

# Using Big Data to Assess Energy System Transitions in Under-resourced Communities

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## ABSTRACT

More work is needed to understand energy system transformations within under-resourced communities, including health co-benefits and potential unintended consequences of decarbonization initiatives.

This paper summarizes a first-of-its-kind study that integrated community-level energy system modeling with local outreach and indoor air quality data collection in single-family homes. A site-level analysis identified load curve and energy bill changes associated with multiple scenarios. Scenarios included appliance electrification and distributed energy resources (DERs) in a variety of homes in an under-resourced community. These results were then aggregated and extended into technology adoption scenarios over the next thirty years.

The study highlighted important aspects of energy use in under-resourced communities. For example, analysis of hourly indoor temperature changes revealed that not all residents were using their cooling systems: indoor temperatures during the summer monitoring period were, on average, over 85°F every hour for 24 hours across two weeks.

Site-level scenario analysis demonstrated the need to pursue full electrification through a pairing of EE and DERs to avoid increases in monthly energy bills and community-wide peak load. This study found each electrification scenario has unique benefits and optimal transformation scenarios at the community level for energy bill, air quality, and GHG impacts. For example, the study found that electrifying gas cooking appliances is expected to provide the greatest improvement to indoor air quality, while electrifying water or space heating will provide the greatest GHG reductions. The study's insights on the range of community-level clean energy technology adoption scenarios can help inform policy and program design.

## Background

California has enacted laws to decarbonize the state by 2045, but there are still uncertainties around how the state will balance electricity supply and demand in a decarbonized grid (Exec. Order No. B-55-18). While Senate Bill 100 mandates 100% zero-carbon electricity supply by 2045, the California Energy Commission forecasts a doubling of electric load by 2050 (California Renewables Portfolio Standard Program).<sup>1</sup> Within this context, the study described in this paper identified and analyzed four primary transition pathways for residential buildings to decarbonize: (i) electrification of natural gas appliances, (ii) retrofits for energy efficiency, (iii) electrification of vehicles, and (iv) deployment of distributed energy resources. These pathways were then aggregated to provide insight into energy needs community-wide. The study focused on understanding the rates of energy system transformations within under-resourced

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<sup>1</sup> CEC Adoption of Demand Scenario Results. May 31, 2022. [efiling.energy.ca.gov/GetDocument.aspx?tn=243354](https://efiling.energy.ca.gov/GetDocument.aspx?tn=243354)

communities, the resulting health co-benefits of these transformations, and the potential for unintended interactions between various initiatives, with resulting impacts on these communities.

## **Project Purpose**

The project sought to (a) improve the current understanding of indoor air quality within under-resourced households; (b) and the extent to which household and appliance attributes, and occupant energy behaviors are related to pollutant concentrations; (c) better understand the degree to which different energy transition pathways are likely to naturally be pursued within under-resourced communities; (d) enhance the current understanding of interactions between electricity and natural gas systems.

## **Project Scope**

This paper focuses on household-level impacts on customers and the subsequent system-wide impacts that can be expected at various levels of technology adoption. Furthermore, this paper will provide high-level findings from indoor air quality monitoring to explain why certain retrofit packages were analyzed for this effort. The project study area consisted of two adjacent zip codes in Los Angeles County: 91746 within the unincorporated communities of Avocado Heights and Bassett, and 91732 within the City of El Monte.

The major project components included:

- Air-quality monitoring of NO<sub>2</sub> and PM, both indoors and outdoors, with separate winter and summer monitoring periods. (Led by UCLA)
- Building-scale and community-scale modeling.
  - Building-scale prototype and scenario modeling for four building decarbonization pathways. (Led by The Energy Coalition)
  - Community-scale numerical modeling and load profile generation (Led by UCLA)
- A holistic assessment of residential electrification, including calculation of emission changes (locally and grid-wide), and calculation of public health benefits and impacts. (Led by UCLA)

## **Analysis Overview**

### **Air Quality**

The project team conducted monitoring from February 9-24, 2019 (winter) and July 13-28, 2019 (summer). The team collected air quality data inside and outside volunteer participant homes using passive NO<sub>2</sub> samplers and time-resolved particulate matter (PM) monitors. All air quality measurement devices were installed, monitored, and collected by trained field research assistants, who also administered three sets of questionnaires to each participant household. Active SGV, a community-based organization with deep roots in the study area, was instrumental in engaging participant households.

The project team used information gathered during air quality monitoring and analysis of participants' appliances and homes to establish building prototypes. The team also measured

indoor temperature to help validate building energy model outputs and used high-level findings to define the electrification scenarios that were modeled.

## **Building-Scale Prototype and Scenario Modeling**

To characterize current and potential future household-scale energy use, the project team developed a set of prototype building energy models to reflect the study community's most common energy consumption and residential building stock characteristics. These prototype models were informed by data collected from study participants. For each prototype, the project team conducted modeling for baseline conditions and for future residential building energy transition scenarios. The term "scenario" refers to a set of discrete measures or new technologies that can be applied to the energy transition categories examined in this project: distributed energy resource (DER) adoption, light-duty electric vehicle (EV) adoption, energy efficiency (EE) improvements, and natural gas appliance electrification. For purposes of building-scale modeling scenarios (and subsequent community-scale modeling), EE measures were combined with appliance electrification measures. Model outputs included total annual consumption and hourly load profiles for electricity and natural gas, GHG emissions, and utility bill cost estimates.

## **Community-Scale Modeling and Load Profile Generation**

This step of the analysis built on annual hourly kWh load profiles (8,760 hours) generated through building prototype modeling. These load profiles reflect the average baseline performance of a range of buildings representative of the current community building stock, as well as the modeled performance of these buildings under possible energy system transformation scenarios. The project team generated community-scale load profiles by aggregating and scaling building load profiles based on the number of buildings assigned to each model scenario. Future changes in hourly loads were incorporated into an aggregate community-scale hourly load profile. Each pathway simulation generated a 25-year hourly composite load profile (219,000 hours) that reflects the future electricity demand of all the households in the study area, from 2020 to 2045.

## **Methods**

This section focuses on the methods used for the building-scale and community-scale modeling described in the previous section. We will provide details of the transition categories and pathways that underpin the analysis, then we will discuss the modeling work.

### **Transition Categories and Pathways**

To establish an overarching direction for this study, the project team defined three transition categories. Each category shaped the energy interventions modeled at the building-scale. Once each of the three categories was modeled for each residential building, those results were aggregated to show the collective electricity load shape across the study community. The three categories are defined below.

**Transition category 1: residential natural gas appliance electrification.** The residential electrification scenario focused on air and water heating systems, clothes dryers, and cook stove

ranges/ovens because these are the most common natural gas appliances in residential homes. Results from the monitoring component of this project informed the designation of two “indoor air quality focused” transition pathways. The first pathway prioritized the electrification of cooking appliances to provide the greatest reduction in indoor pollutant concentrations from gas combustion. The second pathway electrified heating, ventilation, and air-conditioning (HVAC) systems to provide improved filtration of ambient pollutants. The third pathway, full home electrification, electrified water heating and clothes drying.

**Transition category 2: residential distributed energy resource adoption.** The distributed energy resource scenarios focused on solar photovoltaic (PV) and battery storage systems. The different scenarios reflect households with: no solar PV or battery storage, solar PV and battery storage systems, solar PV only, and battery storage systems only. The optimal sizing and operational characteristics of the solar PV and battery energy storage systems were identified for each scenario using REopt software.

**Transition category 3: residential light-duty vehicle fleet electrification.** The vehicle electrification transition category focused on load profile changes associated with EV ownership. Due to resource limitations and the high proportion of renters within under-resourced communities, we assumed Level 1 charging in all cases.

## **Building Scale Prototypes and Modeling**

Building prototype models were informed by data collected from study participants during the air quality monitoring portion of the project. For each prototype, the following outputs were generated for baseline conditions and for future transition scenarios in each of the three transition categories: total annual consumption, hourly load profiles for electricity and natural gas, GHG emissions, and utility bill cost estimates. The prototype building models were developed to represent building types that were prevalent within the study area community. Since the study only focused on operational costs and not capital costs, the study aimed to minimize the out-of-pocket expense to the customer in the scenario that subsidies provided direct install services at no cost to residents. Key aspects of the building modeling methods are summarized below.

**Tools.** The project team used the Building Energy Optimization Tool (BEopt) to develop the building energy models.<sup>2</sup> BEopt is a National Renewable Energy Laboratory (NREL) open-source tool that can analyze residential building designs and identify energy consumption trends, GHG emissions, and utility bill impacts from energy retrofits. BEopt models heat transfer and other physical properties at a high-resolution time scale. It yields hourly load profiles and quantitative energy and financial metrics. It requires a large data set on building characteristics including area, architecture, building envelope, occupancy, energy system, and utility rate. The project team also used Renewable Energy Integration & Optimization Tool (REopt) to determine the cost of PV and batteries as part of the DER scenario development.<sup>3</sup>

**Steps.** The following steps were taken to create the prototype models:

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<sup>2</sup> Building Energy Optimization Tool website: [www.nrel.gov/buildings/beopt.html](http://www.nrel.gov/buildings/beopt.html)

<sup>3</sup> Renewable Energy Integration & Optimization Tool website: [REopt.nrel.gov](http://REopt.nrel.gov)

1. Used data from the air quality monitoring study, the questionnaire, and survey as the starting point for data inputs.
2. Defined a set of prototype buildings based on HVAC configurations that represent the range of residential buildings in the study community.
3. Defined a set of energy efficiency measures and electrification measures for all gas appliances and their alignments with Title 24 2022 code updates (Building Energy Efficiency Standards, Title 24).
4. Used BEopt for each prototype building, modeled each electrification measure to fully understand energy, thermal comfort, and economic impacts. The team used this information, along with findings from the indoor air quality analysis, to define electrification scenarios.
5. Used BEopt for each prototype building, ran defined electrification scenarios, and created output (time series) files.
6. For each load shape generated, the team applied the REopt software to determine optimal cost and GHG-optimal scenarios for different configurations of DER adoption and created output files for hourly load profiles for each of the buildings' scenarios.

**Data and variables.** The prototype models were grouped by the combination of HVAC systems most common in the participating homes. Table 1 shows the types of HVAC configurations present in single-family homes among the study participants.

Table 1. Single family HVAC configuration frequency

| Space heating method                                     | Space cooling method |      |           | Total |
|----------------------------------------------------------|----------------------|------|-----------|-------|
|                                                          | Central AC           | None | Window AC |       |
| Central furnace and space heater                         | 8                    |      | 4         | 12    |
| Central furnace and wall furnace                         | 1                    |      |           | 1     |
| Central furnace only                                     | 9                    | 2    | 1         | 12    |
| Central furnace, wall furnace and space heater           |                      |      | 1         | 1     |
| No central heat, wall furnace or space heating Indicated |                      | 2    | 5         | 7     |
| Radiant heat and space heater                            |                      |      | 2         | 2     |
| Space heater only <sup>4</sup>                           | 1                    | 2    | 7         | 10    |
| Wall furnace and space heater                            |                      |      | 6         | 6     |
| Wall furnace only                                        | 1                    | 2    | 10        | 13    |
| Grand total                                              | 20                   | 8    | 36        | 64    |

**Model calibration.** The project team performed model calibration using energy consumption data supplied by the investor-owned utility (IOU) and indoor air temperature data, which served

<sup>4</sup>The configuration of 'space heater only' was not modeled because the most common underlying survey response in this category was that the occupant did not know what type of heating system they had, and there was limited access to those homes during the site visit.

as a basis for the selection of heating and cooling setpoints.<sup>5</sup> For each prototype, the team selected the BEopt model that a) was within one standard deviation of the community average energy use intensity (EUI) for natural gas and electricity, b) reflected heating and cooling setpoints based on monitored temperatures, and c) was within or as close as possible to the average EUI for the parametric model runs for that specific prototype. The best fit model run was then isolated and picked as the prototype for the given home with a defined HVAC configuration. Figures were generated to visualize the energy end use breakdown and baseline hourly consumption load profiles for each aggregated building type. The project team also conducted an assessment of how the model outputs compared to the average customer's bills by comparing the model to values derived from representative electricity and natural gas consumption and residential tariffs. Figure 1 and Figure 2 show the measured data for consumption and utility bill amounts respectively.

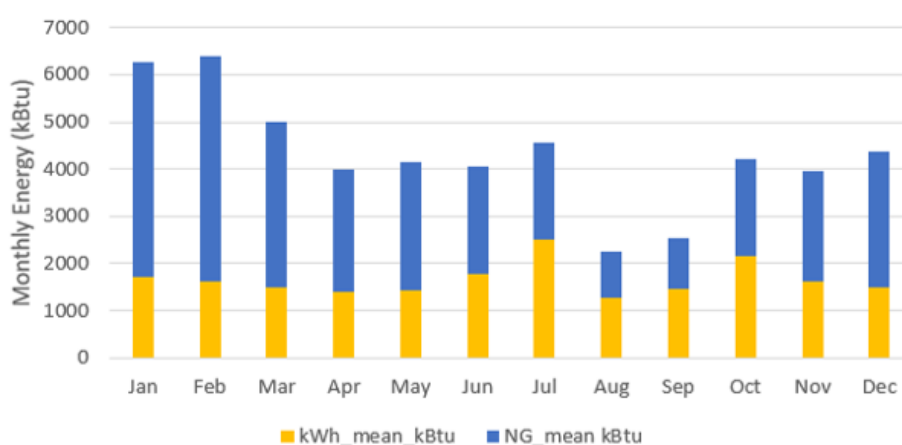


Figure 1. Monthly averages (measured) for energy consumption per household.

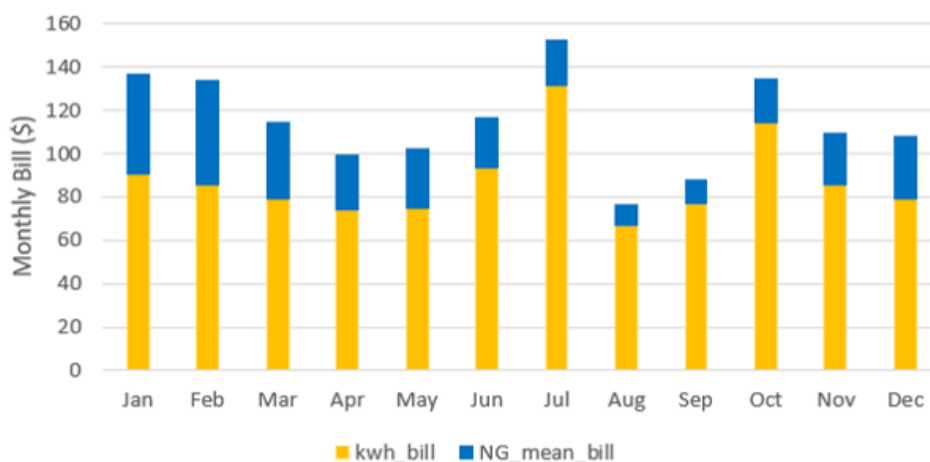


Figure 2. Monthly averages (measured) for energy bills per household.

One of the most valuable pieces of monitored data from participants' homes was the hourly, building-specific data on paired indoor and outdoor air temperatures (Figure 3). Standard

<sup>5</sup> One Purple Air monitor was installed indoors to record indoor air temperature, PM 2.5, and PM 10 and relative humidity.

practice for the ‘energy modeling community’ is to calibrate energy models only to energy consumption data;<sup>6</sup> measured indoor air temperatures are not commonly used. Questionnaires collected participants’ heating and cooling setpoints if available, but only half of the participants in single-family homes had programmable thermostats. The high summer temperatures inside the homes (85 degrees Fahrenheit on average for every hour of the two-week monitoring period) indicate that participants heavily self-regulated their cooling equipment, primarily using it only during a short period of time in the afternoon. The use of heating equipment, on the other hand, seemed to occur for a longer duration and result in a more constant and comfortable indoor temperature.<sup>7</sup> This information was used to set the model’s heating and cooling setpoints *and* schedules to more accurately represent the indoor temperatures for all homes and all prototypes in the study area.

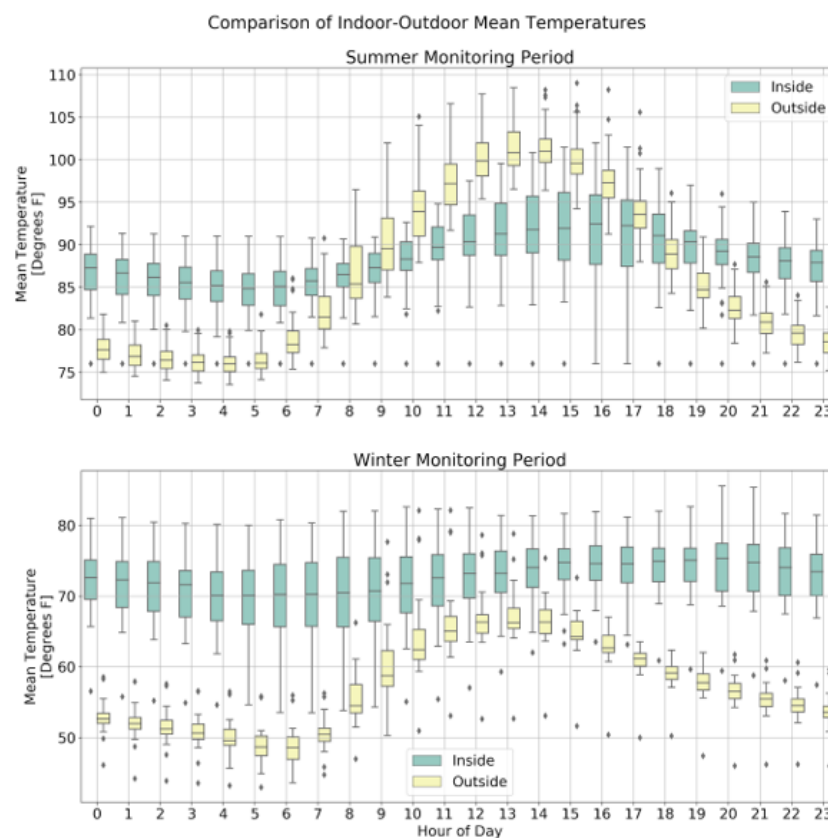


Figure 3. Box plots of hourly indoor and outdoor recorded temperatures.

**Home characteristics: electrification and energy efficiency (EE) scenarios.** Analysis of air quality monitoring data informed the electrification scenarios (discussed in the Results section below), which found that indoor pollutant concentrations were most closely related to the use of natural gas cooking appliances (stoves and ovens). Electrification scenarios, which also included energy efficiency improvements, are summarized in Table 2.

<sup>6</sup> ASHRAE Guideline 14 was used as the standard practice.

<sup>7</sup> ASHRAE Standard 55 is typically used for indoor thermal comfort; however 85F was reasonable to consider outside of the thermal comfort zone.

Table 2. Summary of measures (EE and natural gas appliance replacements) for each electrification scenario

| Measure               | Scenario                              |                        |                                    |                                    |
|-----------------------|---------------------------------------|------------------------|------------------------------------|------------------------------------|
|                       | Baseline                              | Minor IAQ focused      | Moderate IAQ focused               | Full home electrification          |
| Roof/attic insulation | Uninsulated/R13                       | R-49                   | R-49                               | R-49                               |
| Water pipe            | Uninsulated                           | R2 copper              | R2 copper                          | R2 copper                          |
| Air duct              | N/a or 30% leakage                    | N/a or R-6 10% leakage | N/a or R-6 10% leakage             | N/a or R-6 10% leakage             |
| Lighting              | 40/60 or 80% LED                      | 80% LED                | 80% LED                            | 80% LED                            |
| Cooling equipment     | Window unit or central cooling        | Same as baseline       | Mini-split or air source heat pump | Mini-split or air source heat pump |
| Heating equipment     | Wall furnace 60% AFUE/control furnace | Same as baseline       |                                    |                                    |
| Cooling setpoint      | 72F from 3-5PM 95F otherwise          | Same as baseline       | Same as baseline                   | Same as baseline                   |
| Heating setpoint      | 71F with 65F setback                  | Same as baseline       | Same as baseline                   | Same as baseline                   |
| Cooking               | Gas range                             | Induction range        | Induction range                    | Induction range                    |
| Water heater          | 40 Gal natural gas                    | Same as baseline       | Same as baseline                   | 50 gal HPWH                        |
| Clothes dryer         | Natural gas                           | Same as baseline       | ENERGY STAR® electric dryer        | ENERGY STAR® electric dryer        |

For each individual measure considered, the project team used Title 24 2022 codes and standards to specify how efficient the new equipment or retrofit would be. Additionally, the project team included a new HVAC system only if the existing building infrastructure allowed for it (e.g. air ducting was already present). If it was, then a ducted air source heat pump was specified. If ducting was not present, then a ductless mini-split heat pump was specified. Based on their air quality data analysis, there was not a strong correlation between water heating and PM 2.5, PM 10 or NOx. Because of this, and because of the modeled increased energy bills for residents, the heat pump water heaters were included in the full home electrification scenario. Other considerations, such as whether new ducts were installed and if insulation was added to the attic and other attributes, are described below. When comparing the retrofit scenarios to the baseline model, heating and cooling setpoints were not changed, consistent with the Building America Simulation protocol (DOE 2014). This also kept the number of generated load profiles to a manageable number and maintained a “like-for-like” comparison. However, in future studies, this sensitivity is of great interest, because potential changes in the residents’ interactions with new equipment can substantially affect energy consumption and energy bill amounts. The approach of keeping the setpoints constant in pre and post-retrofit scenarios is one limitation of

this study. In the absence of solar PV on the home, it is reasonable to assume that customers in this community will still take a conservative approach to cooling their homes. Future studies will explore increasing the utilization of cooling equipment which, despite being more efficient, is currently not identified as a bill-reduction strategy unless paired with solar PV.

## **Community Scale Simulations**

**Simulation framework.** Individual energy system transition pathways were simulated at the community scale through a set of custom python scripts that specified different rates of change in the combinations of household prototype models within the community.

The project team developed a custom simulation framework for this analysis that models community-scale energy system pathway transformations as an iterative, probabilistic selection procedure. Embedded within each of the three transition categories are a set of assumptions about future changes in the performance and penetration of basic energy efficiency measures within the building stock over time.

At the start of each simulation run, the study area community was represented as an initial collection of single family (SF) and multi-family (MF) prototype building models, with the scaling of each model category determined by the proportion of the total square footage of each building type within the study area community. In the initial time period, households within the community were assigned to one of the prototype models at rates consistent with the present characteristics of the community's building stock. Over the course of the simulation time horizon, the community-scaled energy system model evolved through the transition to the different prototype building models at different rates. Both the rate and extent of these transformations were determined by the scenario's narrative.

The pathway simulation runs required specifications of the initial community building stock and a set of input probability density functions (PDFs). These PDFs mathematically express the rate of change in the community's building stock over time. During a simulation, for each year of the forecast period, a subset of the communities' buildings was randomly selected for transformation to one of the eligible candidate scenario models. Once a building was transformed, it remained in its transformed state throughout the duration of the forecast period.

The project team based the numerical routine that generated the input PDFs for each simulation run on a class of parametric sigmoid functions (saturating growth models), including the Bass Model (Bass 1963). According to this numerical routine, parameters can be specified that dictate the rate of change in the probabilities of transforming to each building scenario alternative. In this way, each different pathway alternative reflected more or less aggressive adoption of different technologies or other measures.

Each pathway alternative contains all the building scenario models, only in different proportions. The differences between the pathway alternatives can be understood in terms of the relative dominance of the different scenario models within them. During the initialization procedure for each pathway simulation, a dominant scenario was specified. This scenario was twice as likely to be chosen as all the others combined. Introducing this concept of scenario dominance allowed the team to isolate and study load-change impacts associated with each scenario while still ensuring that all the scenarios remain possible within each pathway simulation.

Simulation outputs included: hourly load profiles, annual loads, monthly load factors, and hourly peak loads.

**Data sources.** Data for simulation development included: scenarios, transition pathways and forecasts discussed in the Methods Section, and parcel data for the study area zip codes.

Detailed data on parcel counts, use type, and square footage were obtained from the Los Angeles County assessor's parcel database.<sup>8</sup>

**Starting year assumptions.** The project team made the choices outlined in the sections below to parameterize the starting year of the simulations.

**Electricity consumption.** The total annual residential energy consumption value (SF and MF) used to calibrate the start year of the building electrification pathway simulation runs was 113.016 GWh. This value was generated by projecting recent historical trends in electricity load growth per capita and scaling by population projections for the 2020 start year of the simulation period.

**Rooftop solar.** The total number of existing households with installed PV systems during the first year of the DER adoption simulation runs was 93. This value was generated by projecting recent trends in the growth of residential scale PV system capacities per capita, then scaling by population projections for the 2020 start year of the simulation period, and then dividing by a typical rooftop PV system size consistent with the average available amount of suitable rooftop area per household within this community (3 kW).

**Electric vehicles.** The total number of existing EV households (SF and MF) used to parameterize the start year of the vehicle electrification pathway simulation runs was 511. This value was generated by projecting recent trends in EV adoption per capita and scaling by population projections for the 2020 starting year of the simulation period. This process assumes only one EV is registered per EV household.

**Appliance electrification.** For single-family households, during the initial time period of the pathway simulations, the project team assumed that only 500 existing homes should be represented using non-baseline prototype scenario models. This constituted about 5 percent of the total. In the multi-family context, the project team assumed that none of the existing units should be represented with non-baseline prototypes. These initial parameterizations reflect the community's existing building stock, as determined by data collected from project surveys and indoor air quality monitoring program questionnaires.

Under the baseline electrification pathway for single-family households, by 2045 approximately 20 percent of the homes within the study area are expected to have undergone some form of electrification, from partial to full. For multi-family households, by 2045 only 10 percent of the units within the study are expected to have undergone some form of electrification.

## Project Results

The following outputs were generated from building prototype and scenario modeling:

- Hourly load profiles
- Total annual energy use, broken down by electricity and natural gas

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<sup>8</sup> LA County assessor's parcel database: [apps.gis.lacounty.gov/m/](https://apps.gis.lacounty.gov/m/).

- Greenhouse gas emissions
- Utility bill estimates
- Quantitative comparisons of baseline values and scenarios
- Due to the extensive number of models run, only an example set of key outputs is included in this paper.

Homes with central forced air conditioning systems and homes that used central forced air units during the day tended to have lower air pollutant concentrations. On the other hand, homes that used window or wall air conditioning units had, in general, higher air pollutant concentrations.

## Building Prototype and Scenario Modeling

Table 3 below shows summary results for all output metrics for single family prototype baseline configurations compared with electrification scenarios.<sup>9</sup>

Table 3. Summary of changes in total annual utility bills for each prototype and retrofit scenario

| Prototype       | Baseline | Minor indoor air quality focused | Moderate indoor air quality focused | Full home electrification | Full home electrification with PV and BESS | Full home electrification with EV | Full home electrification with EV, PV and BESS |
|-----------------|----------|----------------------------------|-------------------------------------|---------------------------|--------------------------------------------|-----------------------------------|------------------------------------------------|
| Single family 1 | \$1,142  | \$1,164<br>+2%                   | \$1,163<br>+2%                      | \$1,696<br>+49%           | \$947<br>-17%                              | \$3,106<br>+172%                  | \$1,428<br>+25%                                |
| Single family 2 | \$1,610  | \$1,418<br>-12%                  | \$1,234<br>-24%                     | \$1,654<br>+3%            | \$966<br>-40%                              | \$3,097<br>+92%                   | \$1,571<br>-2%                                 |
| Single family 3 | \$977    | \$916<br>-6%                     | \$1,205<br>+23%                     | \$1,478<br>+51%           | \$811<br>-17%                              | \$2,954<br>+202%                  | \$1,364<br>+40%                                |
| Single family 4 | \$1,253  | \$1,072<br>-14%                  | \$1,003<br>-20%                     | \$1,167<br>-7%            | \$534<br>-57%                              | \$2,757<br>+120%                  | \$1,176<br>-6%                                 |
| Single family 5 | \$1,648  | \$1,387<br>-16%                  | \$1,091<br>-34%                     | \$1,466<br>-11%           | \$710<br>-57%                              | \$3,046<br>+85%                   | \$1,285<br>-22%                                |

These results show substantial variations in changes in electric loads and costs from electrification across typical homes in the study community. This is primarily due to the difference in baseline energy system configuration of each prototype model, most notably the HVAC systems. Furthermore, there is a high degree of sensitivity to how the homes use energy based on even minor changes in the age and types of equipment in the homes. This highlights the difficulty of making generalizations about any typical home and points towards the need for

<sup>9</sup> Note that GHG calculations are based on current grid emission values only; later analysis incorporates state mandates for renewable generation to calculate GHG changes through 2045. Emissions data can be found at: [www.epa.gov/egrid/data-explorer](http://www.epa.gov/egrid/data-explorer).

electrification scenarios that target both capital upgrades and operational efficiencies tailored to each home's needs.

For example, the single family prototype 2 home electrification impacts on electrification scenarios are highlighted in Figures 4, 5, and 6. This home had a central AC unit with a central furnace and gas water heater with pre-1978 building code assumptions (Past Building Energy Efficiency Standards 2022). Overall full electrification bill impacts are marginal and DER adoption proves to have the greatest impact when solar and storage are combined with an electric vehicle. The electrification end use breakdown is shown below with increased consumption from the heat pump water heater. However, operational efficiencies from the HPWH offset a significant portion of fuel switching costs.

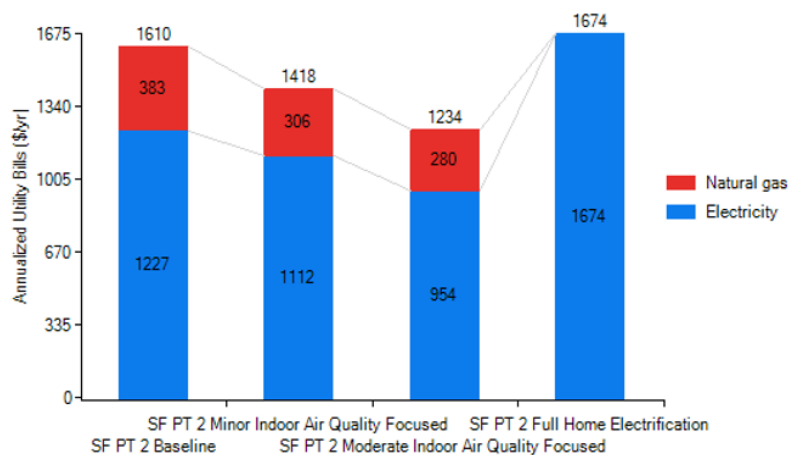


Figure 4. Single family prototype 2: annual bills by fuel type.

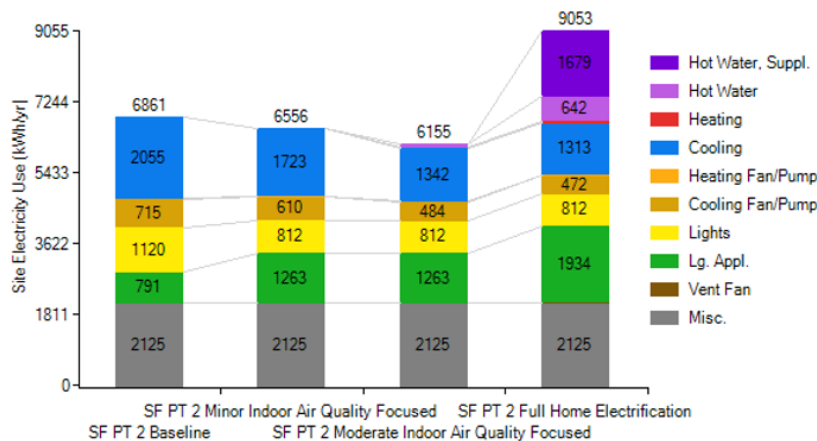


Figure 5. Single family prototype 2: electricity end use breakdown

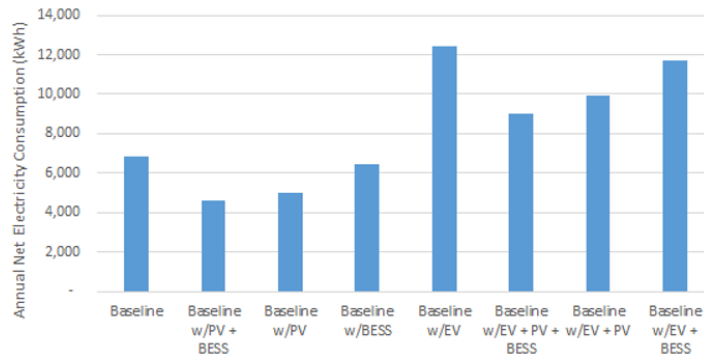


Figure 6. Annual net electricity consumption for Single Family Prototype 2 baseline building with EV, PV, and BESS configurations.

## Community-Scale Simulations

The annual load growth impacts from increasing rates of full home electrification will largely be determined by parallel rates of growth in EV and DER adoption.

By combining the marginal contributions of all discrete pathways generated within each transition category, the future range of possible combined load growth outcomes becomes clear. Figure 7 shows the annual combined deviations from the baseline loads produced by all of the combinations of the discrete SF pathway alternatives (in gray). At the top of this figure, all composite pathways with high amounts (around 95 percent) of fully electrified homes are highlighted in orange. Along the bottom, all composite pathways that achieved similarly high numbers of EV adoptions (left) and PV and BESS adoptions are highlighted in purple and blue, respectively. As these plots illustrate, the magnitude of the load reductions that can be realized through the adoption of optimized PV+BESS systems is roughly equivalent to load increases associated with full house electrification or EV adoption.

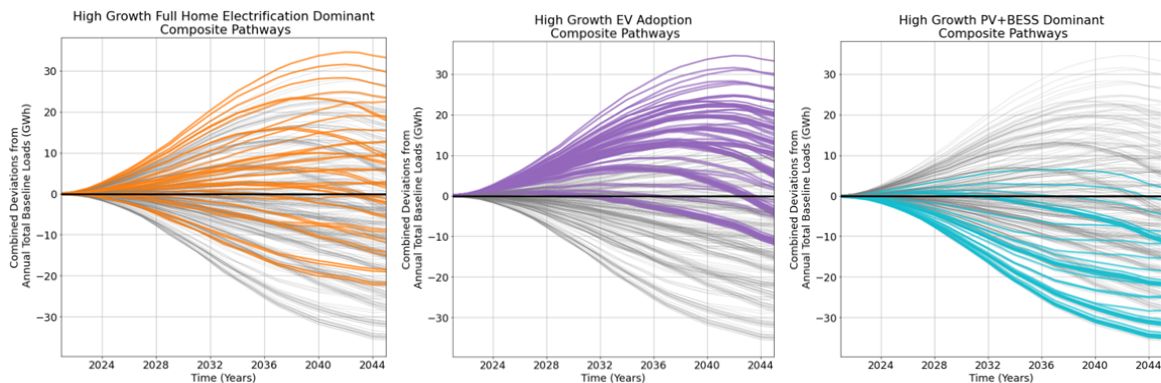


Figure 7. Changes in composite SF loads relative to the baseline when coupling different pairwise combinations of energy system transformation category growth rate assumptions for each year in the simulation time horizon (2020, 2045).

## Discussion and Conclusions

### Building-Scale Modeling and Impacts of Electrification in Under-Resourced Communities

The creation of building scale models for under-resourced communities led to two categories of conclusions. One focuses on the mechanics of creating building energy models, and the second relates to the modeling outputs.

### **Discussion of Building Energy Models in Under-resourced Communities**

The current state of building energy modeling software lacks the functionality needed for the advent of electrification strategies and grid-interactive efficient buildings. While our team followed the Building America House Simulation Protocols and had access to the necessary data inputs, there were limitations. The BEopt user interface lacked equipment selection for loads such as space heaters, secondary refrigerators, and custom schedules per end use were not available for the building stock the study encountered. For retrofit packages, there were inadequate battery storage, electric vehicles, and up-to-date equipment attributes for home energy management systems. While the interface of BEopt is extremely user friendly, the analysis required is better suited for a command line interface approach. However, only BEopt experts would be able to perform even the most basic analysis required for electrification and home automation. The project team investigated both public and private software and found no ‘all-in-one’ software solution with a user interface to model EE and DERs to the granularity required of this study. Despite these challenges, using measured indoor temperature data proved invaluable in model calibration. Industry standards, guidelines, or analytic approaches from research institutions may be helpful for advanced model calibration. Such a calibration for residential homes, particularly in under-resourced communities, can benefit from both energy and indoor air temperature calibration methods that are supported by the building energy modeling community.

### **Conclusions of Electrification Scenarios in Under-resourced Communities**

The project team first saw indications that standard assumptions for operating schedules were inappropriate for under-resourced community homes during the model calibration phase. Utility data load profiles within the participant households do not conform to regional averages. Additionally, load impacts of electrification can vary significantly across typical houses found within under-resourced communities. One reason for this variation is that the default heating and cooling setpoint schedules in BEopt and the Building America House Simulation Protocols were not reflective of the household patterns in the study area. BEopt and/or the Building America House Simulation Protocols assumptions for relationships between occupancy and number of bedrooms were also not accurate for the study’s households. Lastly, the presence of HVAC equipment does not necessarily mean that residents use them, which poses challenges in forecasting electrification and demand flexibility impacts in programs supporting such communities.

Ultimately, the study’s electrification scenarios showed that there is a very wide range of operational and bill impacts to the customer, depending on baseline conditions in the home. This was a result of the low levels, on average, of home cooling and heating equipment in the study community.

The most practical take-away from the building-scale analysis was that California’s “loading order”, where energy efficiency is the first step in a retrofit, may be an inaccurate assumption for under-resourced communities. The project highlights the need for solar and storage (along with EE improvements) concurrent with appliance electrification to reduce the

risk of bill increases for under-resourced communities. The study team recommends future legislation and regulatory proceedings consider this approach as we rapidly electrify housing stock, particularly for under-resourced communities.

## **Community Energy**

Overall, the study showed that even extreme high-growth, high-adoption of electrification strategies can result in minimal impacts on net peak load on the grid if coupled with high adoption of DERs. The rightmost image in Figure 9 depicts this scenario, where high electrification combined with high solar PV and battery storage result in transformation pathways that either match or decrease the baseline peak loads.

## **Discussion of Community Energy Analysis**

Tying the community analysis back to the building-scale analysis is a critical aspect of the project worth discussing. Even if we assume that buildings receive heat pump water heaters with efficiency factors that are less than the current state of the art, this study's analysis has shown that we can manage grid impacts from electrification by adding onsite battery storage. Furthermore, the load profiles at the building-scale were not subject to advanced control strategies, home energy management systems, model predictive controls, and other local energy market economic incentives. Thus, the building-scale load profiles that were considered in this study can be considered conservative in their impact on peak load, since the technology efficacy of EE and DERs will only increase over time.

## **Conclusions of Community Energy Analysis**

A statewide electrification strategy must account for multiple impacts of fuel switching, including differences in the cost of purchasing, installing, and operating electric appliances and the impacts of their use on the timing and magnitude of peak energy demanded from the power system. These considerations are especially acute within under-resourced communities with energy consumption, appliance ownership, and appliance use that differs from average baselines. Pursuing partial electrification retrofits, focusing first on appliances with the highest end-use energy efficiency gains, coupled with DER adoption can significantly mitigate overall load growth impacts.

From an air quality perspective, the capabilities of common DER (solar PV and battery) systems are not yet sufficient to avoid localized ambient emissions increases from full-house electrification. This is because fully electrified homes still contribute to peak load increases, which necessitate increased power output from fossil fueled electricity generation units. Furthermore, the present capabilities of avoided emissions/impacts quantification tools preclude the analysis of statewide electrification initiatives - as these existing tools can only evaluate the impact of marginal changes in electricity consumption patterns which are consistent with historically precedent electricity generator unit operations. Despite these limitations, we have identified a number of transition pathways that demonstrate how electrifying homes can deliver improved air quality with minimal on-bill increases and only modest load growth impacts on the grid. These pathways require the coordination of electrification efforts with enhanced distributed energy resource adoption, which could be brought about through holistic energy resource policy and planning.

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