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Impact Evaluation of Technology and Equipment for Clean Heating (TECH) Initiative

Workplan

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Subcontractor(s)



Table of Contents

1. Impact Evaluation Overview	4
1.1 Evaluation Objectives	4
1.2 Overview of Evaluation Approach	6
2. Evaluation Tasks	8
2.1 Task 1: Impact Evaluation Plan	8
2.2 Task 2: Manage, Collect and Clean Impact Evaluation Data Streams.....	8
2.3 GHG Emissions Reduction Analysis.....	10
2.3.1 Sample-Based Pathway: Project Specific Electric Impact Comparison and Load Shape Development.....	12
2.3.2 Population-Based Pathway: Consumption Analysis.....	17
2.3.3 GHG Emissions Reduction Analysis	20
2.4 Task 5: Utility Bill Impact Estimation	21
2.5 Task 6: Develop EM&V Framework to Support Scalability.....	22
2.6 Task 7: Reporting and Feedback.....	23
3. Timelines and Deliverables	25

Table of Tables

Table 1. Summary of TECH Evaluation Research Questions	5
Table 2. Anticipated Evaluation Data Streams.....	9
Table 3. Preliminary Sample Design	14
Table 7. Written Report and Presentation Schedule.....	25

Table of Figures

Figure 1. Impact Evaluation Approach and Research Tasks	6
Figure 2. GHG Emissions Reduction Analytical Framework.....	11
Figure 3. Sample-Based Pathway Steps	13
Figure 4. Population-Based Pathway Steps.....	18

1. Impact Evaluation Overview

Building energy consumption is responsible for a quarter of California’s greenhouse gas (GHG) emissions. To address these emissions, the California Legislature passed Senate Bill (SB) 1477, which calls on the California Public Utilities Commission (CPUC) to develop the Technology and Equipment for Clean Heating (TECH) Initiative. The TECH Initiative is designed to accelerate market adoption of low-emissions space conditioning and water heating technologies for existing single family and multifamily residential housing units across California. Given the potential of heat pump technologies to reduce GHG emissions, the CPUC is looking to heat pump technologies as a key element to meeting the state’s mission to achieve carbon neutrality by 2045. The TECH Initiative is designed to address and reduce market barriers to accelerate the longer-term adoption of low-emission space and water heating technology and transform the market over time while striving for cost-effectiveness and regulatory simplicity.

When reviewing this impact evaluation plan, it is essential to note that the TECH Initiative is a pilot that is continuing to evolve, so the impact evaluation will evolve and adapt with it. Our evaluation approach is guided by the current status of pilot implementation as well as the *Decision Establishing Building Decarbonization Pilot Programs* (D. 20-03-027)¹ that provides a framework for its evaluation. In the spirit of embedded evaluation,² the evaluation activities described in this plan will be timed and performed in coordination with program delivery, the evolving technology mix, and the participant composition of the program. The Opinion Dynamics team will work in close coordination with the CPUC and program implementers.

Please note that this impact evaluation plan, and the associated activities, will be complementary to the process and market evaluation research that the Opinion Dynamics team is already conducting for the TECH Initiative.³

1.1 Evaluation Objectives

The overarching goal is to evaluate the TECH Initiative impacts. The Opinion Dynamics team will use an embedded evaluation approach to our research which allows us to adapt our approaches early in the implementation process and provide insights at key decision points throughout the pilot lifecycle. This approach allows us to develop relationships with Energy Solutions, the prime implementer for the Initiative, and its team of subcontractors early on so that we can infuse evaluation insights into program design and implementation optimization. This approach creates effective feedback loops to help all parties better understand complex market adoption patterns, effectiveness of program strategies, and opportunities for course correction.

The impact evaluation plan addresses the following evaluation objectives:

- Evaluate the ex-post GHG emissions reductions and cost per metric ton of avoided GHG emissions delivered by the Initiative

¹ When appropriate and feasible for both the BUILD Program and TECH Initiative, the program evaluator *shall use meter-based data as part of the data used to calculate and evaluate cost per metric ton of avoided GHG*. When not appropriate or not feasible, the program evaluator shall work with Energy Division staff to determine the best method for *quantifying and valuing all GHG emissions, including those associated with methane and refrigerants*.

² Embedded Evaluation is based on the principles of Developmental Evaluation as defined by Dr. Michael Quinn. It is an approach to insert evaluation within the program design, implementation, and reporting processes to support ongoing evidence-based decision-making.

³ The overall TECH Evaluation Plan can be found here: <https://techcleanca.com/public-data/evaluation-studies/>.

- Determine the utility bill impacts associated with the Initiative

This evaluation plan also addresses a larger policy and measurement question: *What is the appropriate measurement, verification, and evaluation framework for California’s current and future electrification and decarbonization retrofit pilots and programs?* In California, energy efficiency EM&V protocols and pathways for claiming savings provide guidance for energy efficiency programs. This evaluation presents a unique opportunity to assess these various approaches to measuring impacts—their accuracy, uncertainty, and costs—and whether they can be appropriately applied to electrification and decarbonization pilots and programs. As a result, this evaluation will also develop a preliminary EM&V framework for electrification and decarbonization programs to support scalable design, implementation, and measurement.

To determine the ex-post GHG emissions reductions, cost per metric ton, and utility bill impacts of TECH, as well as whether the existing measurement pathways are feasible, the evaluation team will address the following research questions as part of the evaluation (Table 1).

Table 1. Summary of TECH Evaluation Research Questions

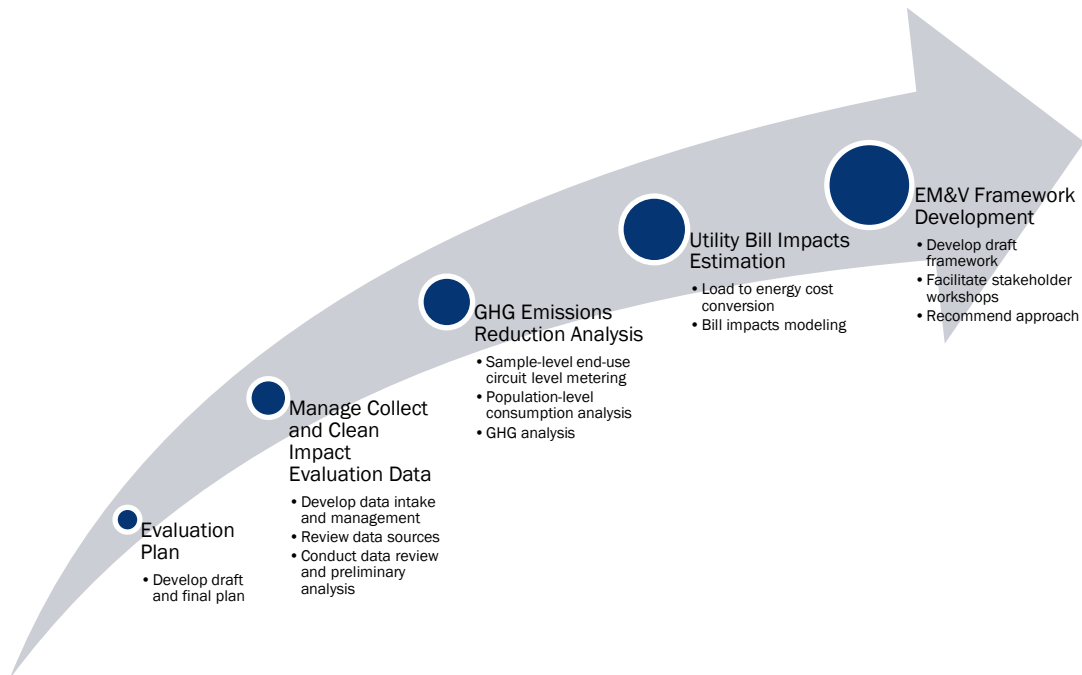
Task	Research Questions
GHG Emissions Reduction Analysis	<ul style="list-style-type: none"> ■ What are the electric and gas energy impacts associated with the Pilot? What are the impacts associated with various customer segments of interest? ■ What are the GHG emissions reductions and cost per metric ton of avoided GHG associated with the Pilot? ■ What is the impact of customer behavior and other exogenous factors on electric energy impacts? ■ Do the assumptions in the current Statewide Deemed Measure Package Lists hold for fuel-substitution measures for planning purposes or for evaluation purposes? ■ Are there load shapes that are more appropriate for these fuel substitution measures that can be employed for future measurement? ■ How can onsite electrical panel circuit-level metering and 8760 load shapes serve to inform GHG impacts moving forward? ■ Can onsite electrical panel circuit-level metered data be used to help adjust or improve population-level consumption data analysis energy impacts? Should onsite electrical panel circuit-level metering be included in evaluation of a full-scale program? ■ With what degree of certainty can whole house meter data produce electric energy impact results? What project features produce high degrees of uncertainty? ■ Does the implementation team’s Electrification Value Stream⁴ modeling assumptions and approach support customer targeting? Are they in alignment, and to what degree should they be in alignment, with ex-post impact measurement?
Utility Bill Impact Estimation	<ul style="list-style-type: none"> ■ What are the average changes in energy costs for TECH pilot participants? ■ What is the range of energy costs across different participant groups (e.g., low-income, rural, tribal, etc.)? ■ How do energy costs vary throughout the year for TECH participants?
EM&V Framework Development	<ul style="list-style-type: none"> ■ To what extent can the existing energy-savings based impact evaluation frameworks (deemed, custom, NMEC) be adapted for electrification/decarbonization policy, GHG savings, and measurement needs? ■ Which impact framework approach and/or element combinations produce the most robust, accurate, transparent, and scalable approach to measurement, verification and evaluation of current pilot and future electrification retrofit programs? ■ How should energy and GHG impacts be developed and claimed to ensure an accurate, “best” estimate of impacts? Is a population-level pathway needed to capture the diversity in system types and energy impacts? Or are deemed fuel substitution measures a sufficient proxy for estimating energy, GHG, and customer bill impacts? Since GHG reductions are the primary goal instead of EE and cost-effectiveness, are new deemed decarbonization measures needed? ■ What impact claims and reporting requirements are relevant for electrification pilots and future programs?

⁴ “TECH Clean California Workplan”, TECH Clean California Team, Nov. 5, 2021, p. 137, Table 39. *Electrification Value Stream Analysis* is defined as the “Quantified grid value of the initiative electrification projects.” Results will be delivered as a stand-alone report.

1.2 Overview of Evaluation Approach

The impact evaluation will seek to answer whether the installation of TECH-incented technologies contributed to hourly GHG emissions reductions, as well as contributed to customer savings on utility bills. Figure 1 provides a summary of the various tasks involved in the evaluation. Each of the tasks shown in Figure 1 are discussed in detail throughout the remainder of this plan.

Figure 1. Impact Evaluation Approach and Research Tasks



The evaluation will gather information to inform what measurement approaches are appropriate for electrification and decarbonization programs by comparing deemed savings and normalized metered energy consumption (NMEC) approaches. Each of these approaches will be supplemented by end-use circuit level metering that will be conducted for a sample of TECH initiative participants. The combination of these approaches will result in an inclusive impact evaluation that builds on an EE EM&V foundation but reflects electrification and decarbonization policy and program needs. The evaluation team will use the energy impacts derived from these approaches as the primary inputs for estimating GHG emissions reductions and customer bill savings.

The TECH Initiative currently uses deemed measure impacts as a first cut at calculating program energy impacts. The deemed savings are largely placeholder values that are updated based on population-level NMEC savings estimates produced by the implementation team. However, deemed measure impacts are used as the primary savings estimates for any residences where NMEC savings estimates cannot be determined, such as homes where there is a change in occupancy in the 12 months prior to the heat pump installation, so it is not possible to develop a full-year baseline. This evaluation includes both deemed and NMEC measurement approaches, along with end-use circuit level metering. The end-use metering will be used to assess the accuracy of the NMEC and deemed savings approaches. Together, these three approaches will result in an inclusive impact evaluation approach that provides a unique opportunity to compare measurement

approaches for accuracy, rigor, and cost. Finally, by conducting an inclusive impact evaluation, the Opinion Dynamics team will have the data and tools necessary to inform the development of a preliminary EM&V framework for residential electrification and decarbonization efforts. The approaches we plan to include in this evaluation are summarized in Table 2.

Table 2. Overview of Energy Impact Evaluation Approaches

Evaluation Approach	Inputs	Outputs	Limitations
Deemed savings for fuel substitution measures	Program tracking data; eTRM measure package mapping to tracking data; non-eTRM measure development and mapping	Measure-level energy and demand savings; Identify incorrect measure mappings	Does not leverage actual energy consumption; does not account for occupant behavior; likely simplified versus the actual pre and post equipment configurations
End-use circuit level metering	Whole-home use, PV generation, and equipment-level (dedicated circuit) energy usage	Whole-home use & generation, equipment-level, and end-use level load shapes	Post-retrofit metering and only electric; device and monitoring costs; small sample size; CZs limited by program participation; sufficient space in electric panel
Normalized metered energy consumption analysis	AMI electric and gas billing data for participants and comparison group, building and occupant characteristics, weather data	Whole-home and energy and demand savings, disaggregated end-use savings, whole-home and end-use level load shapes	Identifying and procuring <u>all</u> utility services and consumption data for a participant; Significant home changes during analysis period; Presence of PV, battery storage, EVs

2. Evaluation Tasks

The evaluation team will implement the activities outlined in the sections below to evaluate the TECH Initiative and provide feedback and recommendations to improve program design.

2.1 Task 1: Impact Evaluation Plan

A best-in-class evaluation effort begins with rigorous and strategic planning that balances evaluation needs with evaluation resources. Building on the February 25, 2022, Evaluation of Technology and Equipment for Clean Heating (TECH) Initiative workplan, we developed this more detailed draft impact evaluation plan that aligns with CPUC evaluation requirements as well as data availability. We will initially share this impact evaluation plan with CPUC Staff. We will address their comments and then share the impact evaluation plan with Energy Solutions, the TECH implementer and Southern California Edison, the TECH contracting agent. We will address these comments and post the updated version to the CPUC Public Documents Area (PDA) for public review. Once we address any comments from the PDA, we will finalize this impact plan. This final plan will be the foundation to our impact analyses; however, as noted above, the pilot is continuing to evolve, so we expect the impact evaluation plan to evolve and adapt with it.

Deliverables:

- Drafts and final evaluation plan

2.2 Task 2: Manage, Collect and Clean Impact Evaluation Data Streams

Our team will ingest, collect, and review primary and secondary data to support an array of analytical activities and reporting outcomes. Opinion Dynamics will develop a draft Data Collection Plan and timeline.

Data Intake and Management

For this evaluation, we will follow a data intake and management process workflow beginning with formal documentation of data requirements and specifications. The data specifications include steps for data cleaning, transformation, and the data schema for the master analytic data set.

Our workflow acknowledges that the process from data intake to analysis is iterative and will likely require some back and forth between our data management team, the CPUC, and the implementation team. All data required for the project will go through our pre-defined Data Quality and Exploration (DQX) process to assess the accuracy, completeness, and appropriateness of the data as compared to the data request. The DQX process leverages our library of R and Python code, as well as Power BI to perform initial data quality assessments and better understand the raw data through visualizations.

Once the data intake and processing workflows are established, we will leverage our Microsoft Azure data management platform, including virtual machines, Azure Data Factory, SQL Server, Power BI, and Databricks, to ensure the data pipeline is secure, scalable, and can be automated to the extent possible. We will ensure that data are encrypted while in transit and at rest and will use a Microsoft Azure SQL Database to securely store the data. Access to the database will be restricted to our team members working on the project using multi-factor authentication.

Data Sources

The anticipated data streams are codified in Table 2, along with the evaluation objectives they support.

Table 3. Anticipated Evaluation Data Streams

Data Inputs	Provider	Data Source*	GHG Emissions Reductions Analysis	Utility Bill Impact Estimation	EM&V Framework Development
Program participation information <ul style="list-style-type: none"> ▪ Measure(s) installed ▪ Date of installation ▪ Climate zone ▪ Disadvantaged Community (DAC) Indicator ▪ Incentives 	Energy Solutions	TECH program tracking data & project documents	√	√	√
Program cost information	Energy Solutions	<ul style="list-style-type: none"> ▪ TECH program tracking data ▪ CARB reporting data 	√		√
Electric hourly and gas daily AMI interval data and associated meta data	CEC	T20 Section 1353 Data Request	√	√	√
Customer information <ul style="list-style-type: none"> ▪ Customer rate code ▪ Experian or Axiom equivalent ▪ Utility ▪ Address ▪ Contact information ▪ Unique identifiers 	CEC	T20 Section 1353 Data Request	√	√	√
Marginal hourly avoided cost and GHG system hourly emissions rate	Opinion Dynamics	CEC/E3 CBECC ⁵	√		√
Weather data, including historical year and normal weather data	Opinion Dynamics	CALMAC ⁶	√	√	√
Rate schedules	Opinion Dynamics	MIDAS		√	√

⁵ The CPUC expressed a preference for GHG impacts to be measured consistently for TECH and BUILD. The (TDV) 8760-hour emissions factors (EFs) are defined by Title 24 climate zone and hour of the year for electricity and are the EFs inherently used for BUILD, because they are built into the California Building Energy Code Compliance (CBECC) tool. Therefore, we will apply TDV EFs to calculate the GHG impacts for the electricity impacts for both programs. This approach has been reviewed and accepted by the California Air Resource Board (CARB) as in compliance with CARB funding requirements for these programs.

⁶ California weather files for historical (actual) and typical/normal years are maintained at <https://www.calmac.org/weather.asp>

Data Inputs	Provider	Data Source*	GHG Emissions Reductions Analysis	Utility Bill Impact Estimation	EM&V Framework Development
End-use circuit-level electric metering data	Opinion Dynamics	Emporia Gen2 device*	√	√	√
Implementation team energy, GHG, and bill impact claims methods and results	Energy Solutions / Recurve	TBD	√		√
eTRM deemed measure package lists, energy impacts, and load shapes (if available)	Cal TF/ DEER	eTRM			√
Ex post energy, GHG, and bill impacts	Opinion Dynamics	Evaluation Results*	√	√	√

√ Indicates required data stream to support the analysis.
 * Indicates primary research data from the evaluation team.

Data Review and Preliminary Analysis

Data review and initial analysis is critical to ensuring that the evaluation team has relevant and sufficient data to complete the analytical tasks outlined below. As part of this activity, we will conduct preliminary data cleaning and develop summaries to support confirmation that our analytical framework is feasible given the available data. For example, we will leverage the TECH program tracking data collected by Energy Solutions for a variety of analytical tasks:

- We will look at the incidence of measure installations and configurations across participants, by climate zone and by rate schedule. Based on this preliminary review, we will draw a sample of customers to support comparison group matching activities described in Section 2.3.2. To the extent feasible, we will coordinate with the implementation team to limit any redundancies.⁷
- We will also leverage participant information to understand what parameters are collected and available for characterizing the project, site, and equipment to determine our sample design for circuit-level metering (see Section 2.3.1).

We will conduct similar data review and preliminary analyses for all data sources enumerated in Table 2. As part of this process, we will also perform data cleaning and quality checks, and will provide feedback to data providers should any issues be identified.

Deliverables:

- None

2.3 GHG Emissions Reduction Analysis

SB 1477 requires TECH Initiative metrics to include an assessment of cost per metric ton of avoided GHG emissions. We will conduct three research tasks to develop robust estimates of GHG reductions for the TECH

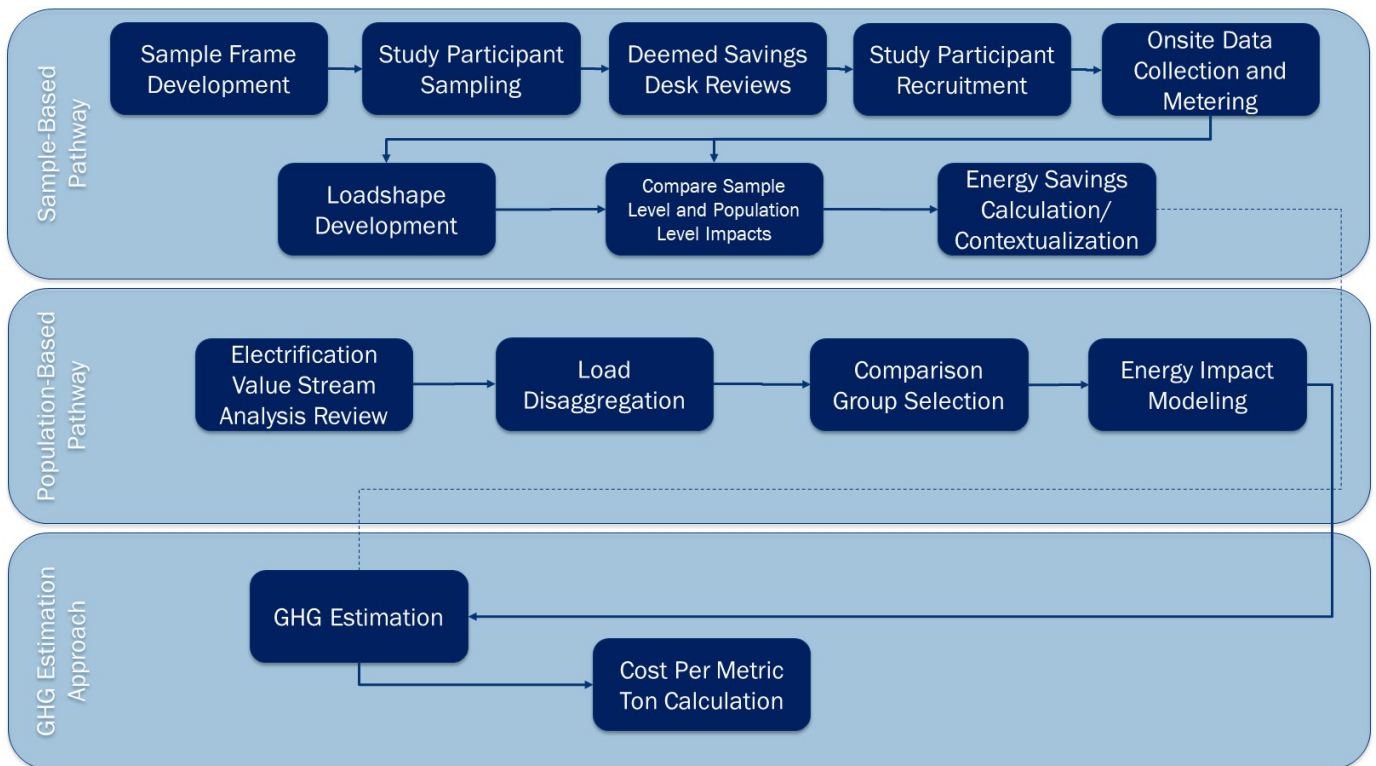
⁷ For example, should Energy Solution’s sub-contractor Recurve conduct fuzzy matching for electric and gas data, we will review their code, and if acceptable, use their outputs rather than duplicating this effort.

program, as well as identify the comparative merits of each of these approaches for calculating GHG emissions reductions. These research tasks include:

- A sample-based pathway, which will engage a targeted sample of participants for onsite electrical panel circuit-level metering supported by utility meter data modeling and other primary data collection, to determine project-specific load shapes and electric energy impacts contextualized to customer behavior and exogenous factors
- A population-based pathway, which will use the entire TECH participant population and rely on utility meter-based modeling, to estimate electric and gas energy impacts
- Application of the marginal GHG emissions factors and program costs to electric and gas energy impact results to develop lifetime GHG emissions reductions and cost per metric ton.

Figure 2 presents a graphical display of the analytical framework for evaluating GHG emission reduction resulting from the installation of measures incented through the TECH initiative. The framework relies on statistical modeling of electric and gas consumption data supported by engineering reviews and customer and onsite primary data collection, including electrical panel circuit-level metering. The sequencing of analytical and data management steps is designed to ensure an efficient and streamlined approach while pursuing distinct modeling and analytical pathways for the GHG and bill impact analysis, respectively. The research tasks also support a comparative analysis of population-level energy impact results to primary data collected from sampled projects to support validating measurement approaches moving forward. Details regarding each step in the analytical framework are provided in the sections below.

Figure 2. GHG Emissions Reduction Analytical Framework



2.3.1 Sample-Based Pathway: Project Specific Electric Impact Comparison and Load Shape Development

The sample-based pathway will leverage primary data collection efforts including the installation of long-term onsite meters for TECH program measures to determine project-specific load shapes and electric energy impacts contextualized to customer behavior and exogenous factors.

The research questions are:

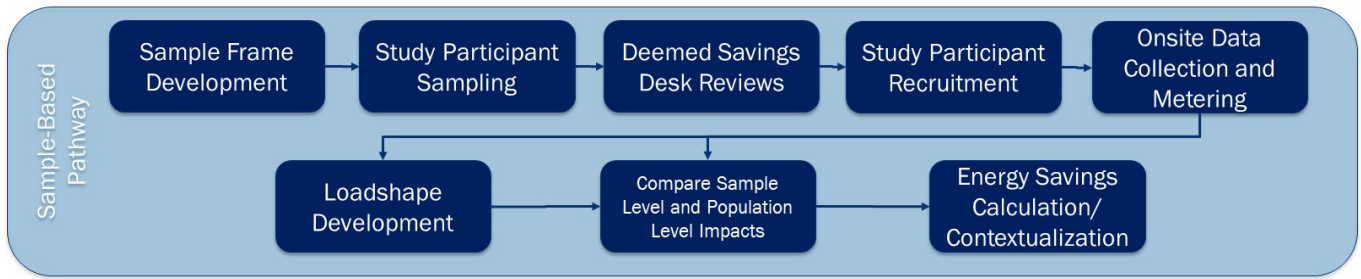
- What is the impact of customer behavior and other exogenous factors on electric energy impacts?
- Do the assumptions in the current Statewide Deemed Measure Lists hold for fuel-substitution measures for planning purposes or for evaluation purposes?
- Are there load shapes that are more appropriate for these fuel substitution measures that can be employed for future measurement?
- How can onsite electrical panel circuit-level metering 8760 load shapes serve to inform GHG impacts moving forward?
- Can onsite electrical panel circuit-level metered data be used to help adjust or improve population level consumption data analysis energy impacts? Should onsite electrical panel circuit-level metering be included in evaluation for a full-scale program?
- For residences that previously did not have air conditioning, should the added air conditioning load—which further increases electrification load and bills—be treated separately?

Notably, the sample-based pathway provides a suite of data to support contextualizing electric energy impacts, as well as comparing various measurement approaches as potential EM&V options for current and future electrification and decarbonization initiatives. However, there are limitations associated with this approach which renders it infeasible as a standalone energy impact method. These include:

- Circuit-level and end-use submetering will only capture post-period electricity use. Given the program implementation schedule and process, the evaluation team will be unable to capture pre-installation electricity use. End-use metering will not be used for gas use as it will be readily available from pre- and post-installation whole house consumption data for a majority of the population (see Section 2.3.2).
- The level of effort and cost of conducting end-use circuit-level metering can be substantial, so our sample design approach will develop a cost-efficient sample that produces targeted representative results as well as contextualizing information. We acknowledge, that the results from this analysis will not produce sufficiently generalizable results across the population of TECH participants but it will inform the need for a larger end-use metering effort beyond the pilot study or as part of a full mainstream program.

The sample-based pathway will be a long-term submetering effort of a representative sample of TECH participant homes to derive measure-level usage trends over time. Figure 3 below provides specific steps that we will complete as part of this pathway, which are discussed in detail below.

Figure 3. Sample-Based Pathway Steps



Sample Frame Development

The effort will focus on participants who completed installations between December 2021 and October 2022. To balance the rigor of the study with available budgets, we will focus our efforts on a subpopulation of participants and measures most prominent in the program. To that end, we will focus the study on single-family homes and exclude small duct high velocity (SDHV) systems. Participants residing in multifamily homes represent a small percent of the participant population, and SDHV systems are installed in a very small percent of homes. Furthermore, to reduce variation, we will focus our efforts on homes with only one installed measure type, such as heat pump water heaters or HVAC heat pumps. This is consistent with the program to date, where the majority of participants have only installed one measure. Because we anticipate leveraging utility metered data for this study, we will limit our sample frame further to only include participants with sufficient pre-period whole house consumption data. This step will help maximize the use of onsite and utility metered data to reconcile, explain, and validate population-level pathway consumption analysis results (See Section 2.3.2). We will work with the CPUC, and relevant stakeholders, to refine and finalize our sample frame as needed.

Study Participant Sampling

From the sample frame developed in the step above, we will draw a representative sample of homes to participate in the end-use metering study. We anticipate leveraging a stratified sample design to allocate sample points across observable characteristics of importance to optimize variation in measurement as well as costs. We anticipate preparing a detailed sampling plan as part of this step. Our sampling strategy focuses on optimizing variation around electric load shapes⁸ and allocating sample into each stratum to minimize variation. Given that the participant population is distributed across climate zone and measure types, we anticipate at a very minimum stratifying our sample by measure type and climate zone(s). We also anticipate that given the size of the sample frame and anticipated response rate, in certain cases, we will pursue a census attempt in an effort to achieve desired sample sizes for the metering study. Our sampling efforts will be supported by review of project documentation as well as analysis of additional information available on participants, which may result in sampling and stratification enhancements. Furthermore, in an effort to optimize study costs, including driving distance from site to site for metering purposes, we will consider incorporating clustering techniques to target homes within close geographic proximity to one another.

We will draw our survey sample with consideration of anticipated response and cooperation rates, as well as with the goal of 90% confidence and 10% relative precision around key TECH system types, namely heat pump

⁸ Notably, our onsite electrical panel circuit-level metering will not include electric data prior to HP installation given the current TECH initiative participation process.

water heaters and HVAC heat pump systems, including ductless mini splits and central unitary systems.⁹ Table 4 provides an overview of the preliminary sampling approach. We will use it as a starting point in developing our final sample design. Overall, we are aiming to deploy submetering equipment at 80 participating sites.

Table 4. Preliminary Sample Design

System Type	Measure	Anticipated Sample Frame (Number of Participants)	Anticipated Sample Needed for Onsite Metering Recruitment	Anticipated Survey Recruitment Sample	Anticipated Site Metering Sample	Participant Recruitment Census Attempt
Heat Pump Water Heater	Heat Pump Water Heater	1,053	1,000	100	20	Yes
HVAC Heat Pumps	Ductless Mini Splits	2,210	1,000	100	20	No
	Central Unitary Systems	6,629	2,000	200	40	No
Total		9,892	4,000	400	80	

Deemed Savings Desk Reviews

To support our participant sampling and submetering analysis, as well as to develop a greater understanding of the applicability of existing deemed measure packages for fuel substitution claims and impacts, we will conduct a series of desk reviews drawing from our end-use metering participant sample. We will:

- Develop an understanding of the pre-installation state through review of program tracking data, and AMI data for each of the sampled sites,
- Capture contextualizing information to support our end-use metering analysis,
- Assess whether the assumptions in the current Statewide Deemed Measure Lists hold for fuel-substitution measures for planning purposes as well as for evaluation purposes based on empirical household data,
- Provide the implementation team with feedback on their analytical approach, and
- Inform the development of the EM&V framework.

For each sampled project, we will review an array of primary and secondary data, including:

- TECH program tracking data and project documentation to determine the make/model of pre- and post-retrofit equipment to validate the tracking data values and energy impact estimates.
- Participant survey data captured by the evaluation team including post-installation customer survey data where present and a pre-installation survey for end-use metering participants which will be used to gather additional contextual site and heat pump operation information.
- Assigned deemed measure packages and assumptions used by Energy Solutions to develop their ex-ante impacts. In cases where deemed measures were not used, we will request the energy impact estimation methods from Energy Solutions.

⁹ Given the anticipated sample frame for heat pump water heater participants, we anticipate attempting a census of participants to achieve desired metered sample sizes.

We will aggregate these data to inform our sample-based annual post-installation electricity use (from the onsite metering) and develop load shapes for both HPWH and HVAC HPs. We will also capture the implementation team's approach to mapping eTRM/DEER deemed fuel substitution measures to TECH decarbonization projects. This activity will help us to understand how valid the current EE measure package assumptions are for current and future electrification measures. To do so, we will review Energy Solutions mapping of TECH tracking data to existing deemed measure package lists. Note that the fuel-substitution measures are focused on overall (source) energy savings and cost-effectiveness, while the TECH decarbonization measures are focused on GHG reductions, so we anticipate significant differences between the deemed measure assumptions and energy impacts versus the TECH tracking data. We will also compare the actual home characteristics and load shapes gathered from our onsite data collection to make recommendations for adjustments to those assumptions.

End-Use Metering Participant Recruitment

Once the sample design is finalized, we will deploy a recruitment survey with participants. To the extent feasible, we will leverage existing process and market surveys including the six-month post-installation customer survey to support onsite metering recruitment efforts.

A key component of the recruitment survey is to qualify and recruit participants for the onsite metering study. We will use the survey to collect data on housing characteristics (e.g., vintage, square footage, etc.), energy using systems (e.g., location of the water heating, heating, and cooling equipment, existing equipment and systems, their vintage and use, etc.), participant characteristics (number and age of occupants, employment status, income), and behaviors (system replacement motivators, use of new equipment, anticipated changes in the coming months, etc.) that is not already collected in the TECH application database. The data collected during the recruitment survey will not only be used to explain trends in end-use metered consumption data, but also support relevant post-stratification of the metered sites to ensure representativeness. We will administer recruitment surveys using a mixed mode approach starting with an online survey for participants with email addresses followed by telephone follow up as needed.

To encourage participants to enroll in the metering study, we will offer a \$300 incentive—\$200 upfront and \$100 at the close of the metering period when the devices are removed—for their participation and agreement to use anonymized data. It is possible that the Opinion Dynamics team will not be able to install circuit-level metering equipment at some participant homes. In these cases, we will offer a \$50 incentive to customers as a way of acknowledging the time they invested trying to participate in the onsite portion of the study.

We will field the recruitment survey geographically to ensure timely and efficient site visits while minimizing cooperation rate effects.

Onsite Data Collection and Metering

Field technicians will be provided with a detailed, step-by-step site visit data collection and meter installation protocol. All site technicians will undergo thorough training on the protocol prior to going into the field to ensure consistency of deployment and program participant satisfaction.

Our onsite metering solution consists of an Emporia Gen 2 Vue Energy Monitor installed in the resident's breaker panel by a licensed electrician or journeyman. These devices have the capability to monitor up to 16 separate circuits in addition to the house mains (whole building load) and communicate over a 2.4 GHz Wi-Fi network. A dedicated Wi-Fi hotspot using a separate Cradlepoint router will be set up by the field technician so as not to burden nor risk changes to the residence's Wi-Fi. The Cradlepoint device will be plugged into an

outlet close to the electrical panel and its use explained to the resident. But it will be placed out of sight and labeled with a “Do Not Remove” sticker to avoid tampering or accidental removal by the resident.

Onsite metering will be used to monitor the incentivized HVAC HPs or HPWHs, as well as whole building, PV and EV (if present) circuits. Central HVAC systems may require multiple circuits to be monitored including the forced air unit (fan), compressor/condenser (for cooling and heating), and back-up electric resistance heating. If there are multiple HVAC units present, we will monitor all of them. HPWHs will typically only require a single 240V circuit and will be monitored to examine the operation cycle durations and modes (compressor, back-up, defrost cycle, demand response, etc.). For sites with on-site solar PV generation, the Emporia logger will also be used to track the energy generation, which will be used to examine the fraction of HP energy use that occurs during generation periods. EV charger circuits will also be monitored to determine their impact (if any) on HP loads determined from the AMI data pre/post and disaggregation analysis.

We will use the electrical panel photos included in project documentation to assess the feasibility for installing the metering equipment. Meters will be left in the field for at least a year in order to capture seasonal variation in energy consumption of the metered systems. All metering devices will be removed from the residence once monitoring is concluded.

During the onsite visits (installation and retrieval), the field technician will interview the customer to determine:

- How they are operating their heat pump equipment in the heating and cooling seasons,
- How they interact with their thermostats or integrated controllers, and
- If they changed switchover temperature settings since installation, and if so and why.

Data Management and Analysis

The evaluation team will download, store, and aggregate electrical panel circuit-level metered data, associated project information collected from Energy Solutions, deemed measure package lists, whole house meter data, as well as participant survey data. The circuit-level meter data will be matched up with utility meter data disaggregated into key loads (heating, cooling, and baseload) as part of the task below (Section 2.3.2) as well as all of the other data sources to provide a complete end-use metered, contextual and consumption engineering analysis data set for each of the sampled households.

All onsite electrical panel circuit-level meter data will be downloaded through the Emporia API. The evaluation team will download data periodically to ensure that meters are functional and will capture data throughout the course of the metering period. All data will be processed, cleaned, and checked for quality control. The Fulcrum™ app to track field installation activities. This tool will provide a log of all installs, removals, and troubleshooting throughout the installation process. All data will be transferred at the end of the project to the CPUC.

As noted above, we anticipate that each site will have at least 12 months of post-installation HP data. Drawing upon this data, we will conduct the following analytical activities:

- For each site, compare end-use energy use, load shapes and other data against that household’s consumption data. This will provide the team with an opportunity to assess how well disaggregated AMI data can reflect changes in electric consumption due to varied HP operation modes and the implications of any non-routine events on that accuracy, as well as any measures of uncertainty.

- Compare aggregated electrical panel circuit-level metering data to post-installation disaggregated cooling, heating, and baseline whole house consumption data. This analysis will produce measures of uncertainty around whole house versus measure-level energy impact estimates.
- Aggregate onsite electrical panel circuit-level meter data with other project information, including project documentation, participant survey data, to inform development of case studies by sample stratum or other distinguishing features.
- Analyze onsite electrical panel circuit-level metered data to develop technology-specific end-use load shapes, as well as identify any potential peak demand impacts and use components of that peak, to inform inputs for measure package lists as well as measurement strategies.
- Contextualize and validate population level energy impacts to inform GHG emissions reductions (see Section 2.3.2)

Deliverables:

- Draft and final sample designs
- Assessment of Statewide Deemed Measure Lists applicability to fuel substitution measures
- Metering installation protocol
- Onsite metered electric data and analysis results to inform GHG analysis, load shape and EM&V framework development
- Measure-level electric impacts and context drawn sample-based pathway

2.3.2 Population-Based Pathway: Consumption Analysis

The population-based pathway will leverage gas and electric consumption data for the pre- and post-participation period for all TECH initiative participants and a matched comparison group of non-participants to control for exogenous changes in consumption over time to estimate electric and gas energy impacts.

To the extent feasible, the evaluation activities will attempt to conduct all analytical activities at a granular level to support providing estimates for key program or participant characteristics. All our analyses will seek to identify impacts across various customer types, as relevant, based on their incidence in the population of program participants. This may include gas or electric utility, climate zone, measure installation configuration, rate code, etc. These activities will support the evaluation team’s ability to validate, reproduce and assess the extent to which there are large degrees of uncertainty based on measurement methods (e.g., data cleaning, data management, comparison group development and modeling steps) as well as by customer types (e.g., measure installed, home retrofitted, climate zone, etc.)

Notably, we will conduct a review of the applicability of the consumption analysis approach detailed below on our sample of homes with circuit level metering in Section 2.3.1., the implementation team’s Electrification Value Stream population, and the evaluators population of participants.

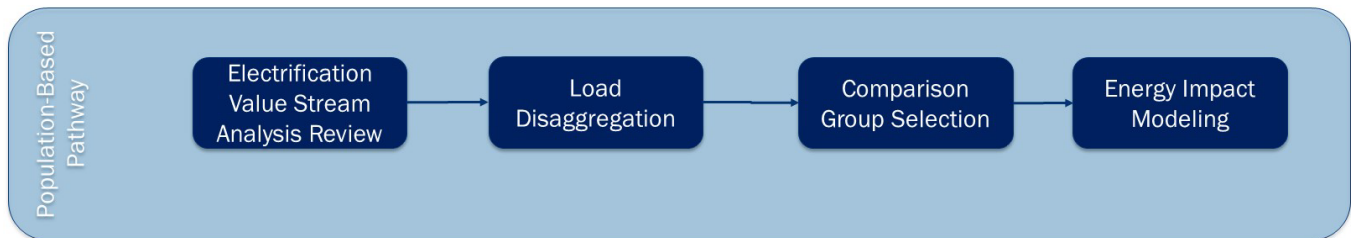
The research questions addressed by this analysis are:

- What are the electric and gas energy impacts associated with the Pilot? What are the impacts associated with various customer segments of interest?
- With what degree of certainty can whole house meter data produce electric energy impact results? What project features produce high degrees of uncertainty?

- Does the implementation team’s Electrification Value Stream modeling assumptions and approach support customer targeting? Are these implementation aspects in alignment with ex post impact measurement, and to what degree should they be in alignment?

Below are the analytical steps that we will perform as part of this pathway:

Figure 4. Population-Based Pathway Steps



Electrification Value Stream Analysis Review

The program implementer is conducting an Electrification Value Stream analysis, which includes energy, GHG, and bill impact estimates, to support future participant targeting. This activity includes a consumption analysis utilizing a matched comparison group. Opinion Dynamics will review the consumption analysis approach and results to:

- Assess the extent to which the evaluation team can leverage the implementers’ data management, cleaning, comparison group and modeling, as well as and analytical results to support the following ex-post impact activities
- Provide the implementation team with feedback on their analytical approach and its support of participant targeting, and
- Inform the development of the EM&V framework given the high degrees of uncertainty regarding impact evaluation approaches relevant for building electrification retrofits.

To conduct our review, we will request and review:

- A sample of Recurve’s raw data (e.g., customer and energy interval data),
- Recurve’s data audit, cleaning and transformation, and preparation code and outcomes,
- Recurve’s matched comparison group development code and outcomes, and
- Recurves econometric analysis code and results (including for GHG emissions and utility bill impact estimation).

Load Disaggregation

Leveraging gas and electric consumption data for participants and non-participants, we will disaggregate whole house loads into cooling, heating, and baseload components. Load disaggregation will allow for more precise matching of a comparison group, support modeling of loads associated with the TECH-incented measures, as well as allow for flexibility in exploring participant pre- and post-consumption patterns associated with the source of load that was modified as a result of the TECH Initiative (e.g., cooling and heating load for

HVAC system installations and baseload for water heating installations). In addition to disaggregating load, as part of this task, we will use typical meteorological year weather data (CZ2022¹⁰) to develop pre- and post-participation Normalized Annual Consumption (NAC) estimates.

Comparison Group Selection

The use of the comparison group allows control for exogenous factors, such as energy prices, general economic conditions, natural disasters, pandemics, and other health events that occur concurrently with, but are unrelated to, the intervention under evaluation (in this case, HP installations performed because of the TECH Initiative). The comparison group estimate of exogenous change is used to adjust the treatment group, thus removing, or controlling, for that exogenous change.¹¹ When a program is not designed as an experiment, wherein a control group is set aside prior to the start of the intervention, a comparison group can be developed using a quasi-experimental design framework.

We will develop a matched comparison group consisting of similar non-participants using disaggregated electric and gas load, as well as available participation and customer information. The TECH Initiative incentivizes heat pump water heaters, the installation of which affects the water heating load, and HVAC systems, the installation of which affects the heating and cooling load. Furthermore, most of the installations replace existing gas systems with electric systems. Finally, TECH-incented HP installation occurs across multiple climate zones in California and in homes with and without PV arrays. We will consider these characteristics in selecting a comparison group. More specifically, we will conduct matching with stratification by climate zone, presence of PV arrays (as reflected in customer net metering status), and customer rate schedule (CARE vs. Non-CARE) at a minimum. Energy consumption is highly dependent on the housing structure and vintage. We will explore the presence of these data points and incorporate them into the matching process as a stratification dimension as available.

We will conduct matching in two stages using disaggregated pre-period consumption data. During the first stage, we will match on energy consumption data selecting multiple matches for each participant (we will aim for 30:1 ratio to ensure a sufficient pool of matched non-participants to support the second stage). During the second stage of matching, we will match on electric consumption data, incorporating both monthly and seasonal consumption patterns, as well as peak consumption patterns into the matching process. We anticipate deploying Euclidean and Mahalanobis distance matching algorithms. We will strive to find matches for each participant that align on both electric and gas use; however, we anticipate there may be substantial data loss as part of the data cleaning process due to challenges matching accounts to premises as well as data sufficiency requirements. As a result, our approach will balance data availability and quality of match.

As part of the comparison group selection process, we will run checks to ascertain comparison group equivalency. In addition to assessing measures of standardized bias, which signify matching quality,¹² we will compare participants and matched non-participants on weather using heating degree day (HDD) and cooling degree day (CDD) metrics. We will also bring other available information on customers to ensure a balanced comparison group in relation to the participant population.

¹⁰ Since The California Energy Commission (CEC) will be adopting new time-dependent valuation (TDV) costs and the CZ2022 weather data for the 2022 Title 24 update, effective January 1, 2023, we will also use CZ2022 weather data for this analysis.

<https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M387/K465/387465216.PDF>

¹¹ <https://www1.eere.energy.gov/wip/pdfs/53827-8.pdf>

¹² The standardized bias for continuous covariates is calculated by dividing the difference in means of the covariate between the treated group and the comparison group by the standard deviation. This metric acts as a measure of successful balance achieved through matching with 0.25 value being a widely accepted cutoff point. (Cochran WG, Rubin DB. Controlling bias in observational studies: A review. *Sankhya*, Ser. A. 1973;35:417-446.)

Energy Impact Modeling

Using the disaggregated load for participants and comparison group customers, we will specify a series of pooled models to derive changes in energy consumption. As part of the modeling process, we will review guidance related to data structuring, model specification, and model validation from the CPUC NMEC Rulebook¹³, CalTRACK¹⁴, Lawrence Berkely National Laboratory (LBNL), and other sources. We will specify distinct models by fuel source and will leverage hourly methods (Time-Of-Week and Temperature model) to develop changes in electric energy consumption and leverage monthly methods to develop changes in gas consumption. As part of the modeling process, we will develop distinct impact estimates for each system type (heat pump water heaters, central heat pumps, and ductless heat pumps), as well as by climate zone. We will incorporate presence of PV arrays as well as rate schedules into the modeling process as needed. Depending on the total number of participants we can model, their various characteristics, and data available, we may provide results by other features of interest, such as DAC or gas utility service territory.

Modeling of gas data will provide an annual, and where feasible seasonal, estimate of per-participant energy impacts by climate zone and system type. Modeling of electric data will produce 8760 per-participant energy impact estimates by climate zone and system type. Impacts will be normalized to a typical weather year using CZ2022 weather data.

We will incorporate the annual impact estimates resulting from the modeling efforts as a direct input into GHG emission reduction calculations described below.

Deliverables:

- Results from review of implementer Electrification Value Stream analysis, where relevant
- Ex-post population-level electric and gas energy impacts (total and average) as well as by associated sub-segments, where feasible
- Comparison between population-based and sample-based pathway electric estimates to inform GHG analysis and EM&V framework development

2.3.3 GHG Emissions Reduction Analysis

Once the energy impact analytical pathways are complete, we will incorporate this information to serve as inputs to our GHG emissions reduction analysis. The research question addressed by this analysis is:

- What are the GHG emissions reductions and cost per metric ton of avoided GHG associated with the Pilot?

GHG Emission Reduction Estimation

Using the final impact estimates, we will apply marginal GHG emission factors to convert energy impacts to GHG emission reductions. On the gas side, we will apply average annual weather normalized savings by the marginal gas emission factor. We will apply climate zone-specific 8760 marginal emission factors to convert electric impacts into GHG emission reductions.¹⁵ We will then aggregate gas and electric emissions across

¹³ <https://www.cpuc.ca.gov/-/media/cpuc-website/files/legacyfiles/n/6442463694-nmec-rulebook2-0.pdf>

¹⁴ <https://www.caltrack.org/>

¹⁵ We will use marginal emission factors determined through the 2020 Time Dependent Valuation of Energy for Developing Building Efficiency Standards study. <https://efiling.energy.ca.gov/GetDocument.aspx?tn=74439>

measures, climate zones, and other strata to the program level applying participant weights to determine program level overall GHG emission reductions. We will then translate these into lifetime impacts.¹⁶

The BUILD and TECH teams planned to use different emission factors, but Opinion Dynamics and the CPUC felt strongly that it is important to standardize the emission factors used. Thus, this approach is consistent with activities employed across both TECH and BUILD.

To support CARB Allocated Allowance Value Form reporting, we will disaggregate participants by gas utility service territory and apply ex-post assumptions to estimate GHG emissions reductions associated with installations within each service territory. This will serve as an input to the broader estimation of expected GHG emissions reductions associated with use of the allocated allowance value.¹⁷

Cost Per Metric Ton of Avoided GHG

We expect the package of measures installed, the need for additional services like panel upgrades, and the corresponding project costs to vary for each household intervention. So, in addition to the basic program-level metric, we will also develop this metric for additional project type subcategories (specific measure packages, panel upgrades, etc.) to provide additional insights for the program. We will then develop the cost per metric ton of avoided GHG emissions using program and project costs, and the energy changes produced by same fuel (e.g., electric resistance to heat pump), fuel substitution (e.g., natural gas to electric), and fuel switching (e.g., propane to electric) interventions. We will utilize the energy impacts generated in the consumption analysis described in the preceding section for our calculations.

Deliverables:

- Total avoided GHG emissions annually
- Cost per metric ton of avoided GHG annually

2.4 Task 5: Utility Bill Impact Estimation

The TECH Initiative provides electric appliances to replace existing appliances traditionally fueled by natural gas or propane. Assessing bill impacts for customers who electrify is particularly important for low-income customers as there can often be increases in customer costs.

The research questions for this analytical exercise are:

- What are the average changes in energy costs for TECH pilot participants?
- What is the distribution of changes in energy costs for participants?

The utility bill impact analysis will result in estimates of changes in energy costs following participation in the TECH Initiative. To support the analysis, we will leverage disaggregated gas and electric consumption data for the population of participants and their matched comparison group developed as part of the population-based

¹⁶ Lifetime impacts will be calculated based on the measure lives of the TECH initiative equipment.

¹⁷ CARB guidance states "[t]he GHG benefits of auction proceeds use are prorated to the percentage of total expected lifetime project costs that are covered by auction proceeds in the Data year, **including auction proceeds used in the Data Year for administration and outreach of the project**" (emphasis added). Therefore, for CARB reporting purposes, the results of this analysis will serve to update total expected project savings over the life of the project, which will then be allocated to each reporting year. (source: CARB Instructions for GHG Benefits and Electric Vehicle GHG benefits Estimation Tool. https://ww2.arb.ca.gov/sites/default/files/cap-and-trade/allowanceallocation/ghg_benefits_estimation_tools_instructions.pdf. Accessed November 8, 2022)

pathway. We will then convert energy consumption data into bill amounts by cross-referencing and applying each participant's rate schedule. We will leverage customer billing history, California Energy Commission's (CEC) customer rate database, and the Market Informed Demand Automation Server (MIDAS), to extract rate-related detail. The resulting data will reflect time series energy costs.¹⁸

We will then run modeling efforts similar in scope to the energy impacts models described in detail under the Population-Based Pathway section above to develop bill impact estimates. The models will incorporate weather, among other predictors. As part of the modeling process, we anticipate developing bill impact estimates by rate class and climate zone. We also anticipate developing bill impacts for disadvantaged vs. non-disadvantaged communities (DACs vs. non-DACs). Electric models will result in 8760 estimates of per-participant bill impacts while gas models will provide an average seasonal and annual per-participant change in customer bills following participation in the TECH Initiative. We will aggregate gas and electric bill impacts by multiplying each by the respective participant population and then summing them together to arrive at the program level total first year bill impacts.

Notably, our stage one modeling will also produce weather normalized individual energy costs in the pre- and post-periods. As a result, we will also produce frequency distributions of energy cost changes for the entire population of participants to understand if there are any hardships associated with customer types. To the extent feasible, we will correlate any trends to customer characteristics.

Deliverables:

- Total and average utility bill impacts for the TECH Initiative and by specific customer/utility sub-categories, as relevant

2.5 Task 6: Develop EM&V Framework to Support Scalability

Given that this is a first of its kind pilot in California and nationally, the evaluation team will incorporate results from the evaluation activities listed above to develop a preliminary evaluation framework for future electrification and decarbonization pilots and programs. The available approaches to estimating changes in energy use, GHG, and customer bills draw upon existing energy efficiency EM&V protocols, but are sufficiently distinct (e.g., bidirectional impacts, integration with multiple DERs) and thus, careful consideration will be taken to ensure appropriate methodologies are deployed that deliver the most transparent, scalable, and accurate estimates of impacts. This preliminary framework is intended to serve as a reference for future electrification and decarbonization evaluations. The framework will also provide a foundation for future EM&V framework developments that will likely include a broader set of stakeholders and account for the ongoing changes in technologies, market actors, and market interventions in the electrification and decarbonization space.

The research questions addressed by this task are:

- To what extent can the existing energy-savings based impact evaluation frameworks (deemed, custom, NMEC) be adapted for electrification/decarbonization policy, GHG savings, and measurement needs?

¹⁸ As part of the analytical approach, we considered leveraging actual billing data. We decided against that approach due to lack of granularity (especially on the residential side given that billing data will be at monthly cadence) and more importantly, billing data imperfections such as inability to discern and remove billing adjustments and credits that are distinct from the rate schedule. We also considered converting energy impacts into bill impacts instead of converting units of energy into dollars and cents and decided against that approach due to inability to effectively control for rate schedule changes from pre-period to post-period, as well as during the post-period.

- Which impact framework approach and/or element combinations produce the most robust, accurate, transparent, and scalable approach to measurement, verification and evaluation of current pilot and future electrification retrofit programs?
- How should energy and GHG impacts be developed and claimed to ensure an accurate, “best” estimate of impacts? Is a population-level pathway needed to capture the diversity in system types and energy impacts? Or are deemed fuel substitution measures a sufficient proxy for estimating energy, GHG, and customer bill impacts? Since GHG reductions are the primary goal instead of EE and cost-effectiveness, are new deemed decarbonization measures needed?
- What impact claims and reporting requirements are relevant for electrification and decarbonization pilots and future programs?

We anticipate drawing upon the results from the analytical activities within this plan as well as additional evaluations nationally to develop a draft framework. Once completed, we will facilitate workshops with key stakeholders to finalize the framework.

Develop Draft Framework

This analysis will help to identify any uncertainties as well as costs associated with EM&V activities, and support recommendations for accurate, transparent, and scalable future measurement activities. We will take the analytical outputs and propose a draft EM&V framework that considers the results, uncertainty, and costs associated with various methodological and reporting approaches.

Facilitate Stakeholder Workshops

Once the draft framework is completed, we will facilitate two workshops with key stakeholders (e.g., CPUC, CEC, Program Coordination Group (PCG) members, IOUs, and implementers) to discuss any concerns or recommendations for the framework. We will present results from the analytical outputs and address questions with stakeholders.

Recommend EM&V Approach

Integrating results from the facilitated workshops, we will produce a final EM&V framework for public review and comment.

Deliverables:

- Draft evaluation framework
- Workshop facilitation
- Final framework

2.6 Task 7: Reporting and Feedback

We will time our retrospective evaluation research to ensure early feedback on impact results, but also incorporate most TECH Initiative participants. This will allow our team to produce results that are generalizable to the population of Initiative participants. As a result, we anticipate commencing our analytical activities after a sufficient number of participants have twelve months of post-period energy consumption data, likely Q3 2023. Upfront data management and analytical activities will begin Q4 2022. We will develop an Interim Population-Based Pathway Draft Report for review by stakeholders in February 2024. We will also provide draft

Evaluation Tasks

CARB reporting for BUILD and TECH in May of each year and final CARB reporting in June of each year through 2024. We will provide a draft of the Final Report Integrating All Impact Evaluation Activities for stakeholder review in October of 2024.

3. Timelines and Deliverables

The program years for TECH are defined by the calendar year.

Table 5. Written Report and Presentation Schedule

Deliverable Milestone	Milestone (Estimated Timing)
Finalize Access to T20 Section 1353 Data Request	December 2022
Draft Impact Evaluation Plan	January 2023
Final Evaluation Plan	February 2023
Population-Based Pathway	
Electrification Value Stream Analysis	July 2023
Load Disaggregation	August 2023
Comparison Group Selections	September 2023
Energy Impact Modeling	December 2023
GHG Estimation Approach	
GHG Estimation	January 2024
Cost Per Metric Ton Calculation	January 2024
Interim Population-Based Pathway Draft Report	February 2024
Sample-Based Pathway	
Sample Frame Development and Participant Sampling	February 2023
Deemed Savings Desk Reviews/ Participant Recruitment	April 2023
Onsite Data Collection and Metering	May 2023 – June 2024
Loadshape Development	July 2024
Compare Sample and Population Impacts	August 2024
Energy Savings Calculation/ Contextualization	August 2024
EM&V Framework Development	
Draft EM&V Framework	September 2024
Workshop #1	October 2024
Workshop #2	November 2024
CARB Reporting	
Draft CARB Reporting	May 2023 and May 2024
Final CARB Reporting	June 2023 and June 2024
Draft Final Report Integrating All Impact Evaluation Activities	October 2024
End of Contract	January 1, 2025

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