average price across the different optimization approaches, the team ultimately decided to apply the average cost associated with a sub-panel in the data tool. Respondents indicated that sub-panels are the optimization approach used most frequently.[1] The report will include additional optimization costs that stakeholders can use to update the tool later. The team believes the sub-panel cost is the most appropriate and representative value for overall panel optimization costs at this time.

The panel optimization pricing in the workbook also accounts for the simple connection costs associated with fuel substitution measures. In other words, the pricing for panel optimization in the workbook includes a) the average price of a sub-panel and b) the cost to connect the fuel substitution measure to the sub-panel.

Multifamily Adjustment Factor

For multifamily infrastructure upgrade costs, we used a simplified approach that asked electricians to estimate the relative cost for a multifamily installation versus a single-family installation. We took this approach to avoid having the electricians run through the extensive pricing scenarios again. The team used the survey responses to develop a multifamily adjustment factor. The team applied this adjustment factor to the single-family costs to develop an estimated cost for each multifamily building scenario. The electrician survey asked whether multifamily projects were more expensive, less expensive, or the same compared to the single-family scenarios. Respondents who indicated multifamily projects were typically more or less expensive were asked to provide a percentage estimate of the typical cost change.

The team calculated a 113% adjustment factor for multifamily fuel substitution infrastructure costs based on the survey responses. In other words, multifamily projects are typically 13% more expensive than a comparably scoped single-family project. Electricians cited a lack of access to attic and crawl spaces and additional logistics dealing with landlords or property managers as reasons multifamily projects are slightly more expensive than single-family projects. Please note that the respondents were split on this question – 40% said multifamily projects would be less costly by

[1] For the residential electrician survey, 31% said they use sub-panels 'most often', 40% said they use them 'often', and 29% said they use them 'sometimes'. For the commercial electrician survey the results were 21% for 'most often', 45% for 'often', and 33% for 'sometimes'. The other optimization approaches were commonly cites as being used 'sometimes', 'rarely', or 'never'.

16%, 34% said they would be more expensive by 56%, and 26% said the price would be about the same. The 113% adjustment factor represents a weighted average of these results.

Electrician Cost Estimates

The team applied the cost estimates from both the residential and commercial electrician surveys. The next section of this document (i.e., Electrician Cost Mapping) details the specific scenario and cost mapping. Before finalizing cost estimates for the data tool, the team removed outliers from each electrician scenario analysis using the interquartile range (IQR).[2] First, the team calculated the quartiles associated with the response distributions for each fuel substitution scenario. Next, the team calculated the IQR, which is the difference between the first and third quartiles. The team then set upper and lower thresholds for inclusion in the analysis by applying 1.5 times the IQR to the first and third quartiles. Specifically, the lower threshold is the first quartile minus 1.5 times the IQR, while the upper threshold is the third quartile plus 1.5 times the IQR. The team removed any electrician responses falling outside the lower or upper thresholds for that fuel substitution scenario. All of the outliers removed from the analysis fell outside the upper threshold.

Accounting for Multiple Applicable Measures

The residential and commercial electrician surveys focused on scenarios where customers converted one or two pieces of equipment from natural gas to electricity. The survey asked electricians to provide pricing for a single piece of heating or water heating equipment in the 'Heating Only' and 'Water Heating Only' scenarios. A few scenarios, for example, the 'Heating and Water Heating' scenario, asked electricians to estimate the costs of connecting both heating and water heating systems. The electrician survey scenarios did not consider that a home or business may have multiple measures eligible for fuel substitution, even within the same end use (e.g., multiple natural gas furnaces in the same house or business). As a result, the electrician scenario cost estimates do not account for the full suite of eligible fuel substitution measures.

To account for this, the team asked electricians how costs would change if an additional heat pump technology were connected during the same visit. In other words, if they were already onsite and had the relevant tools and materials, how much more would it cost to install two heat pumps instead of one in the same job? The residential and commercial electrician surveys included these questions, and the team used the responses to adjust the scenario pricing provided by electricians. Specifically, the team identified the average number of eligible fuel substitution measures in each scenario (and strata) based on the residential occupant and commercial customer surveys. The team then multiplied the electrician costs associated with connecting an additional heat pump by the number of eligible fuel substitution measures to account for these extra pieces of equipment. The team added this value to the electrician scenario price estimates to develop an estimated price for fuel substitution infrastructure upgrades for all eligible measures. An example calculation is shown below for the 'Heating Only' scenario in the Marine climate region for single-family homes.

$$Weighted\ Average\ Infrastructure\ Cost\ for\ a\ Single\ Heat\ Pump = \$3{,}221$$ [3]

$$Average\ number\ of\ systems\ per\ home = 1.1$$

$$Average\ cost\ to\ connect\ one\ additional\ heat\ pump = \$1{,}185$$

$$Weighted\ Average\ Cost\ for\ All\ Applicable\ FS\ Measures = \$3{,}221 + [(1.1 - 1) \times \$1{,}185]\ or\ \$3{,}340$$

[2] The IQR is a common way to identify outliers in a dataset. Specifically, the IQR represents the middle 50% of the dataset and is defined as the difference between the 75th and 25th percentiles of the data.

[3] This is a weighted average of the simple connection costs, panel upgrade costs, and panel optimization costs based on the relevant proportions of those scenarios.

Electrician Cost Mapping

Below, we summarize the price mapping that the team used in the data tool. Table 2 presents the residential fuel substitution scenario and cost mapping. Note that all multifamily pricing includes the adjustment factor described in the previous section.

Table 2. Residential Fuel Substitution Scenario and Cost Mapping

Fuel Substitution Measure Scenario and Cost Components	Column
Space Heating Only	
Simple Connection Infrastructure Costs	Applied the mean cost from the' Gas Fired Furnace w/Central Air Conditioning (CAC) to Air Source Heat Pump (ASHP)' scenario, including connecting the heat pump to the panel.
Panel Upgrade Infrastructure Costs	Applied the mean cost from the "Gas Fired Furnace w/no CAC to ASHP' scenario that included installing a 200-amp panel, a 240 volt (v) circuit, a disconnect, and connecting the heat pump to the panel.
Panel Optimization Infrastructure Costs	Added the 'Simple Connection Infrastructure Costs' to the average price of a sub-panel installation. Sub-panels were the predominant approach for panel optimization, according to electricians.
Average Cost Across Scenarios	The results of the scenarios listed above were weighted based on their frequency from the scenario analysis.
Total Costs – All Applicable Units	Multiplied the 'Average Cost Across Scenarios' by the average number of systems that were replaced in the heating-only fuel substitution scenario. The previous costs only account for a single heating fuel substitution measure. This calculation accounts for the fact that some homes have multiple heating systems eligible for fuel substitution.
DHW Only	
Simple Connection Infrastructure Costs	Applied the mean cost from the' 50-gallon gas Domestic Hot Water (DHW) to Heat Pump Water Heater (HPWH)' scenario that included installing a 240v circuit and a disconnect and connecting the HPWH to the panel.
Panel Upgrade Infrastructure Costs	Applied the mean cost from the '50-gallon gas DHW to HPWH' scenario that included installing a 200-amp panel, a 240v circuit, and a disconnect and connecting the HPWH to the panel.
Panel Optimization Infrastructure Costs	Added the 'Simple Connection Infrastructure Costs' to the average price of a sub-panel installation. Sub-panels were the predominant approach for panel optimization, according to electricians.
Average Cost Across Scenarios	The results of the scenarios listed above were weighted based on their frequency from the scenario analysis.
Total Costs – All Applicable Units	Multiplied the 'Average Cost Across Scenarios' by the average number of systems that were replaced in the DHW-only fuel substitution scenario. The previous costs only account for a single water heating fuel substitution measure. This calculation accounts for the fact that some homes have multiple water heating systems eligible for fuel substitution.
Space Heating and DHW	
Simple Connection Infrastructure Costs	Applied the mean cost from the 'Gas Furnace w/CAC AND Gas DHW to ASHP and HPWH' scenario that included installing a 240v circuit and a disconnect and connecting the ASHP and HPWH to the panel.
Panel Upgrade Infrastructure Costs	Applied the mean cost from the 'Gas Furnace w/CAC AND Gas DHW to ASHP and HPWH' scenario that included installing a 200-amp panel, a 240v circuit, and a disconnect, as well as connecting the ASHP and HPWH to the panel.

Panel Optimization Infrastructure Costs	Added the 'Simple Connection Infrastructure Costs' to the average price of a sub-panel installation. Sub-panels were the predominant approach for panel optimization, according to electricians.
Average Cost Across Scenarios	The results of the scenarios listed above were weighted based on their frequency from the scenario analysis.
Total Costs – All Applicable Units	Multiplied the 'Average Cost Across Scenarios' by the average number of systems that were replaced in the Heating and DHW fuel substitution scenario. The previous costs only account for a single HPWH and ASHP, respectively. This calculation accounts for the fact that some homes have multiple heating or water heating systems eligible for fuel substitution.
All Electric (Convert all FS eligible measures to electric)	
Simple Connection Infrastructure Costs	Averaged the following mean costs from the electrician scenario results: ▪ 'Gas Fired Furnace w/CAC to ASHP' – connect ASHP to panel ▪ ' 50-gallon gas DHW to HPWH' – install 240v circuit and disconnect, connect HPWH to panel ▪ 'Gas-Powered Range to Induction Range' – connect induction range to panel
Panel Upgrade Infrastructure Costs	Averaged the following mean costs from the electrician scenario results: ▪ 'Gas Fired Furnace w/no CAC to ASHP' – install 200-amp panel, install 240v circuit and disconnect, connect ASHP to panel ▪ ' 50-gallon gas DHW to HPWH' – install 200-amp panel, install 240v circuit and disconnect, connect HPWH to panel ▪ 'Gas-Powered Range to Induction Range' – install 200-amp panel and connect induction range to panel
Panel Optimization Infrastructure Costs	Added the 'Simple Connection Infrastructure Costs' to the average price of a sub-panel installation. Sub-panels were the predominant approach for panel optimization, according to electricians.
Average Cost Across Scenarios	The results of the scenarios listed above were weighted based on their frequency from the scenario analysis.
Total Costs – All Applicable Units	Multiplied the 'Average Cost Across Scenarios' by the average number of systems that were replaced in the All-Electric fuel substitution scenario. The previous costs only account for a single technology. This calculation accounts for the fact that some homes have multiple gas measures eligible for fuel substitution.

Table 3 presents the nonresidential fuel substitution scenario and cost mapping.

Table 3. Nonresidential Fuel Substitution Scenario and Cost Mapping

Fuel Substitution Measure Scenario and Cost Components	Column
Space Heating Only	
Simple Connection Infrastructure Costs	The mean cost from the 'Packaged AC/Gas Furnace to Packed Heat Pump (HP) with Electric Resistance Back-up' scenario was applied, which included connecting the heat pump to the panel.
Panel Upgrade Infrastructure Costs	Averaged the following mean costs from the electrician scenario results: ▪ 'Packaged AC/Gas Furnace to Packed HP with Electric Resistance Back-up' – install a 600-amp panel, connect ASHP to panel ▪ '60-gallon gas DHW to 80-gallon HPWH' – install 400-amp panel, 240v circuit and disconnect, connect HPWH to panel The water heater scenario was added to account for a 400-amp panel upgrade, not just a 600-amp panel upgrade.

Panel Optimization Infrastructure Costs	Added the 'Simple Connection Infrastructure Costs' to the average price of a sub-panel installation. Sub-panels were the predominant approach for panel optimization, according to electricians.
Average Cost Across Scenarios	The results of the scenarios listed above were weighted based on their frequency from the scenario analysis.
Total Costs – All Applicable Units	Multiplied the 'Average Cost Across Scenarios' by the average number of systems that were replaced in the heating-only fuel substitution scenario. The previous costs only account for a single heating fuel substitution measure. This calculation accounts for the fact that some buildings have multiple heating systems that are eligible for fuel substitution.
DHW Only	
Simple Connection Infrastructure Costs	Applied the mean cost from the '60-gallon gas DHW to 80-gallon HPWH' scenario that included installing a 240v circuit and disconnect and connecting the HPWH to the panel.
Panel Upgrade Infrastructure Costs	Averaged the following mean costs from the electrician scenario results: ▪ '60-gallon gas DHW to 80-gallon HPWH' – install 400-amp panel, 240v circuit and disconnect, connect HPWH to panel ▪ 'Packaged AC/Gas Furnace to Packed HP with Electric Resistance Back-up' – install a 600-amp panel, connect ASHP to panel The heating scenario was added to account for a 600-amp panel upgrade, not just a 400-amp panel upgrade.
Panel Optimization Infrastructure Costs	Added the 'Simple Connection Infrastructure Costs' to the average price of a sub-panel installation. Sub-panels were the predominant approach for panel optimization, according to electricians.
Average Cost Across Scenarios	The results of the scenarios listed above were weighted based on their frequency from the scenario analysis.
Total Costs – All Applicable Units	Multiplied the 'Average Cost Across Scenarios' by the average number of systems that were replaced in the DHW-only fuel substitution scenario. The previous costs only account for a single water heating fuel substitution measure. This calculation accounts for the fact that some buildings have multiple water heating systems that are eligible for fuel substitution.
Space Heating and DHW	
Simple Connection Infrastructure Costs	Applied the mean cost from the 'Forced Air Gas Fired Furnace AND 60-gallon DHW to ASHP and 80-gallon HPWH' scenario that included installing a circuit and disconnect and connecting the HPWH and ASHP to the panel.
Panel Upgrade Infrastructure Costs	Applied the mean cost from the 'Forced Air Gas Fired Furnace AND 60-gallon DHW to ASHP and 80-gallon HPWH' scenario that included installing a 400-amp panel, a circuit and disconnect, as well as connecting the HPWH and ASHP to the panel.
Panel Optimization Infrastructure Costs	Added the 'Simple Connection Infrastructure Costs' to the average price of a sub-panel installation. Sub-panels were the predominant approach for panel optimization, according to electricians.
Average Cost Across Scenarios	The results of the scenarios listed above were weighted based on their frequency from the scenario analysis.
Total Costs – All Applicable Units	Multiplied the 'Average Cost Across Scenarios' by the average number of systems that were replaced in the Heating and DHW fuel substitution scenario. The previous costs only account for a single HPWH and ASHP, respectively. This calculation accounts for the fact that some buildings have multiple heating or water heating systems that are eligible for fuel substitution.
Cooking	
Simple Connection Infrastructure Costs	Averaged the following mean costs from the electrician scenario results: ▪ 'Gas Fryer to Electric Fryer' – Add circuit, disconnect, connect fryer to panel ▪ 'Gas Oven to Electric Oven' – Add circuit, disconnect, connect fryer to panel
Panel Upgrade Infrastructure Costs	Averaged the following mean costs from the electrician scenario results:

	▪ 'Gas Fryer to Electric Fryer' – Install 400-amp panel, add circuit, disconnect, connect fryer to panel ▪ 'Gas Oven to Electric Oven' – Install 600-amp panel, add circuit, disconnect, connect fryer to panel
Panel Optimization Infrastructure Costs	Added the 'Simple Connection Infrastructure Costs' to the average price of a sub-panel installation. Sub-panels were the predominant approach for panel optimization, according to electricians.
Average Cost Across Scenarios	The results of the scenarios listed above were weighted based on their frequency from the scenario analysis.
Total Costs – All Applicable Units	Multiplied the 'Average Cost Across Scenarios' by the average number of systems that were replaced in the Cooking fuel substitution scenario. The previous costs only account for a single piece of cooking equipment. This calculation accounts for the fact that some buildings have multiple pieces of cooking equipment eligible for fuel substitution.
All Electric (Convert all FS eligible measures to electric)	
Simple Connection Infrastructure Costs	Averaged the following mean costs from the electrician scenario results: ▪ 'Packaged AC/Gas Furnace to Packed HP with Electric Resistance Back-up' – connect packaged heat pump to panel ▪ 60-gallon gas DHW to 80-gallon HPWH' – install 240v circuit and disconnect, connect HPWH to panel ▪ 'Gas Fryer to Electric Fryer' – Add circuit, disconnect, connect fryer to panel ▪ 'Gas Oven to Electric Oven' – Add circuit, disconnect, connect fryer to panel
Panel Upgrade Infrastructure Costs	Averaged the following mean costs from the electrician scenario results: ▪ 'Packaged AC/Gas Furnace to Packed HP with Electric Resistance Back-up' – install a 600-amp panel, connect ASHP to panel ▪ '60-gallon gas DHW to 80-gallon HPWH' – install 400-amp panel, 240v circuit and disconnect, connect HPWH to panel ▪ 'Gas Fryer to Electric Fryer' – Install 400-amp panel, add circuit, disconnect, connect fryer to panel ▪ 'Gas Oven to Electric Oven' – Install 600-amp panel, add circuit, disconnect, connect fryer to panel
Panel Optimization Infrastructure Costs	Added the 'Simple Connection Infrastructure Costs' to the average price of a sub-panel installation. Sub-panels were the predominant approach for panel optimization, according to electricians.
Average Cost Across Scenarios	The results of the scenarios listed above were weighted based on their frequency from the scenario analysis.
Total Costs – All Applicable Units	Multiplied the 'Average Cost Across Scenarios' by the average number of systems that were replaced in the All-Electric fuel substitution scenario. The previous costs only account for a single technology. This calculation accounts for the fact that some buildings have multiple gas measures that are eligible for fuel substitution.

Statewide Weighted Results

The data tool has a tab dedicated to overall weighted statewide results. For the residential sector, the team used counts from the 2022 Title 24 housing stock provided by the California Energy Commission to calculate the statewide proportions of single-family and multifamily buildings by climate region. In comparison to the sample sizes within each scenario and building strata, the team used these proportions to develop weighted statewide estimates for each fuel substitution scenario for single-family buildings, multifamily buildings, and all residential buildings. The counts and proportional weights used in our analyses are presented in Table 4 and Table 5. The first table shows the counts and proportions by California climate zone, while the second table presents the data by climate region.

Table 4. 2022 Housing Counts by Title 24 Climate Zones

Climate Zone	Single Family Count	Single Family Proportion	Multifamily Count	Multifamily Proportion
1	66,706	1%	16,524	0%
2	314,980	3%	82,327	2%
3	975,049	10%	563,325	12%
4	486,183	5%	304,527	7%
5	112,644	1%	33,494	1%
6	653,776	7%	393,615	9%
7	509,587	5%	298,199	7%
8	984,134	10%	638,398	14%
9	1,235,365	13%	964,907	21%
10	1,120,416	12%	362,504	8%
11	347,458	4%	78,943	2%
12	1,394,955	15%	488,090	11%
13	635,273	7%	168,618	4%
14	259,501	3%	92,410	2%
15	178,926	2%	46,467	1%
16	160,587	2%	38,423	1%
Total	**9,435,541**	**100%**	**4,570,770**	**100%**

Notes: The CEC used 2022 housing stock data from Moody's and aligned it with the Title 24 Building Climate Zones
Source: California Energy Commission

Table 5. 2022 Housing Counts by Title 24 Climate Zones

Climate Region	Single Family Count	Single Family Proportion	Multifamily Count	Multifamily Proportion
Marine	2,609,338	28%	1,393,811	30%
Hot-Dry	6,665,616	71%	3,138,536	69%
Cold	160,587	2%	38,423	1%
Total	**9,435,541**	**100%**	**4,570,770**	**100%**

Notes: The CEC used 2022 housing stock data from Moody's and aligned it with the Title 24 Building Climate Zones
Source: California Energy Commission

For the nonresidential sector, the team used statewide floor space estimates from the 2021 Commercial End-Use Survey (CEUS) to calculate the proportion of floor space represented by various building types statewide (Table 6). Compared to the square footages within each scenario and building type in our sample, the team used these proportions to develop weighted statewide estimates for each fuel substitution scenario.

Table 6. 2021 CEUS Floor Space Stock by Building Type

2021 CEUS Building Type	Square Feet (10^6)	Proportion
Restaurant	186.7	3%
Retail	1,145.4	15%
Food Stores	302.3	4%
School	579.0	8%

2021 CEUS Building Type	Square Feet (10^6)	Proportion
College	305.7	4%
Health Care	381.8	5%
Lodging	358.8	5%
Refrigerated Warehouse	59.3	1%
Warehouse	1,091.8	15%
Miscellaneous	1,380.3	19%
Office, Large	1,288.9	17%
Office, Small	372.7	5%
Total	**7,452.7**	**100%**

Source: California Energy Commission

The team aggregated the building type categories presented in Table 6 so that they applied to the building type categorizations captured in the nonresidential survey effort. The aggregated building type distributions are shown in Table 7.

Table 7. Adjusted 2021 CEUS Floor Space Stock by Building Type

2021 CEUS Building Type	Square Feet (10^6)	Proportion
Restaurant	186.7	3%
Retail	1,145.4	15%
Food Stores	302.3	4%
Education	884.7	12%
Health Care	381.8	5%
Lodging	358.8	5%
Warehouse	1,151.1	15%
Miscellaneous	1,380.3	19%
Offices	1,661.6	22%
Total	**7,452.7**	**100%**

Source: California Energy Commission

Regression Analysis

The team conducted a regression analysis on the residential occupant and commercial customer survey data in two stages. The first stage was a correlation analysis in which we leveraged univariate methods to assess the extent and direction of the **individual** relationships between each variable of interest and the panel upgrade outcome. We completed the correlation analysis first because it allowed us to provide timely preliminary findings, formulate preliminary hypotheses, and identify if any relationships warranted a regression analysis. Based on the results of the correlation analysis, the second stage was a multivariate regression analysis conducted to assess the **combined** relationship between the variables of interest and the panel upgrade outcome. Compared to correlation analysis, multivariate regression analysis is more appropriate for trying to explain or predict a given customer's need for a panel upgrade because it accounts for how a variety of unique customer characteristics interact to affect that outcome.

The team produced adjusted odds ratios to aid in interpreting the results. In a multivariate regression, an adjusted odds ratio represents the relative likelihood of the outcome happening when a given factor is true while holding all the other independent variables in the analysis constant. We needed to choose one category for categorical variables as the "reference." The results represent whether being in another category makes you more or less likely to need the upgrade than being in the reference category (e.g., if having a home built between 1976 and 1999 makes you more or less likely to need a panel upgrade than having a house built in 2000 or later). It is possible to obtain a different result with a different reference category; however, we tried to choose logical reference categories where they existed (e.g., being in the coldest region or having the newest home).

The results of this analysis can be used to identify customers that are particularly likely or unlikely to require a panel upgrade. That said, the observed variables only partially explain the need for a panel upgrade, and there are likely other factors that affect the need for a panel upgrade but are not available for analysis currently given data limitations.

Electrician Survey Instrument

CPUC Fuel
Substitution Study_