Electrical Service Panel Capacity in California Households with Insights for Equitable Building Electrification

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ABSTRACT

Decarbonizing the U.S. housing stock necessitates upgrading building infrastructure, including replacing electrical service panels. The scale of this effort remains uncertain. Panels, customer-owned hardware connecting new electrical loads to utility service, must be assessed for existing capacity to understand potential load additions and necessary replacements for full electrification. Replacement likelihood may be higher for homes with smaller service panel ratings (e.g., 100A or less), incurring additional costs and planning burdens that hinder affordability. Two methods for assessing panel capacity in California's single-family housing stock are explored: LBNL's field data-based machine learning model applied to ResStock metadata, and UCLA's as-built panel estimates and replacement prediction based on permit database mining. Both methods estimate panel distributions similarly, showing 200A panels as most common (39-47%), followed by 100A panels (32-33%), with smaller (<100A) and larger (201+A) panels being less common. Analysis indicates smaller, older homes and those facing equity challenges are more likely to have 100A or lower panels, suggesting future research should focus on evaluating electrical infrastructure in these homes.

Introduction

When existing homes are electrified, current fuel-fired end-uses are replaced by their electric equivalents. The most common end-uses to be electrified are space heating, water heating, cooking and clothes drying. Some dwellings will also add entirely new equipment, including electric vehicle charging, solar photovoltaics and home battery technologies. These additional new electric loads need to be accommodated in electric service panels that were not originally designed for these loads, and some homes may require service panel replacements (i.e., same amperage rating) or upsizing (i.e., increased amperage rating) in order to accommodate the new branch circuits and/or electrical loads. These service panel replacements are both costly and time consuming, representing a major barrier to residential electrification. Cost estimates in California vary widely with reports from about \$2,000 up to \$9,000 (Pena et al. (2022), TRC (2016) and SMUD (2021)). Utility service capacity changes often go hand-in-hand with panel replacement. In this paper, we focus on the ratings of installed electric panels in California, but our results are generally reflective of the available utility service capacity, as well. It is critical from an affordability and grid-impact perspective that we get a better understanding of the magnitude of the panel replacement issue.

A number of data sources exist that record panel capacity in California households (e.g., TECH Clean CA, Bay Ren HES, HEA Home Intel, CPUC VEA), but none of these are representative of the housing stock in its entirety. Most have important biases, such as representing only those households that participate in energy efficiency programs or have recorded projects in the recent building permit record. Due to their lack of representativeness and potential for bias, these raw data sources are of limited use as a basis for public policy or for technical and economic evaluations. Methods are needed that support making reliable panel rating predictions beyond these raw data sources, based on associations observed with housing characteristics known more broadly (e.g., floor area or vintage). Characterization of the building stock as a whole is a necessary precursor to efforts aimed at exploring the potential scope and costs of service panel replacements under an all-electric future. An accurate baseline is needed in order to assess strategies that avoid unnecessary panel replacements, as well as to identify household characteristics or demographics associated with increased burdens.

In order to address the biases evident in the raw data sources listed above, this paper presents two methods of predicting the installed capacity of service panels in California's single-family housing stock. As part of this analysis, we explore the possibility that homes facing equity challenges may encounter additional barriers when trying to electrify, due to constraints on existing capacity or other issues such as space limitations for existing panels. Of greatest concern is the frequency of panels less than or equal to 100A, because these homes will face additional challenges to electrification without substantial innovation and departure from business-as-usual construction practice. The frequency of these smaller electrical panels might be higher in households facing equity challenges, which would pose additional barriers, costs and time-delays to electrification of these households.

Methods

This paper explores two fundamentally different approaches to estimating the distribution of electrical service panel ratings present in the single-family housing stock of the state of California. Each of these two methods are described in further detail in the sub-sections below, including a description of the data sources, predictive methods and housing stock models used to extend results statewide. The analyses are based on panel capacity in Amps (A). For this analysis, we separated the panel capacities into five bins related to commonly used panel capacities: <100A, 100A, 101-199A, 200A and 200+A.

LBNL Machine Learning Method

Data Sources. LBNL assembled and combined publicly available and proprietary data sets[1] from across the US totaling 37,291 households. These data include housing characteristics (e.g.,

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[1] 53% of the data are from the TECH Clean California program. 20% are from a dataset of Minneapolis homes produced by the Minnesota Center for Energy and Environment. 17% of the model training data are from a Home Energy Score program operated by the Bay Area Renewable Energy Network (BayRen). 5% of the data are from a building electrification program operated by Home Energy Analytics. 3% are from a survey of buildings in Washington, Oregon, Idaho, and Montana conducted by the Northwest Energy Efficiency Alliance (NEEA). A nation-wide self-reported survey of building occupants (Gul and Meier 2024) and data collected for the California Public Utilities Commission (CPUC) each provide 1% of the data.

floor area, vintage, appliance fuels) and panel information (e.g., amperage ratings, breaker slots). The source data were diverse and varied in the levels of detail and the housing characteristics included. California households accounted for 75% of the dataset. The multi-state dataset provides a mix of buildings types, with both fossil and electric space and water heating. This diversity is important for the national characterization of panel capacity presented in Murphy et al forthcoming and the large share of California buildings in the overall dataset likely strengthens the California panel predictions.

Predictions. Murphy et al. forthcoming developed gradient-boosted decision models for predicting panel capacity trained on these data sources. Due to variation in the fields and data completion across the data sources, the sample size decreased as the number of predictor variables increased. To explore the tradeoffs in sample size and the number of predictor variables, the paper compared the performance of models with different sets of predictor variables using the weighted F1 score. Additionally, the paper separated the training and cross-validation data for buildings with and without electric heating buildings. Final predictor variables for the non-electrically-heated building model included building floor area, building vintage, and building type. Final predictors for the electrically-heated building model include all those in the non-electrically heated model as well as the presence of rooftop photovoltaics, cooling type, and the fuels used for space and water heating, cooking, and clothes drying. Notably, the predictive model does not include geographic (e.g. zip code) or equity variables. Some sources included building zip codes, but the predictive model developed in Murphy at al. was intended to be applied nationally, so including geographic variables would have limited its scope. Equity variables were diverse and not consistently tracked in the source data sets. However, Murphy et al. still predicts relationships between panel capacity and area median income (AMI) due to correlations between the building characteristics in the training data and AMI.

LBNL used the machine learning model to predict panel ratings for the 30,673 single-family households in the National Renewable Energy Lab's (NREL) ResStock model. Each ResStock house represents around 260 real California homes. For a given set of household characteristics, the model provides the probability of a panel rating in each of the five panel capacity bins (e.g., <100A (3%), 100A (50%), 101-199A (25%), 200A (19%), and 201+A (3%)). The panel rating for each individual home is then selected by randomly sampling from these panel capacity bin probabilities. This provides a specific panel rating for each home in ResStock, while ensuring alignment with model predictions over larger groups of homes.

UCLA Permit Data Method

Data Sources. UCLA's method used a proprietary parcel attribute database from CoreLogic licensed by the California Energy Commission, which was filtered to cover 95.14% of detached single-family homes in California (7,240,031). The dataset included properties from all counties and was unbiased regarding disadvantaged communities' locations. While unpermitted panel replacements might introduce bias, they are deemed rare due to utility notification requirements and safety concerns. Permit data from 54 municipalities, including cities, counties, and unincorporated areas, were compiled in a convenience sample, totaling 4,853,032 raw permit records. These records were filtered and coded based on work descriptions, and they were integrated with parcel attributes from the CoreLogic database by spatially joining parcel boundary geometries against the geocoded centroids of the permit's address fields. Additional details on the methods and results of the UCLA method can be found in Fournier et al (2024).

Predictions. The UCLA team estimated as-built existing panel sizes by initially assigning best estimates based on property size and vintage year, using a lookup table derived from historical National Electrical Code (NEC) requirements and empirical data from sampled homes (Pecan Street, 2021; Armstrong, 2021; Davis, 2022; TECH Clean California, 2024).

About 4.51% of single-family properties were linked to building permit data. For properties with enumerated panel replacement permits (1.37%), existing capacities were directly assigned. For those with permits lacking explicit panel ratings (0.85%), amperages were inferred from an upsizing routine based on initial conditions. Properties with permits for related work (2.29%) (e.g., solar PV, EV, HVAC heat pump) had panel sizes determined by the permitted work combinations. For the 95.49% of households lacking permits, predictions of panel replacements were made using a set of 20 empirical cumulative density functions (ECDF) based on property age and DAC status. The ECDF were fit using data about the ages of properties at the time of observed panel replacements within the permit data record. Each ECDF was fit to a subset of the permitted properties sampled at 5 percentage point increments based on the CalEnviroScreen-4.0 (CES-4.0) percentile scores of the tracts in which they are located. Where panel replacement was predicted (42.99%), the upsizing procedure was applied; where not (52.50%), as-built sizes were assumed.

Replacement panel sizes followed a ladder of historically common amperage sizes, grouped into categories (Small, Medium, Large, XL, XXL) to avoid trivial capacity increases. For properties not in the largest category (XXL), upsizing resulted in the next size category up from as-built. Specific sizes were pseudo-randomly assigned based on observed distributions within permit records.

This methodological approach ensured comprehensive coverage of single-family properties and accounted for panel upsizing and as-built conditions, considering historical trends and empirical data. The use of predictive models and permit records allowed for nuanced assessments, balancing robustness and practicality in estimating panel capacities across a diverse housing stock.

Equity Indicators

A key element we explore in this paper is the equity implications of the resulting panel ratings throughout the state. Each of the two prediction methods described above relies on different underlying data sources for panel ratings and representations of the state's housing stock. As a result, each uses different indicator variables for representing equity in the prediction methods and results. These differences hinder one-to-one comparisons of results from each method, but both provide important indications of the equity implications of the home electrification challenge. In this paper, we characterize homes as "facing equity challenges" based on their income and community burdens.

The UCLA approach uses the California Office of Health Hazard and Exposure Assessment's (OEHHA) CalEnviroScreen-4.0 (CES-4.0) tool to identify households in disadvantaged communities (DACs). The CES-4.0 scores are based on numerous demographic and socio-economic indicators, as well as various other measures of environmental pollution burden. These scores are calculated at the census tract level, not for each individual household, because they are meant to represent the community-level environmental burdens. Census tracts in the state are put in ranked order, and any parcel located in a census tract within the top 25% of all scores statewide are classified as DAC in the UCLA results. The TECH Clean California data set uses this same definition for DACs in its reporting.

The LBNL approach uses the AMI as an equity indicator in its representation of the California housing stock. For each home in a given area, the household's estimated annual income is divided by the AMI for its region, producing a percent value that is distinct for each home in the housing stock. The California Department of Housing and Community Development (HCD)[2] defines "low income" households as those earning less than 80% of the AMI. It categorizes 'acute,' 'extreme,' and 'very low-income' groups within the range of 0-50% of AMI.

Results

We present the results of both methods described above in two distinct ways. First, we present the raw data used by each of the methods, which includes actual recordings of panel amperage, either as part of a data collection effort (LBNL), or directly extracted from the building permit record (UCLA). These are the values actually observed in the data sources used to develop predictions for the larger building stock. Neither of these approaches represent a statistically random sample of California's housing stock. Instead, both are biased in different ways, based on their underlying data sources. Second, we show the results for each method applied against representations of California's housing stock. Given the fundamental distinctions between these two methods, we will explore how their predictions are similar and distinct, with a focus on where those differences are functionally important for household electrification.

Raw Panel Data

Figure 1 shows the distribution of electrical panel capacities recorded in the raw LBNL dataset. For data sources that included actual home upgrades (i.e., TECH), the pre-upgrade panel ratings were used here. Panel upsizing was rare in the TECH data, with only roughly 5% of homes reporting panel upsizing in association with heat pump installation. We cannot rule out the possibility that some homes were recorded in multiple data sets, as street addresses and occupant names were strictly excluded from our data collection. Overall, about 40% of buildings have 200A panels and about 40% have 100A panels, with few panels less than 100A (1-5%) or greater than 200A (3-10%). 100A panels were more common in TECH DAC (41%) than in non-DAC (31%) households. Variation between the programs may reflect differences in the participants and building stock that the programs service. The BayRen program, for example, operates only in the mild San Francisco Bay Area, where the use of air conditioning is less common. In contrast, the TECH program operates statewide and includes regions with high cooling demand. The median building in the BayRen program is slightly older (built in 1965) and smaller (1400 ft^2) than the median building in the TECH program (built in 1978, 1900 ft^2). The CEE data represents Minneapolis households, which are substantially older, larger and

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[2] https://www.hcd.ca.gov/grants-and-funding/income-limits#:~:text=Acutely%20low%20income%3A%200%2D15,80%25%20to%20120%25%20of%20AMI

almost exclusively heated with natural gas. Participation in these programs may also select for more affluent households, which could affect the representativeness of each data source.

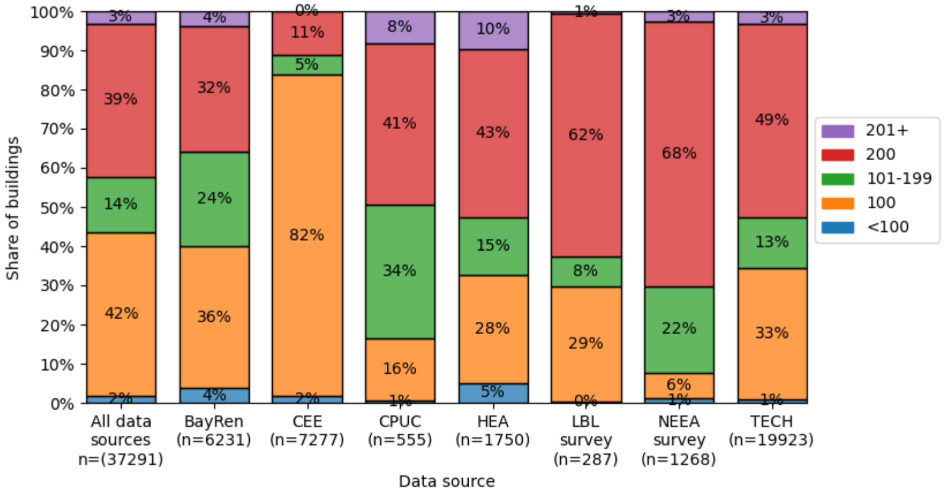

Figure 1: Distribution of panel capacities in LBNL dataset. Pre-retrofit data used in TECH homes. Select data sets include households from outside of California, including CEE (Minneapolis, MN), LBL survey (US national) and NEEA survey (Pacific Northwest).

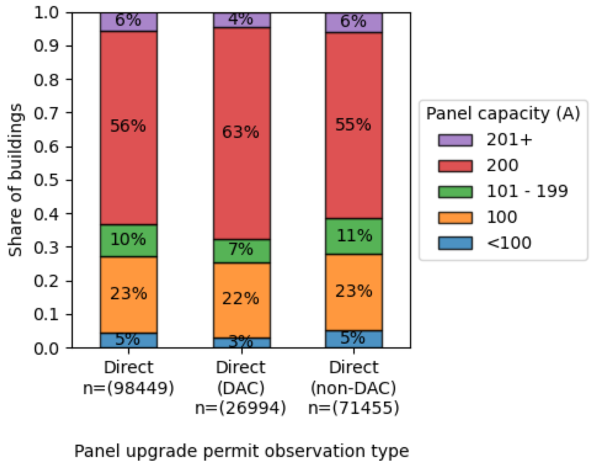

Figure 2. Distribution of new, upsized panel capacities among single family buildings as reported in UCLA's statewide municipal permit database for directly observed panel replacement permits, disaggregated by DAC status.

Figure 2 illustrates the distribution of the permitted panel capacities (i.e., the capacity of the replacement panel, not the capacity before the panel change) for direct observed panel replacement permits. These correspond to the set of permits that were used to fit the set of ECDFs to perform panel upsizing inference. Within this direct replacement permit category, statistics are shown both for the full sample (left), as well as disaggregated by DAC and non-DAC status. The DAC and non-DAC samples are roughly similar, with more than half of homes having 200A panels, just under a quarter of homes having 100A panels, and small numbers of homes with either <100A (3-5%) or 200A+ panels (4-6%). 27% of direct panel replacement permits were recorded in DAC homes, which is proportional to the percent of parcels in the state located in DACs. This suggests that rates of panel replacement are similar between DAC and non-DAC households in this permit record.

When we compare the LBNL and UCLA panel rating data, some important distinctions appear. First, the UCLA data shows higher fractions of 200A panels relative to the LBNL data (56% vs. 39%). Similarly, the UCLA data shows lower fractions of 100A panels (23% vs. 42%). These distinctions may be due to the tendency for permitted panel replacements to lead to larger panel ratings in homes, which would support finding more 200A panels and fewer 100A panels. Both raw data sets agree that there are relatively few numbers of panels <100A or 200+A, though the exact estimates differ.

If we compare DAC and non-DAC homes from the TECH data and the UCLA permit data, we observe further distinctions. In the LBNL TECH data, DAC homes are substantially more likely to have 100A panels (41% vs. 31% in DAC and non-DAC homes), with a corresponding shift in the other direction for 200A panels (39% vs. 53% in DAC and non-DAC homes). In contrast, the UCLA data shows very similar numbers of 100A panels in DAC and non-DAC homes (22% and 23%, respectively), but with overall higher numbers of 200A panels in DAC homes (63% vs. 55%). Again, all observations in the UCLA data set are homes that have reported permitted panel replacements, which might generally bias these results towards larger 200A panels and away from smaller 100A panels.

California Building Stock

After applying the LBNL and UCLA predictive methods described above to representations of the California housing stock, we estimated the share of buildings with each panel capacity bin using the two key variables discussed above: building vintage and floor area. Finally, we evaluate the results of these building stock predictions using equity indicators (i.e., DAC status for the UCLA housing stock data and area-median income for the LBNL housing stock data). These disaggregations are reported for each prediction method and are compared below.

The goal of the building stock characterization is to expand coverage of panel ratings beyond some of the limitations of the raw data presented in the previous section. In particular, both the LBNL and UCLA raw data sets are potentially biased towards homes that have either engaged directly in home upgrades (e.g., through installing a heat pump or doing other permitted work) or are otherwise engaged in energy efficiency (e.g., through procurement of a Home Energy Score rating). These data sources run the risk of under-representing households with equity challenges. Other features of non-participating homes may also be under-represented in the raw data.

In order to support this expansion of data coverage, we are relying on correlations between equity indicators (% AMI and DAC status) and the housing features used in both predictive methods, namely floor area and vintage. By relating panel amperage to housing features that also strongly correlate with equity indicators, we hope to improve our panel predictions for homes in this housing segment. One way to assess DAC status in California is based on the 75th percentile of CalEnviroScreen-4.0 composite score percentiles, and we show these composite score percentiles for each census tract in the state compared against median home floor area (left) and home vintage (right) in Figure 3. Both of these variables are strongly correlated with CalEnviroScreen 4.0 percentiles, with DAC census tracts having the smallest average home sizes and the oldest average home vintages. It is perhaps worth noting here, that neither of these building stock attributes are explicit inputs to the CES-4.0 scoring framework.

LBNL evaluated the TECH data files to see if the correlations observed between CalEnviroScreen 4.0 percentiles and floor area and home vintage were reflected in homes installing heat pump technologies. As described in census tract data above, TECH homes located in DACs were also much smaller (1,592 vs. 2,130 ft^2) and were on average 15-years older (1960 vs. 1975) than non-DAC households.

Other DAC definitions can also be used and may lead to distinct results, such as the finding of substantially newer DAC homes in the San Joaquin Valley (SJV) enrolled in energy assistance programs (Opinion Dynamics (2021)). Despite this trend towards newer homes in the SJV, non-DAC homes were even larger and newer. Care must be taken when defining DACs from an equity perspective, and equity variability within DACs should also be considered.

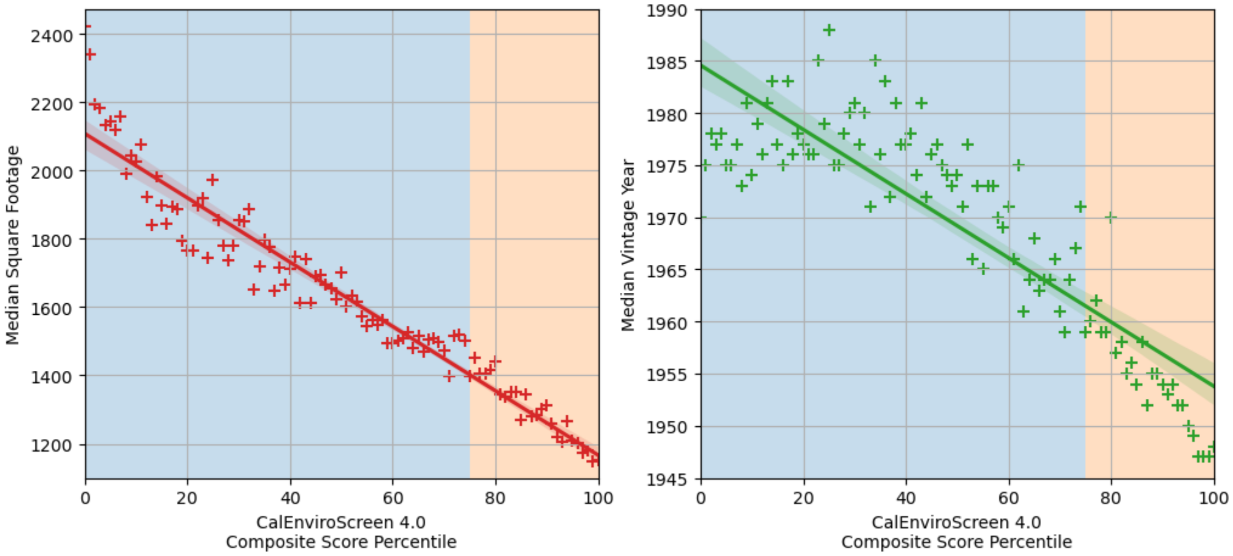

Figure 3. Median home square footages (red) and median construction vintage (green) for California single-family homes relative to the CalEnviroScreen-4.0 composite score percentiles of the census tracts in which they are located. Shaded areas show the commonly used definition for DAC status (i.e. >=75th percentile of scores statewide).

Overall Panel Rating Distributions. The percentages of single-family homes predicted in each panel rating bin are shown for each of the two prediction methods in Table 1. Overall, the agreement between the two methods is strong across all panel rating bins. In particular, both methods provide very similar estimates for the smallest panel rating bins of <100A or 100A. Both methods also identify 200A followed by 100A panels as the most frequent bins across the state. The higher panel rating bins are more distinct, in particular, the panels larger than 200A are more than twice as frequent in the UCLA predictions. Yet, both methods agree that almost exactly half of the state's single-family housing stock has a 200A or larger panel rating. Both methods also suggest that very small panels less than 100A are uncommon (i.e., roughly 3%).

Table 1. Tabulation of overall single-family housing stock panel rating percentages according to each prediction method.

Panel Ratings	LBNL Housing Stock (%)	UCLA Housing Stock (%)
<100A	1.8%	3.0%
100A	33.3%	31.7%
101-199A	15.3%	15.0%
200A	46.6%	39.0%
201+A	3.0%	11.3%

Floor Area. The LBNL and UCLA housing stock predictions are shown according to home floor area in Figure 4 and Figure 5, respectively. Both methods show that panel capacity generally increases with increased home floor area. This result is consistent with how the NEC directly accounts for floor area in the electrical service load calculations, which requires more panel capacity for buildings with more area to service general lighting and receptacle loads. The trend of larger panels in larger homes may also be driven by higher capacity air-conditioning equipment required to serve large homes, as well as by newer homes being both larger and having larger panel ratings. The UCLA method predicts higher numbers of very small panels in the smallest homes and large panels in the largest homes. In contrast, the LBNL method results in a smoother relationship that does not show the same changes at the tails of the home size distribution. The two methods also have substantially different predictions for the fraction of 101-199A panels in the floor area bins between 2,000-4,000 ft^2, but again, both predict more larger panels in the larger homes. An additional exception to the agreement in trends between the methods is the substantial fraction of 200A panels in the UCLA predictions for the smallest home bins. These smallest homes have the highest rates of both 200A panels and <100A panels in the UCLA housing stock prediction.

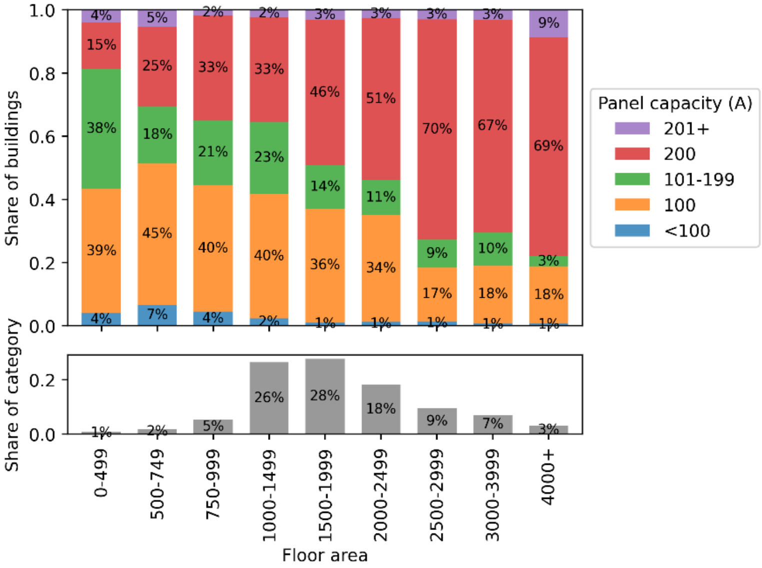

Figure 4. LBNL estimated panel capacities in California single-family buildings, by floor area.

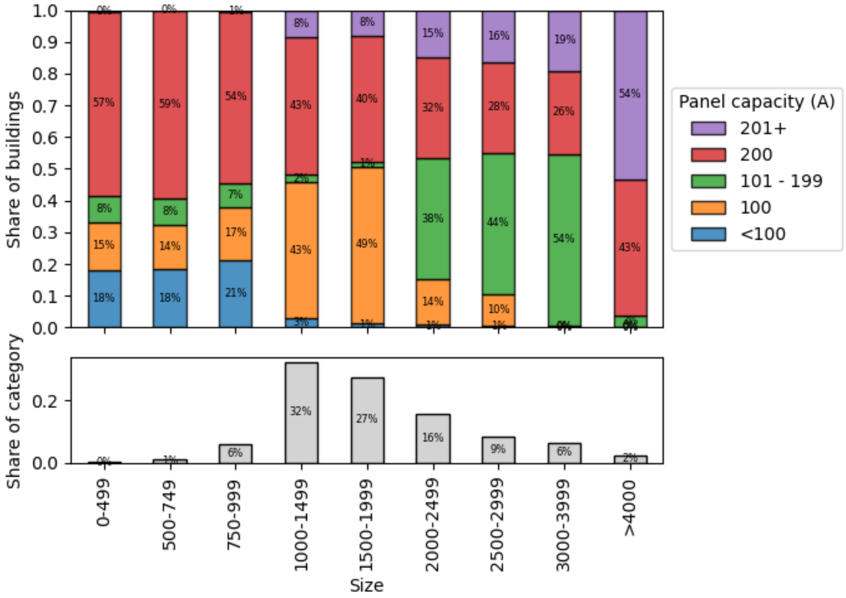

Figure 5. UCLA estimated panel capacities in California single-family buildings, by floor area.

Building Vintage. The LBNL and UCLA methods differ in how they predict panel capacity relates to building vintage (see Figures 6 and 7). The LBNL method predicts a gradual decline in the share of buildings that have 100A panels or less across the vintage bins. In contrast, the UCLA method predicts that the share of panels 100A or less increases through the 1970s. This is due to the UCLA method's expectation that the panels at these properties would not yet be as likely to have been replaced from their original construction condition and still be in functional service. The LBNL method also predicts an increasing share of buildings with 200A panels moving from the oldest (34%) to most recent vintage (74%). In contrast, the UCLA method predicts that the share of buildings with 200A panels declines with vintage from the pre-1940 bin (71%) to the 2000s (14%). In parallel, the UCLA method estimates that the share of buildings with 101-199A panels increases significantly from the 1970s (6%) to the 2000s (52%). Both methods agree that the most recent building vintage (2010s) has almost no panels with capacity less than <100A. However, the LBNL method predicts that 74% of these homes have 200A panels, while the UCLA method predicts 71% have 201+A panels. This finding for newer homes is consistent with the minimum rating of 100A for home electrical service in the NEC.

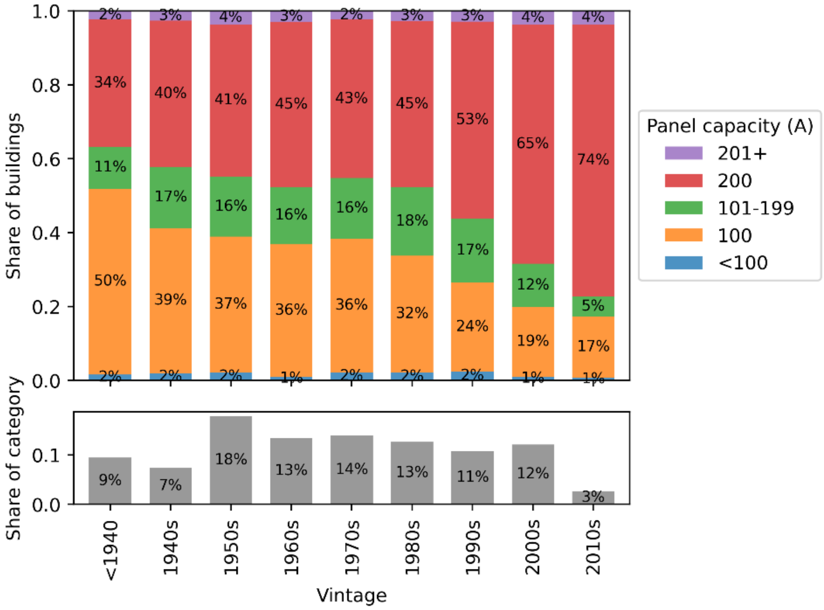

Figure 6. LBNL estimated panel capacities in California single-family buildings, by vintage.

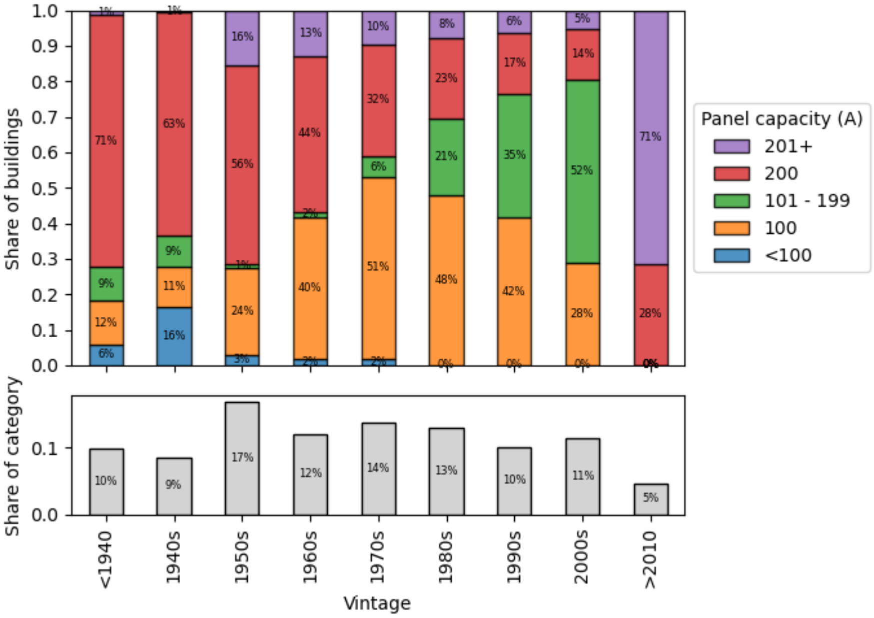

Figure 7. UCLA estimated panel capacities among California single-family buildings, by vintage.

Equity Indicators. As noted in the Methods section, the UCLA and LBNL housing stock predictions do not share the same equity indicator variables. The LBNL predictions use a household's percent of area median income (AMI) as an equity indicator. The UCLA predictions use the DAC status of the census tract in which each home is located, with DAC status being determined by the 75th percentile threshold of CES-4.0 composite scores statewide. We present each housing stock prediction here using the indicator variables available in each data set. The goal is not a one-to-one comparison of results and how they relate to these indicators, but rather an examination of trends (direction and magnitude) that relate panel ratings with indicators for equity.

The LBNL method is plotted according to each home's percent of AMI in Figure 8, and the UCLA housing stock predictions are plotted according to DAC status in Figure 9. Both predictions and indicator variables suggest that households facing equity challenges have more small panels and fewer large panels. The predictions differ in their details, while agreeing on the overall trends and direction. The LBNL method predicts that the share of buildings with 100A panels or less decreases from 39% in the lowest AMI bin (0-30% AMI) to 31% the highest AMI bin (150%+ AMI). The share of buildings predicted to have 200+A increases over the same bins from 43% to 55%. Compared with non-DAC households, the UCLA method predicts that DAC homes have more panels 100A or less (46% vs 31%) and fewer panels 200A+ (45% vs. 51%).

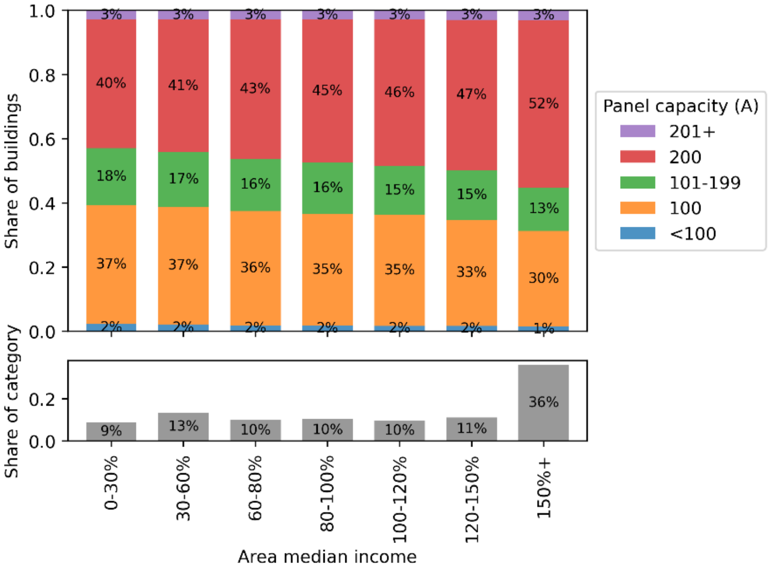

Figure 8. LBNL estimated panel capacities in California single-family buildings, by AMI.

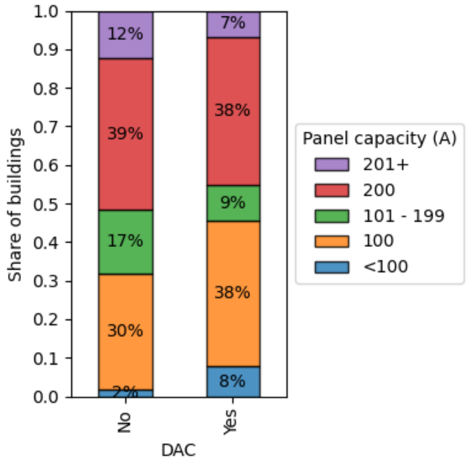

Figure 9. UCLA estimated panel capacities in California single-family buildings, by CES-4.0 DAC status.

Discussion

In this paper, we have summarized and compared the results of two methods of predicting installed panel ratings in the single-family housing stock of California. At the level of the entire housing stock, both methods produce roughly similar statewide predictions of 100A, 101-199A, and 200A panels. Neither approach can be considered "correct," as each has its limitations and neither is based on random samples of the population of California homes.

While the methods rely on different underlying data sets and prediction methods, and while the predictions differ in their specific details, both approaches agree on overall trends as they relate to these variables of interest. Both prediction methods suggest that households facing equity challenges are more likely to have smaller electrical panels of 100A or less and are less likely to have larger panels of 200A or more. Similarly, both methods support the argument that home size and home vintage are key panel rating predictors. Across the state's housing stock, larger, newer homes are more likely to have larger panels, while smaller, older homes are more likely to have smaller panels. These trends have important implications for the potential future need for panel replacements and other infrastructure replacement as the state's housing stock electrifies in coming decades.

We observe that equity indicators are correlated with home floor area, vintage and panel rating. Our methods predict higher rates of small panels in these older homes with smaller floor areas. Using parcel-level data, we observed that homes in DAC census tracts are consistently smaller and older than those found in non-DAC census tracts. Similar results were observed when analyzing floor area and vintage in the TECH clean California data sets.

The observed correlations make sense, because house age and floor area correlate, and together help determine the service load calculated using the NEC. Larger homes have greater lighting and plug loads (treated at 3 volt-amperes/ft^2), and they need larger heating/cooling systems and water heaters. All of these elements contribute to higher electrical service loads. Furthermore, in CA there has been a trend with time to add air-conditioning to existing homes, which further increases electrical loads. We observed that many of the oldest homes already had larger panels, which may be due to the addition of air-conditioning and replacement of aged-out panel hardware. This aging-out was less evident in homes built in the 60s and 70s.

An alternative reason for the observed differences in installed panel ratings in households facing equity challenges could be higher rates of panel replacements over-time in higher-income or non-DAC households. Yet, the data reviewed as part of this work suggest that this alternative explanation may be inadequate. Rates of panel replacements over the 30-year permit record gathered by UCLA are roughly equivalent in DAC and non-DAC households–26% vs. 23% had permitted replacements over the data period, respectively. Consistent with this result, the rate of panel replacements in nearly 19,000 California homes installing heat pump technologies as part of the TECH Clean California program were very similar–5.7% in DAC and 6.1% in non-DAC households. The TECH data does not track replacements over-time in these households. Notably, the single most common panel replacement recorded in the TECH data was the replacement of 200A panels with 300A panels, which complicates the perspective that only smaller panels will be replaced as the housing stock electrifies.

Across both prediction methods, we observe that panel ratings are diverse within any category of interest. For example, our results suggest that smaller homes are more likely to have smaller panels. At the same time, we also observe that substantial minorities of small homes have large panels. Similar diversity is observed for home vintage and income status. Simply put, panel ratings in homes defy simple explanations and rules of thumb (e.g., all homes pre-1960 have 100A panels), and both predictive methods employ probabilistic approaches accordingly in an attempt to capture this diversity. The LBNL method uses probabilistic panel assignments based on a set of model inputs, and the UCLA method uses probabilistic assignment of panel replacement status, based on home age and CES-4.0 percentile scores.

Based on the limitations of both predictive methods and the results presented above, we believe more research on these topics is needed in smaller homes, older homes and homes facing equity challenges. These evaluations should target inclusion of households not participating in upgrade programs and not performing permitted remodeling activities. These homes may face increased infrastructure challenges to electrification. This increased burden justifies targeted research to evaluate these populations of homes across the state, for both their installed panel ratings and other infrastructure challenges to electrification (e.g., knob-and-tube wiring, panel degradation, etc.). Recent publications have addressed these very issues in equity/income-qualified single-family (Solorio et al, 2023), multi-family (McGrath et al, 2023a) and manufactured housing (McGrath et al, 2023b) in the state. As expected, in each housing segment, these reports suggest that barriers to electrification are high in equity households; that small panel ratings and other electrical hazards are common.

Evaluating the ability to electrify these homes on their current panels is a critical element of the required work, because we might learn that while these homes have smaller panels, they may not necessarily require panel replacements (or panel upsizing) at higher rates than other households. This is because smaller homes have smaller panels, because they have less electrical demand and smaller calculated service loads. In fact, we expect that smaller homes with 100A panels can more easily accommodate electrification than larger homes with 100A panels. Smaller homes have fewer overall appliances and the installed appliances may be smaller (e.g., smaller volume clothes dryers, lower capacity heat pumps, etc.). Integration of electric vehicle charging will further tax small and large homes alike. If increased burden is identified in these households, there may be significant implications for the state's electrification policy agenda, as there is likely to be a need to provide increased financial support for homeowners in these households to ensure equitable outcomes as the electrification transition unfolds.

There remains considerable latitude for individual households, designers and programs to choose high versus low-power pathways in this transition. Future evaluations of the ability to electrify existing homes using their current panels will have to assess both high- and low-power scenarios. We currently lack knowledge about the specific character of the end-use appliances and equipment that consumers ultimately prefer (i.e. high power versus lower power demand). Similarly, consumer appetite for power and energy management solutions that can support electrification on existing panels is unknown. , which is a matter for regulators to consider.

In order to improve policies around home electrification, additional changes at the state-level could be prudent, including utilities recording and making public service levels provided to each home, provision of peak power demand from AMI telemetry data for each home to be used in NEC service load calculations, and development of standardized tools for design, permitting and compliance that ensure safety and consistency across the state.

Conclusion

The speed and scale with which existing transportation and domestic fossil fuel end-uses will need to be electrified in order to meet the U.S.' decarbonization objectives portents a period of unprecedented residential electrical load growth. It remains an open question as to precisely how many residential electric service panels will require upsizing to support this transition. This study provides initial guidance by elaborating on two distinct representations of the California's baseline for installed electrical service panels in single-family homes. Both methods predict that the share of homes with panels under 100A (1.8-3.0%) and over 200A (3-11%) is small, and that 200A (39-47%) and 100A (32-33%) panels are most common. We also document important correlations in these panel ratings with house floor area, vintage and equity indicators that may be useful in public policy and utility distribution system planning, as we transition to more sustainable electrified housing in California. Namely, older and smaller homes are more likely to have small panels that could constrain future electrification efforts, and households facing equity challenges are more likely to be both older and smaller. However, we also acknowledge limitations of this study and uncertainty in panel rating predictions. Part of this uncertainty is down to the challenges associated with quantifying the condition of existing panels using the different data sources and analytical methods documented in this study. We suggest future study of panel ratings and evaluation of the ability to electrify using currently installed infrastructure in California homes, with a focus on smaller, older homes facing equity challenges.

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