There's No Place Like Home: Residential Parking, Electrical Access, and Implications for the Future of Electric Vehicle Charging Infrastructure

Yanbo Ge, Christina Simeone, Andrew Duvall, and Eric Wood

National Renewable Energy Laboratory

NREL is a national laboratory of the U.S. Department of Energy
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List of Acronyms

ACS	American Community Survey
APT	apartment
BEV	battery electric vehicle
DCFC	direct current fast charger, also referred to as DC fast charger
EIA	U.S. Energy Information Administration
EV	electric vehicle
EVSE	electric vehicle supply equipment
ICEV	internal combustion engine vehicle
LDV	light-duty vehicle
MFDs	multi-family dwellings
PEV	plug-in electric vehicle
PHEV	plug-in hybrid electric vehicle
PUMA	Public Use Microdata Area
PUMS	Public Use Microdata Sample
RECS	Residential Energy Consumption Survey
SFH	single-family housing
VIF	variation inflation factor
ZEV	zero emission vehicle

Executive Summary

As of 2020, transportation represented the largest source of U.S. greenhouse gases, with light-duty vehicles (LDV) representing nearly 59% of emissions within the sector (US EPA, 2021). The automotive industry has made tremendous strides over the past decade in developing the necessary technologies to electrify their offerings, and the electric power sector is simultaneously decarbonizing the power grid. Recent industry announcements suggest that electric vehicle manufacturing capacity, technology cost, and consumer demand could support dramatic increases in electric vehicle sales, with General Motors going so far as to set a goal of 100% electric vehicle sales by 2035 (Colias, 2021). This potential trajectory implies the need for domestic charging infrastructure to be deployed at a large scale soon, consistent with goals from the federal government to install 500,000 new chargers (The White House, 2021.04) and achieve half of new passenger car sales as zero emission vehicles by 2030 (The White House, 2021.08).

The current foundation of U.S. charging infrastructure has been built upon home charging at residential locations, where vehicles tend to be parked for long durations overnight. Looking forward, there is uncertainty about how effectively home charging can scale as the primary charging location for electric vehicle owners. As the electric vehicle market expands beyond early adopters (typically high-income, single-family homes that have access to off-street parking) to mainstream consumers, planners must consider developing charging infrastructure solutions for households without consistent access to overnight home charging. This includes, but may not be limited to, renters, residents of apartment buildings (and other multi-family dwellings (MFDs)), and individuals in single-family homes (SFH) without access to off-street parking. In situations where residential off-street charging access is unattainable, a portfolio of solutions may be possible, including providing access to public charging in residential neighborhoods (on street), at workplaces, at commonly visited public locations, and (when necessary) at centralized locations via high power fast charging infrastructure (similar to existing gas stations).

This research reviews public information on residential housing attributes with implicit relation to home charging access, including national data on vehicle ownership, residence type, housing density, and housing tenure (i.e., rent or own). These public data are complemented by a panel survey sample of 3,772 U.S. individuals to uncover previously unknown distributions of residential parking availability, parking behavior, existing electrical access, and perceived potential for new electrical access by parking location. These responses connect parking availability and existing or potential electrical access to residence type in order to inform charging access scenarios incorporated into the final projection framework. Charging access trends with respect to residence type are identified and coupled with an electric vehicle likely adopter model to infer national residential charging access scenarios as a function of the national electric vehicle fleet size.

The key insights are:

1. **As electric vehicle adoption progresses, residential charging access among electric vehicle owners is likely to decrease and become more uncertain.** Projection results reveal that residential charging access is expected to remain high (78%–98%) while electric vehicles comprise a small share of the U.S. light-duty fleet (less than 10%), but that uncertainty increases as electrification penetrates the light-duty passenger fleet more broadly. Specifically, in a future where electric vehicles make up over 90% of the fleet, a range from as low as 35% to as high as 75% of electric vehicles are projected to have consistent residential charging access, depending on the scenario considered.

2. **Residential access among multi-family properties presents the greatest challenges.** Multi-family dwellings have significantly less access than single-family homes, and vehicles from owned homes have better access than rented homes. This highlights a significant equity issue to overcome as the country transitions to an electrified light-duty fleet.
3. **Single family homes dominate the US light-duty vehicle stock, however residential access at these properties is not a given.** With 100% light-duty vehicle electrification, according to the most optimistic scenario, 25% of PEVs do not have home charging, of which 45% are from single-family detached homes and 40% are from apartments. Although residential access in apartments is more challenging generally, the relative size of the U.S. fleet owned by residents of single-family detached homes is so large that even a small share of PEVs without residential access in this group becomes substantial at the national level.
4. **Many opportunities exist for improving residential access across all property types.** This research highlights several opportunities to improve residential charging access as the U.S. electric vehicle fleet evolves, including consumer education, investment in residential infrastructure at single- and multi-family homes, behavior change opportunities to take advantage of residential parking locations with convenient electrical access, and sharing of residential infrastructure within multi-vehicle households.
5. **Tradeoffs exist between residential and public infrastructure investment.** These data provide insights into potential public charging infrastructure and funding requirements over the long-term. Investments or requirements (e.g., zoning or codes) may be needed to increase the availability of high-speed public charging as a substitute for residential access in areas that have high concentrations of MFDs and rented SFHs. Public charging to complement residential access for detached SFH with multiple PEVs may also be necessary.

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1 Introduction

In March 2021, the cumulative sale of plug-in electric vehicles (PEVs), including plug-in hybrid electric vehicles (PHEV) and battery electric vehicles (BEV), reached 1.8 million in the United States (Argonne National Laboratory 2021). However, PEV adoption is still in its infancy; its market share has just reached around 3% of new light-duty vehicle (LDV) sales by the end of 2020 (Alliance for Automotive Innovation 2021). Current trends suggest that PEV market share in the United States is increasing. The U.S. Energy Information Administration's (EIA's) 2020 Annual Energy Outlook forecasts PEV registrations to exceed 8 million vehicles by 2030 (AEO 2020). PEV adoption is expected to be led by states that are regulating the sale of zero emission vehicles (ZEVs) (*California Air Resources Board*). California continues to push for more aggressive ZEV regulations; the state recently issued an executive order aimed at 100% of LDV sales being ZEVs by 2035 (*Office of Governor Newsom*). At the federal level, the Biden administration has shown great ambition in encouraging broader electric vehicle (EV) adoption, including setting goals to install 500,000 new chargers (The White House, 2021.04) and achieve half of new passenger car sales as zero emission vehicles by 2030 (The White House, 2021.08).

Access to charging infrastructure is consistently cited as one of the primary barriers to the increased sale of PHEVs and BEVs (Carley et al. 2019). In the United States, PEV charging options are often described using a pyramid structure, with residential charging as the foundation, workplace charging in the middle, and public charging on top (Figure 1). The existing electricity system, which generates, transmits, and distributes electric fuel to residential households, has helped PEVs partially overcome the "chicken and egg" conundrum that has haunted other alternative fuels. Viable home access to electric charging is also an important equity issue, because non-residential PEV charging options (e.g., workplace or public charging stations) are generally more expensive. Households without residential charging access may experience higher total cost of PEV ownership if non-residential charging options are more costly.

Figure 1. EV charging pyramid for consumer light-duty, non-fleet applications (National Research Council, 2015)

Although electricity is already generated and distributed at scale in the United States, investment is still required to provide drivers with access to charging infrastructure (often referred to as electric vehicle supply equipment, or EVSE) at the necessary locations. To date, this investment has largely focused on workplaces, public destinations, and along highways. Given that many current PEV owners come from high-income, single-family households, the foundation of PEV charging is already accessible in the garages of many PEV owners. However, the future of residential charging access in the United States remains uncertain as PEV adoption penetrates beyond these early adopter demographics.

Residential charging access is likely lower among low-income households, renters, and residents of multi-family dwellings (MFDs). Access may also be challenging for residents of single-family homes who own multiple vehicles but only have access to a single parking location suitable for charging. These potential PEV owners not only face greater charging access challenges, but likely also face greater charging costs when charging at home is elusive. This presents a significant equity issue to overcome.

There is a lack of national data on parking and electrical access among each of these sub-populations. The American Community Survey (ACS) gathers information on housing characteristics and LDV ownership, but it does not capture the distribution of available parking options for each housing type. The Residential Energy Consumption Survey (RECS), a nationwide survey nominally conducted every five years (and last in 2015) by the EIA, collects information on household-level garage access, number of parking spaces available in these garages, and the proportion of households that have an electrical outlet within 20 feet of vehicle parking (e.g., garage, carport, or exterior of home).[1] Prior to 2020, the RECS did not collect information about parking options beyond garages or about PEV charging location, and did not consider diverse parking among multi-vehicle households.

Discussion on correlations between residence type, housing tenure (i.e., rent or own), household income, vehicle ownership, parking access, and electrical access is sparse in the literature. Using data from ACS and RECS, Carnegie Mellon University researchers concluded that, as of 2013, only about 22% of vehicles had access to a dedicated home parking space within reach of an outlet (Traut et al. 2013).[2] This estimation was made based on several simplifications and assumptions, due to the lack of information on parking options other than garages. In 2012, using data from a 2007 survey of 2,272 new car buyers, Axsen and Kurani estimated the percentage of new car owners that have access to residential charging (Axsen and Kurani 2012). This study found that approximately half of new-car-buying households in the United States park vehicles within 25 feet of a 120V outlet. It is important to note that new car buyers may have very different demographic profiles (including housing type, tenure, and income) compared to used car buyers. Residential charging accessibility is likely to change as the PEV market progresses. This is because individuals with higher incomes and those that live in single-family homes are likely to be earlier PEV adopters compared to those with lower incomes and those living in MFDs. The interplay between residential charging accessibility and PEV adoption is a critical question that will inform charging infrastructure planning, yet it is largely a gap in the scientific literature.

This study aims to (1) collect nationwide data on residential parking options and electrical access availability, (2) gauge the residential charging potential of the LDV fleet, and (3) develop a procedure for forecasting the evolution of residential charging accessibility with the increase of PEV stock share that can be adapted to any region in the United States.

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[1] More information on the EIA's RECS 2015 and prior surveys is available on EIA's website at https://www.eia.gov/consumption/residential/reports/2015/comparison/ (accessed August 6, 2021).

[2] In addition to the 22% base case, Traut et al. present optimistic and pessimistic cases for vehicles with dedicated parking that have access to electric charging, bounded at 30% of vehicles and 8% of vehicles, respectively. The optimistic case assumes two vehicles (charging at different times) can share one outlet, whereas the pessimistic case assumes only 50% of the outlets near parking can be used for charging due to circuit overloading.

2 Methodology

To address the data gap on residential parking options and electrical access for different housing types, we first conducted a nationwide online questionnaire survey. In addition to basic housing and sociodemographic variables (such as housing type, tenure type, income, etc.), this survey asked the respondents to report the following three categories of information:

- **Parking options available at home.** Respondents were given the option of selecting on-street permit/meter or free parking; driveway/carport; personal garage; public garage; private garage; reserved space in a parking lot; unreserved space in a parking lot; RV park/yard or field; or none. Respondents were also asked to identify the number of parking spaces available at their personal garages (if applicable).
- **Specific information on the vehicles in the household and where the vehicles are typically parked at home.** Respondents were asked how many vehicles were in their household; the make, model, and year of the vehicle(s); if any of the vehicle(s) was a PHEV or BEV; and where the vehicle(s) are parked at home.
- **Existing electrical access and perceived potential to install electrical access for each parking option.** For electrical access, respondents were asked to identify which at-home parking options had electrical outlets available, if any. For perceived potential to install electrical access, respondents were asked to identify which at-home parking options had electrical outlets available or could have electrical outlets installed if necessary.[3] Respondents were also shown images of a 120V and 240V outlet and were asked if they believed it was possible to charge an electric vehicle from each type of outlet.

We recruited 5,250 respondents (resulting in a 3,772 final respondent sample) through a survey panel maintained by an online platform called Prolific. We used the final sample to approximate the housing and charging access distribution for all U.S. LDV owners, as detailed below. The details of the survey design, data collection, and sample description are described in Section 3. A rigorous set of quality control filters was applied to the survey responses to remove those that were internally inconsistent. Of the 5,250 responses, 3,772 (72%) completed surveys were retained for analysis purposes. Based on the survey data, we estimated household-level distributions of parking options, electrical access availability and installation potential, and the typical parking location of all household vehicles. We then calculated the estimated vehicle-level residential charging access probability for each housing type. Combining the residential charging access probability by housing type and the LDV stock information of the ACS datasets, we calculated the estimated residential charging access potential of the whole LDV fleet. The details of these analyses are documented in Section 3.

The estimated residential charging access potential of the LDV fleet depicts the residential charging availability of the future (assuming all LDVs are PEVs). A pressing question to answer for charging infrastructure planning is how residential charging access may evolve as the PEV stock share grows. For example, what is the forecasted residential charging availability in 2035 for a given PEV fleet size? To help address this question, we use the survey data to calibrate a PEV adoption likelihood model that predicts the relative likelihood of a household to purchase a PEV based on the following variables:

---

[3] Perceived potential to install electrical access did not include asking respondents about "right-to-charge" laws in their home jurisdiction. These laws provide MFD residents with the right to install vehicle charging stations for their individual use, provided that the resident covers the cost and other conditions are met.

household income, residence in a state that has ZEV initiatives, housing type and tenure, and the population density of the residential location. The adoption model specification and results are shown in Section 4. We then enriched the ACS data by generating estimates of residential charging access for each household using a Bernoulli distribution, with the success rate being the residential charging access probability by housing type and tenure.

Using the enriched ACS data as inputs for the PEV adoption model, we generated the adoption likelihood for each vehicle in the ACS dataset. By ranking the adoption likelihood, we were able to identify the relative adoption timeline of each household, assuming that households with a relatively high PEV adoption likelihood would become PEV users earlier. This enables us to predict which households will have PEVs for any hypothetical PEV fleet size. This procedure also helps predict the evolution of PEV owner characteristics as a function of the PEV fleet size, including residential charging access, housing type, and household income. Section 4 provides details on this method and the results of the projections.

The analysis workflow for generating PEV residential charging access estimates for the U.S. PEV fleet as a function of PEV fleet size is shown in Figure 2.

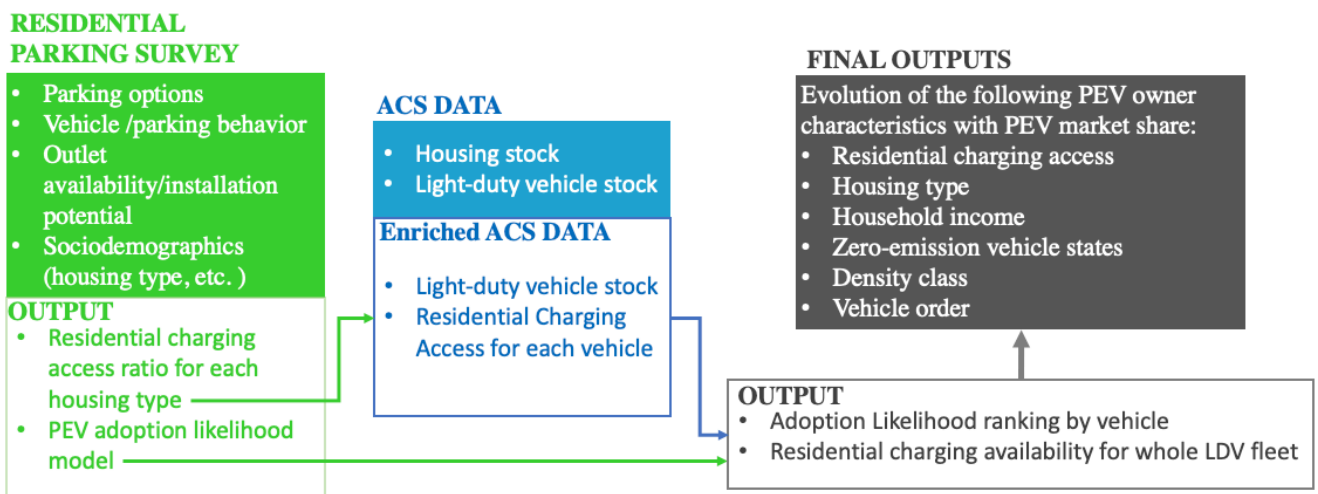

Figure 2. Methodology flow chart

3 Residential Parking & Electrical Access Survey

3.1 Survey & Data

From May 13th to May 31st, 2020, we conducted an online survey by recruiting respondents from a panel maintained by Prolific with an online survey tool created using SurveyMonkey. The respondents were asked to provide information on the following categories: (1) sociodemographic characteristics, (2) housing type and tenure, (3) residential parking options, (4) electrical access availability for each available parking option, (5) vehicle ownership, including the number of vehicles owned, (6) specific information, such as fuel type and home parking location of each vehicle. The parking options we considered included:

- Driveway/carport
- On-street (free)
- On-street (metered)
- Parking garage (private)
- Parking garage (public)
- Parking lot (no reserved space)
- Parking lot (reserved space)
- Personal garage
- RV park/yard/field

We recruited 5,250 survey respondents through Prolific from across the United States. The geographic distribution of responses is representative of the population distribution in the United States, as shown in Figure 3, and did not include participation from respondents in Hawaii or Alaska.

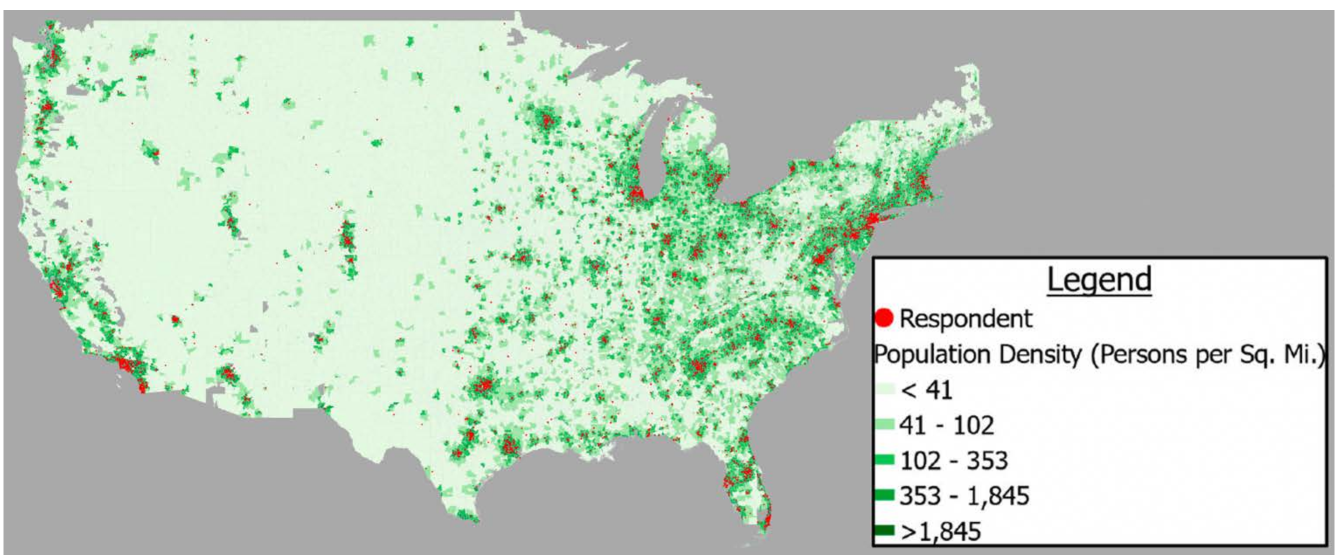

Figure 3. Geographic distribution of the survey respondents overlaid on a population density map

Because most of the questions were multiple choice, we applied several quality-control measures to judge internal consistency of the information reported by the respondents, including the following:

1. When a respondent indicated that there was electrical access for a parking option, the record also had to show that this particular parking option was available to the respondent.

2. The collection of parking options available to the household had to include the parking option where the vehicles were currently parked at home.
3. When a respondent reported more than zero parking stalls in a personal garage or a clothes dryer in their personal garage, their records also had to show that they had a personal garage available in the first place.

When we applied a strict quality control, meaning each response was required to pass all the internal consistency checks, the final respondent sample size was reduced to 3,772. With this being the sample size and the American population aged 18 or older being the targeted population (258.3 million according to the 2020 Census), the margin of error is less than 0.2% corresponding to a confidence interval of 98%. Admittedly, some subsets of the population can have higher margins of error and lower confidence intervals depending on the representativeness of the sample. Figure 4, Figure 5, and Figure 6 show the distributions of household income, education, and residence type of our sample relative to the U.S. national population as reported by ACS. Our final respondent sample underrepresents the highest income bracket, overrepresents those with higher levels of education (e.g., those with bachelor's degrees), underrepresents those with lower levels of education, underrepresents single-family detached housing, and overrepresents single-family attached housing and high-capacity apartments. Here, single-family detached means that the building only consists of one dwelling unit or suite and is usually occupied by one household. Single-family attached, as a type of MFD, means that a housing unit is connected to another housing unit; examples include rowhomes, townhomes, and condos. High-capacity apartments refer to apartments with 20 units or more. Mid-capacity apartments have 5–19 units, and low-capacity apartments have 2–4 units. As the survey data was primarily binned and analyzed according to housing and tenure categories, the difference in the housing type distributions between the sample and the U.S. population is not particularly concerning; however, the discrepancies in the other variables, such as income and education, can potentially cause biases in estimated residential charging access. The direction and magnitude of the biases will be discussed in Section 3.3 where the results are shown.

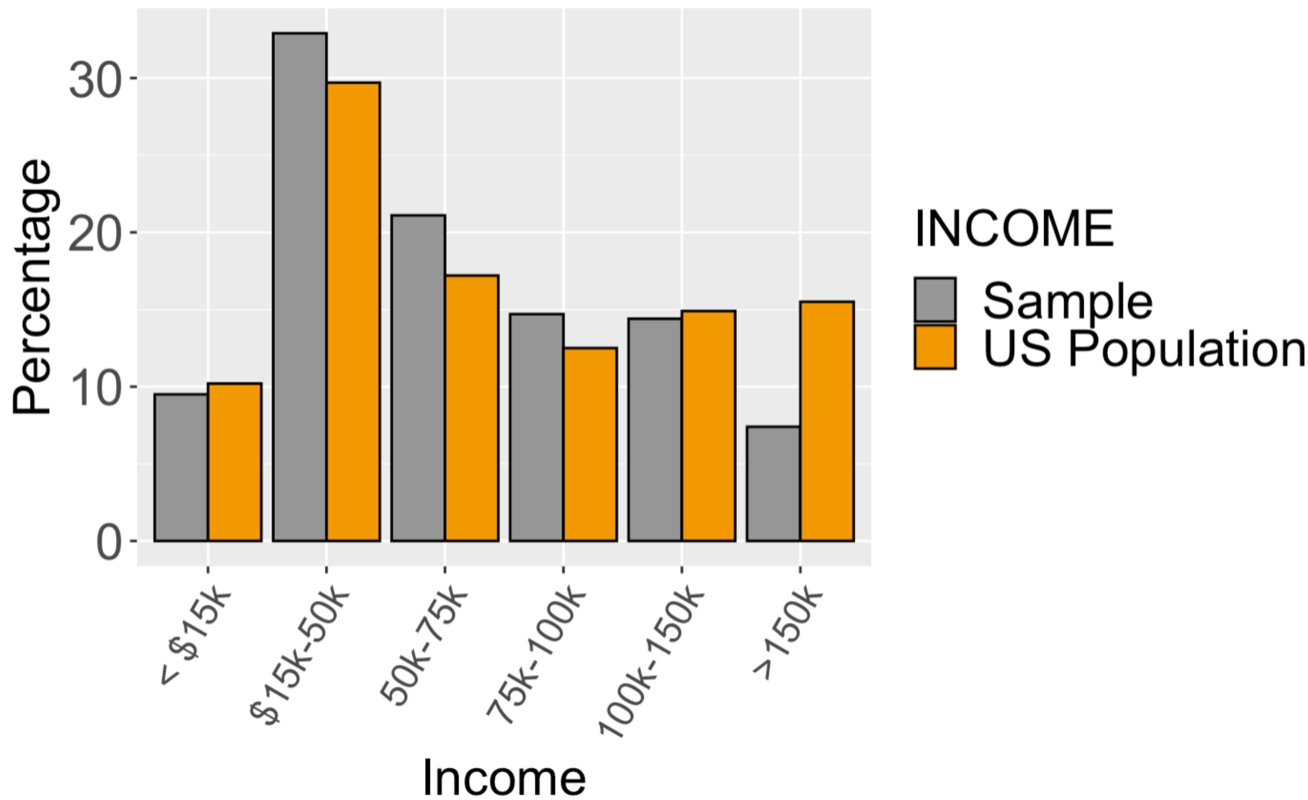

Figure 4. Income distribution of the sample and the U.S. population

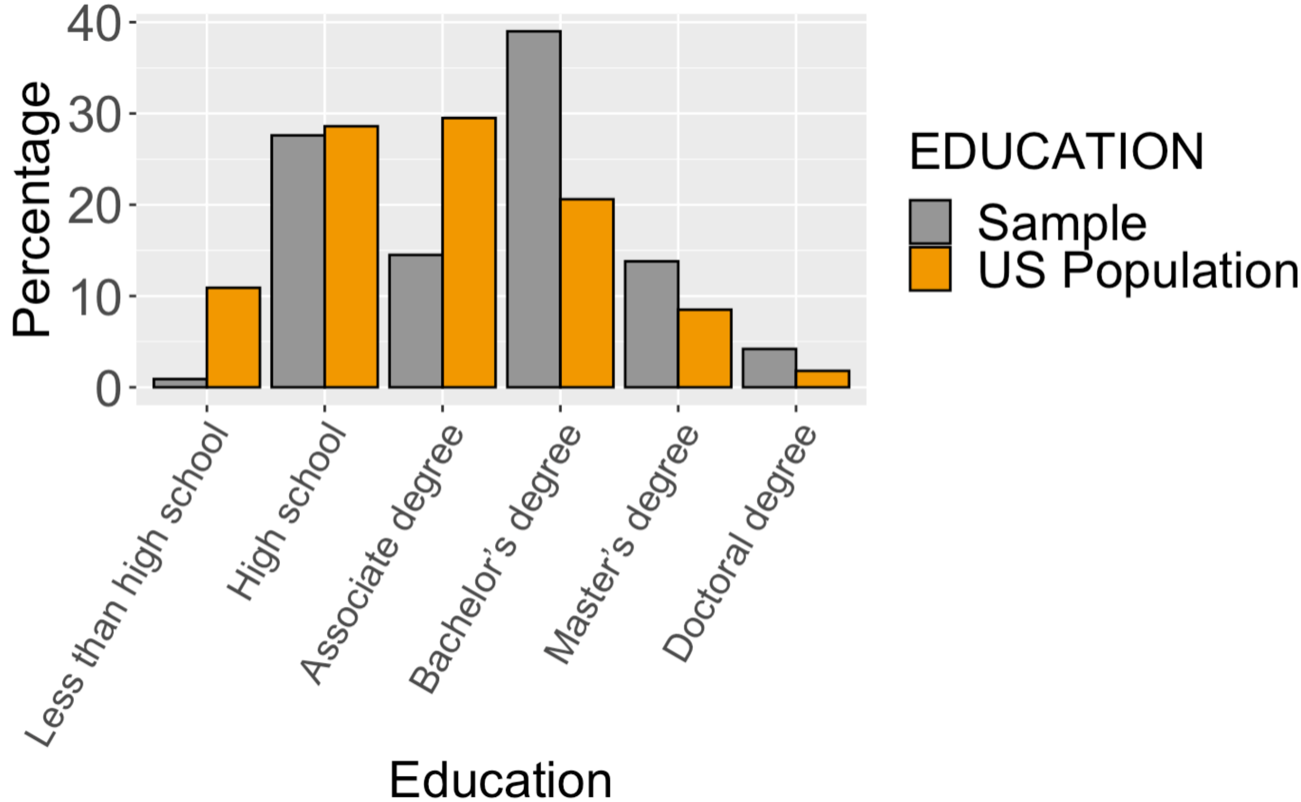

Figure 5. Education distribution of the sample and the U.S. population

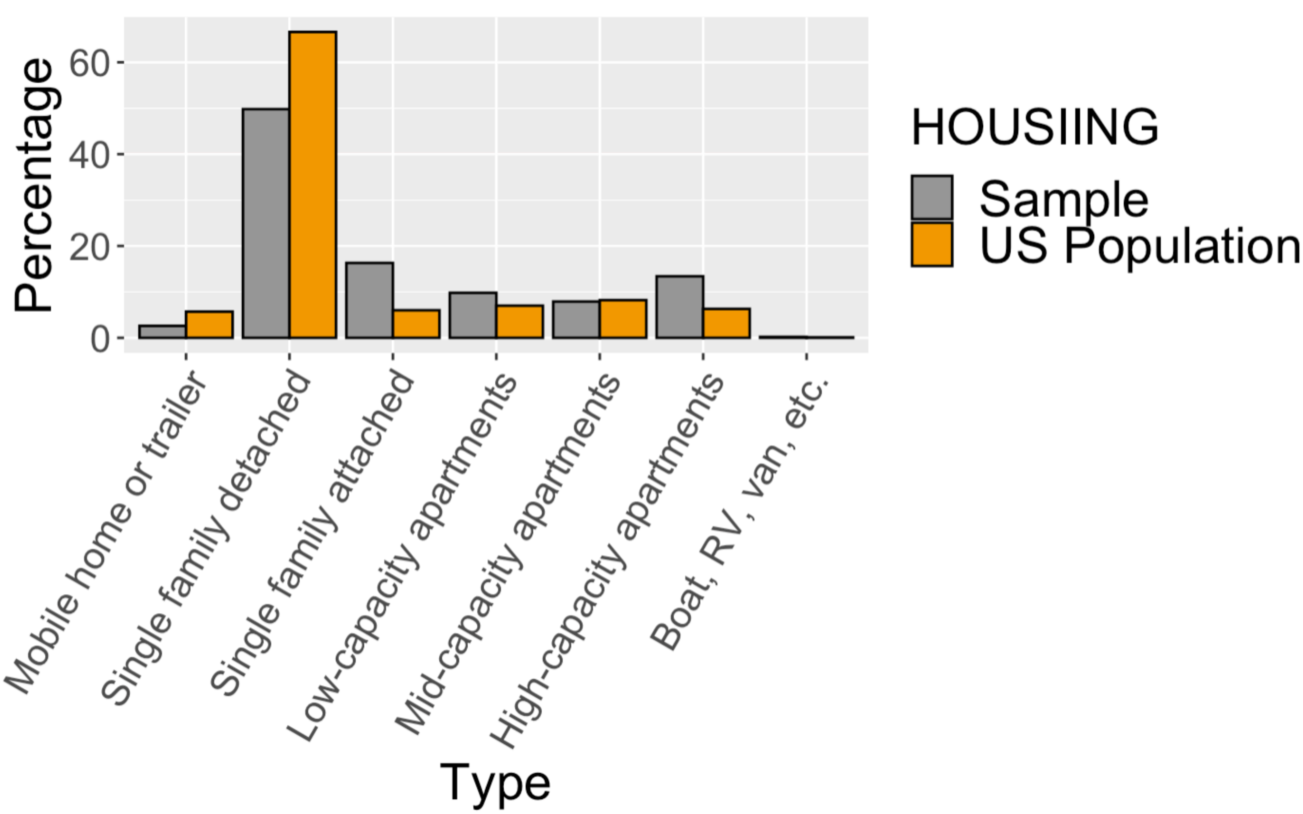

Figure 6. Housing type distribution of the sample and the U.S. population

3.2 Parking Availability and Electrical Access Distribution

Based on responses to the residential parking survey, this section presents parking and electrical access distributions by residence type. Figure 7 illustrates the parking option availability, electrical access availability, and potential to install electrical access for different housing types. Totals for each housing category can be greater than 100% because respondents were able to select all parking options that applied. Existing electrical access refers to the respondent's observation that an electrical outlet was available at the selected home parking option. Potential electrical access refers to the respondent's perception that it would be possible to have an electrical outlet installed at the home parking location, if necessary. Here, we presume the respondent has layperson-level knowledge about the feasibility of installing an additional electrical outlet.

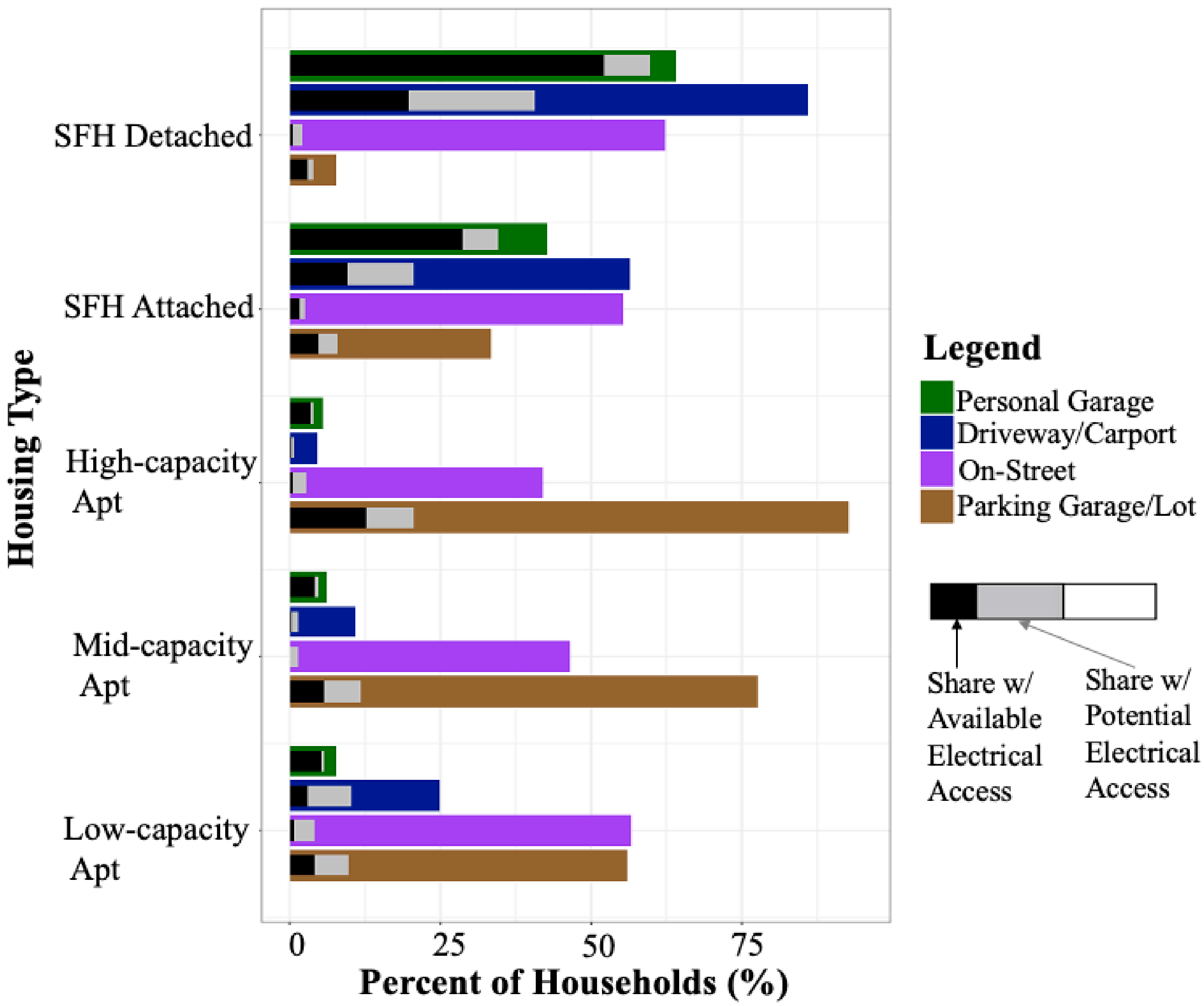

Figure 7. Existing and potential electrical access by residence type and parking option

(Note: the colored bars for the four parking types show the percentage of households that have the parking option available at home. The black and grey narrower bars convey the percentage of households that have existing or potential electrical access for each parking type, respectively. The length that is not covered by the grey and black bars indicates the percentage of households that have that parking option at home, but there is no electrical access at that parking location.)

Driveway/carport and personal garage are the most common parking options available for single-family detached homes, followed by free on-street parking. Most of the personal garages currently have electrical access. About 25% of the driveways/carports have existing electrical access, and another 25% indicate that access can be installed, even though not available currently. Very small proportions of on-street parking and parking garages/lots have existing electrical access. The rate of electrical access and the potential for installation for each parking type is similar between single attached and detached homes. However, compared with single-family detached homes, single-family attached have a higher share of parking garages/lots and a slightly lower share of personal garages. The distribution of parking options for apartments is very different from single-family homes. The most common parking option in low-capacity apartments is on-street parking, followed by parking garage/lot, and then driveway/carport. Mid-capacity apartments have similar parking option availability, but there are more parking garages/lots. Compared with low-capacity and mid-capacity apartments, high-capacity apartments have more parking garages available and much fewer driveways/carports. For apartments, parking garage/lot is the option that is more likely to have electrical access, and there are very few households living in apartments that have personal garages. Admittedly, these distributions probably vary by region. For example, high-capacity apartments in San Francisco are likely to have different parking options than high-capacity apartments in New England; however, due to the sample size limitation, the survey data cannot be further split to be region-specific.

Building on these results, the next section will explore vehicle-level home charging availability in more detail.

3.3 Residential Charging Potential by Housing Type

All things equal, if all the vehicles in a household are replaced by PEVs, how will residential charging availability be impacted? In addition, how does residential charging availability vary by housing type? This section tries to answer these questions using the survey data.

Residential charging availability is defined and calculated according to the following five scenarios.

Scenario 1 - Discounted Existing Electrical Access. In this scenario, residential charging is considered available if the existing vehicle is parked at a location where electrical access is currently available, and its owner thinks a 120V standard outlet can be used to charge a PEV (as is typical for Level 1 charging). The 120V perception variable was generated based on a five-level Likert-scale question in the survey where the respondent was shown an image of a 120V outlet and was asked if it is possible to charge an electric vehicle using this outlet type.[4] Approximately 71% of the respondents answered either no or probably not. Although this is an unlikely outcome, this most conservative scenario is incorporated as a lower bound, and may reflect an important knowledge gap to be addressed.

Scenario 2 - Existing Electrical Access. This scenario removes the 120V perception criteria from Scenario 1 and defines residential charging as available if the vehicle is currently parked near electrical access.

Scenario 3 - Existing Electrical Access with Parking Behavior Modification. Building on Scenario 2, if a vehicle is currently not parked in an area with electrical access but can be moved to a home parking location with electrical access, then residential charging is defined as available. For example, for a vehicle regularly parked in the driveway without electrical access, residential charging is

[4] Respondents could choose between no, probably not, possibly yes, probably yes, or yes.

considered not available for Scenario 2, but is considered available for Scenario 3 if the family also owns a personal garage with electrical access.

Scenario 4 - Enhanced Electrical Access. This scenario is based on the perceived potential for new installation of additional electrical access. It defines residential charging as available if a vehicle is parked at a location where there is either existing electrical access or where the respondent believes new electrical access can be installed. This scenario is similar to Scenario 2, but adds additional charging availability by incorporating respondent perceptions about the feasibility of installing additional electrical outlets.

Scenario 5 - Enhanced Electrical Access with Parking Behavior Modification. Building on Scenario 4, this scenario considers residential charging to be available if a vehicle can be moved to a parking location where the respondent believes new electrical access can be installed.

Table 1 lists the residential charging availability on a vehicle level according to the five scenarios. In general, for all housing types, vehicles in owned homes have much better residential charging access than rented homes, according to all five scenarios. According to Scenario 2 (existing electrical access), in owned single-family detached homes, 45% of the vehicles are parked near electrical access currently, whereas for rented single-family detached homes, that rate is much lower (28%). For rented apartments, it is even lower still: 9% for low-capacity apartments, 7% for mid-capacity apartments, and 14% for high-capacity apartments. For owned apartments (condos), 28% of the vehicles are currently parked near electrical access. Because only a fraction of the respondents believe that 120V outlets can be used for charging electric vehicles, in Scenario 1, residential charging access drops down to 17% for owned single-family detached homes.

When parking behavior modification is taken into account (Scenario 3), the residential charging availability for owned single-family detached homes increases to 72% from 45%. Similarly, when the potential for installation of new electrical access is considered (Scenario 4), the rate rises to 64% from 45% (again for owned single-family detached homes). If we assume both installation and parking modification are possible (Scenario 5), the residential charging access for owned and rented single-family detached homes increases to 89% and 68% respectively. Overall, for each scenario, single-family detached homes have much better residential charging potential than MFDs. Among the apartments, high-capacity apartments are more likely to have residential charging available than mid/low-capacity apartments due to more availability of private garages/lots (Figure 7).

Admittedly, due to the discrepancies between the sample distribution and the U.S. population distribution regarding variables such as household income and education (Figure 4 and Figure 5), these estimates are subject to further scrutiny for potential biases. Because the survey sample underrepresents the high-income (above $150,000) group, and intuitively, higher income means better residential charging access when housing characteristics are the same, this discrepancy may cause the residential charging access to be biased downward. However, because the sample overrepresents the higher education group, and intuitively, higher education is likely to be correlated with better residential access, the estimated residential charging access ratios may be biased upward. Unfortunately, there is no rigorous way to test the collective influence of these biases without a larger sample size that enables weighted calculation based on these two variables. However, we speculate that because housing type is the major contributor to differences in residential charging access, the biases caused by income and education inconsistencies are relatively small.

Table 1. Residential Charging Availability Scenarios (% of Vehicles)

Housing	Tenure	Number of Respondents in the Sample	Number of Vehicles in the Sample	**Scenario 1:** Discounted Existing Electrical Access	**Scenario 2:** Existing Electrical Access	**Scenario 3:** Existing Electrical Access (w/ parking behavior mod)	**Scenario 4:** Enhanced Electrical Access	**Scenario 5:** Enhanced Electrical Access (w/ parking behavior mod)
SFH detached	own	1,378	3,065	0.17	0.45	0.72	0.64	0.89
SFH detached	rent	392	669	0.1	0.28	0.49	0.44	0.68
SFH attached	own	344	653	0.16	0.35	0.53	0.51	0.7
SFH attached	rent	240	369	0.07	0.15	0.28	0.3	0.47
High-capacity apt (20+)	rent	465	562	0.05	0.14	0.19	0.23	0.29
Mid-capacity apt (5–19)	rent	274	309	0.03	0.07	0.11	0.14	0.19
Low-capacity apt (2–4)	rent	342	433	0.02	0.09	0.12	0.21	0.26
Apartments	own	73	88	0.1	0.28	0.4	0.36	0.48
Mobile Home	own	66	110	0.11	0.41	0.43	0.6	0.63
Mobile Home	rent	32	49	0.03	0.29	0.29	0.51	0.51
Unknown Housing or Tenure Type		166	359	0.09	0.25	0.47	0.44	0.69

To distinguish residential charging access for each vehicle within a household, Figure 8 shows the residential charging access probability distribution in Scenario 2 (Existing Electrical Access) for the first, second, and third (+) vehicles in a household, respectively. As there is no way to know in what order the vehicles of one household might be replaced by PEVs based on the survey data, we define the first vehicle as the one that has the highest charging access at home. For example, in Scenario 2, the first vehicle in a single-family detached home has a 58% probability of having electrical access, whereas the third vehicle has a 22% chance of having electrical access. For most housing types, the first vehicle has a significantly higher home charging access ratio than the subsequent vehicle. The residential charging access ratios by vehicle order for all five scenarios are listed in Appendix A. When we assume individuals are willing to change the parking locations of their vehicles, as in for Scenario 3 (Existing Electrical Access (w/ parking behavior mod)) and Scenario 5 (Enhanced Electrical Access (w/ parking behavior mod)), the residential charging availability is the same for all vehicles in one household as multiple vehicles can share one charger at home.

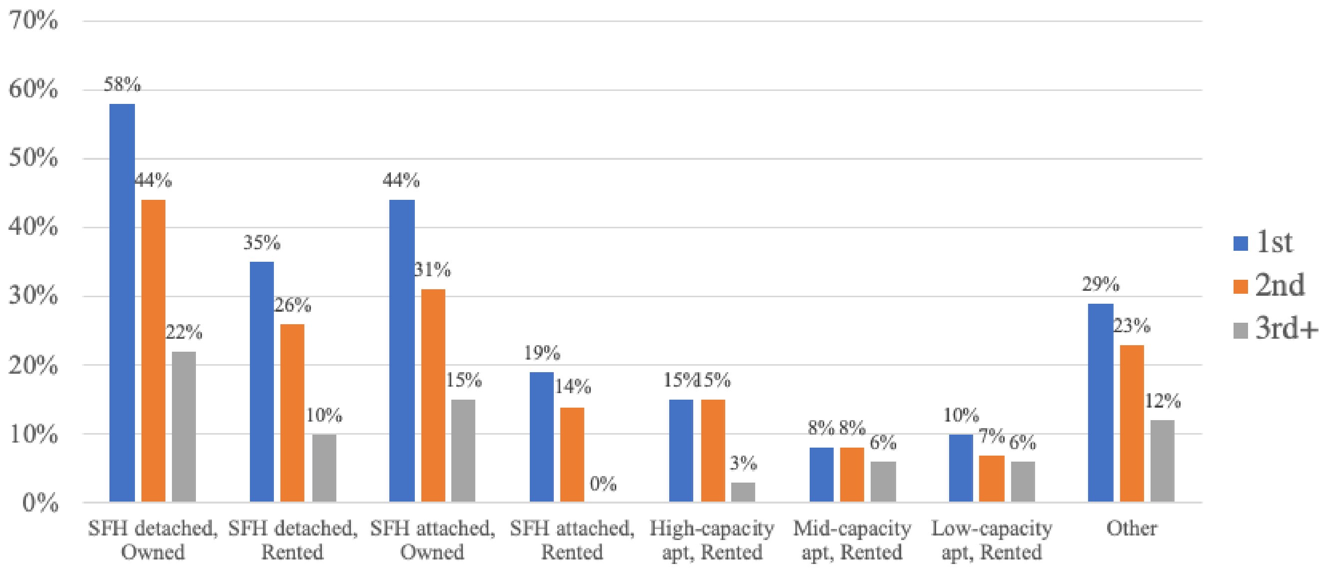

Figure 8. Residential charging access ratio by household vehicle rank, according to Scenario 2 (Existing Electrical Access Scenario)

3.4 Residential Charging Potential for the Whole LDV Fleet

Combining information from ACS datasets with the household-level residential access probabilities calculated in Section 3.3, this section estimates the residential charging potential for the whole LDV fleet. The dataset used in this analysis is the 2017 five-year Public Use Microdata Sample (PUMS) collected by ACS, which includes 7,539,832 survey records. This is a sample of approximately 5.9% of the 2016 population of U.S. households. PUMS data have the following three key attributes: housing tenure, housing type, and number of vehicles owned for each housing category. Individual PUMS records are weighted using values provided by ACS to generate estimates of the U.S. population.

The residential charging potential for the LDV fleet is calculated as the weighted average of the access probability by housing type (shown in Table 1), with the weight being the share of LDVs in each housing type according to the PUMS data. In Scenario 2, 33% of all vehicles in the entire existing LDV fleet are parked in a location where electrical access is currently available (Figure 9). This is higher than the estimation by Carnegie Mellon University (Traut et al. 2013), which is 22%. In the most conservative scenario (Scenario 1), where only a small portion of respondents are aware that a 120V outlet can be used to charge a PEV, residential electrical access is 12%. The share of vehicles that could park near electrical access if the owners changed their parking behavior (Scenario 3) is 60%. The share of vehicles currently parked near existing electrical access or parked in locations where owners think new electrical installation could occur (Scenario 4) is 46%. In Scenario 5, charging availability rises to 75% if the vehicles can be moved to park in locations where electrical access is available or new electrical installation is possible.

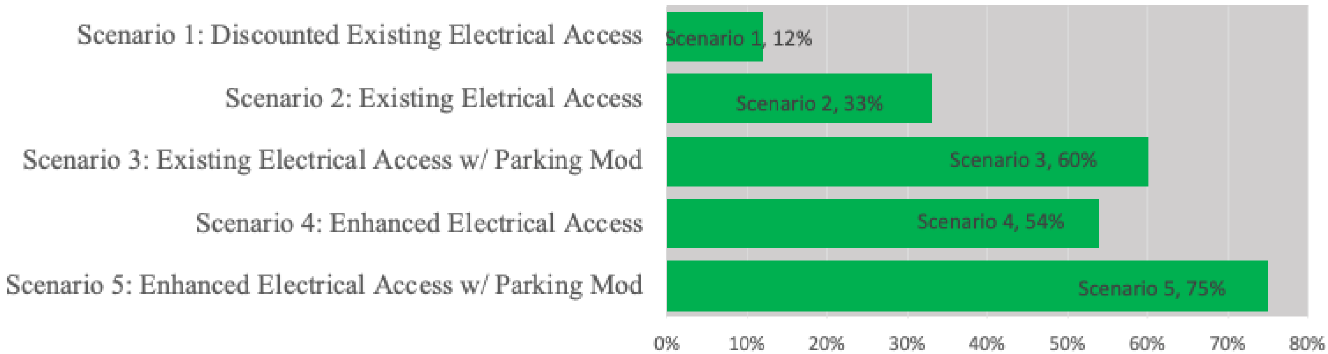

Figure 9. Residential charging potential for the existing LDV fleet

4 Residential Charging Availability Projection

To estimate how residential charging availability could evolve over time as the PEV stock increases, it is critical to understand what drives individuals' adoption behavior. Using the survey data, we calibrated a binomial logistic regression model to quantify how the following variables influence household-level PEV adoption: income, housing type, housing tenure, whether the respondent is from a state with ZEV initiatives, and population density class. We only explored binomial logistic regression instead of experimenting with other machine learning models because of the sample size limitation. Section 4.1 discusses the model framework, model specification, and results in detail. Section 4.2 applies the likelihood of adoption to generate a relative adoption ranking among ACS households. Section 4.3 presents composite results that describe national scenarios for the potential evolution of residential charging access.

4.1 PEV Adoption Model

Table 2 shows the descriptive analyses of the dependent and independent variables for the PEV adoption model. The dependent variable of the binomial logistic regression model is defined as whether a household owns at least one PEV. Among the 3,772 respondents in the survey sample, 228 respondents (about 6% of the sample) had at least one PEV in their household.

The income brackets reported by the respondents, labeled *INC*, were used as a continuous variable in the utility function. The variable on housing type, labeled I_{SFH}, is defined as a dummy variable that indicates whether the housing type is single-family housing ($I_{SFH} = 1$) or MFD ($I_{SFH} = 0$). Here, mobile homes are categorized as MFD, and SFH includes both single-family attached and detached homes. The tenure type variable, labeled *TEN*, is defined as a dummy variable, with 1 being owned, and 0 being rented. The variable ZEV refers to whether a respondent lives in California (ZEV = 3) or in another state that has ZEV initiatives (ZEV = 2), which at the time of the analysis included Colorado, Connecticut, Maine, Maryland, Massachusetts, New Jersey, New York, Oregon, Rhode Island, and Vermont and Washington. California is encoded with its own ZEV class due to the historically high adoption of ZEV technology, even relative to other ZEV states. ZEV is 1 if the respondent lives in a state that does not have ZEV initiatives.

Population density class of each respondent's home location was generated per Public Use Microdata Areas (PUMA), which are statistical geographic areas for disseminating ACS population density. Locations were grouped into four classes based on the following thresholds identified in the literature (Montgomery 2018):

A. Urban: >2,213 households per square mile

B. Suburban (high density): 800–2,213 households per square mile

C. Suburban (low density): 102–800 households per square mile

D. Rural: <102 households per square mile.

As a categorical variable, density class enters the model as a factor, with the reference level being high-density suburban area, and the other three categories labeled as $I_{low-density-suburb}$, I_{rural}, and I_{urban}.

Table 2. Descriptive Analyses for PEV Adoption Model

Subsets	Variables	Categories	Frequency	Percentage (%)
PEV owners (228, 6%)	Housing type	SFH	182	80
		MFD	45	20
	Income	Under $30k	41	18
		$30k–$50k	32	14
		$50k–$75k	34	15
		$75k–$100k	25	11
		$100k–$150k	58	25
		Over $150k	29	13
	Tenure	Owned	150	66
		Not owned	78	34
	ZEV	1: Non-ZEV states	150	66
		2: Non-California ZEV states	37	16
		3: California	41	18
	Density class	Suburban (high density)	81	36
		Suburban (low density)	67	29
		Rural	19	8
		Urban	42	18
Non PEV owners (3,544, 94%)	Housing type	SFH	2,400	68
		MFD	1,118	32
	Income	Under $30k	850	24
		$30k–$50k	704	20
		$50k–$75k	742	21
		$75k–$100k	490	14
		$100k–$150k	456	13
		Over $150k	225	6
	Tenure	Owned	1,715	48
		Not owned	1,829	52
	ZEV	1: Non-ZEV states	2,470	70
		2: Non-California ZEV states	676	19
		3: California	398	11
	Density class	Suburban (high density)	944	27
		Suburban (low density)	1,048	30
		Rural	526	15
		Urban	686	19

The model takes the form of a binary logistic regression model based on utility theory, and it is assumed that individuals make decisions to maximize utility. The utility is a linear combination of the independent variables, with the weights being the coefficients to be estimated. The probability function is shown by Equation 4.1, and the utility function specification of owning a PEV is shown by Equation 4.2. To avoid perfect multicollinearity, we calculated the variation inflation factor (VIF) scores of the predictors of the regression model. The highest VIF score among all variables is of the variable tenure category (TEN), and at 1.53, it is lower than the threshold of the rule of thumb (5.0) (James et al. 2013). Therefore, the model is parsimonious, and all the aforementioned factors can enter the regression as predictors.

$$P_{PEV} = \frac{e^{u_{PEV}}}{1 + e^{u_{PEV}}} \tag{4.1}$$

$$u_{PEV} = \beta_0 + \beta_{ten} * TEN + \beta_{INC} * INC + \tag{4.2}$$

$$\beta_{sfh} * I_{SFH} + \beta_{zev} * ZEV +$$
$$\beta_{lds} * I_{low-density-suburb} + \beta_{rural} * I_{rural} +$$
$$\beta_{urban} * I_{urban} + \varepsilon$$

The model results are listed in Table 3. The p-values show that housing tenure, income, residence in a ZEV state, and population density class all significantly correlated with household-level PEV adoption decisions, and the directions are consistent with intuition (Coffman et al. 2015). Owning the home, being in higher income group, and living in California are all positively correlated with PEV adoption. Living in a SFH is not significantly correlated with PEV adoption, according to the regression result, though the direction of the coefficient indicates those that live in single-family homes might be more likely to adopt PEVs. A larger sample size is required to test whether this speculation can be supported. Compared to those living in high-density suburban areas, individuals that live in low-density suburban neighborhoods or in rural areas are less likely to adopt PEV, and that effect is statistically significant. The coefficient of living in an urban area is negative, which would suggest that, compared to a high-density suburban area, the probability of adoption in an urban area is lower (after controlling for income, housing type, etc.). However, because the p-value is larger than 0.05, this effect is not statistically significant, meaning that a larger sample size is required to test whether this difference is accurate.

Table 3. PEV Likely Adopter Model Based on Survey Data

Variable	Estimates	Std. Error	z value	Pr(>|z|)
(Intercept) (β_0)	-3.785	0.2650	-14.28	<0.01
Tenure (Owned) (β_{TEN})	0.4521	0.1898	2.38	0.02
Income (β_{INC})	0.1613	0.0483	3.24	<0.01
Housing Type (SFH) (β_{SFH})	0.3387	0.2167	1.56	0.12
ZEV (β_{ZEV})	0.2160	0.1007	2.15	0.03
Low-Density Suburb (β_{lds})	-0.3641	0.1777	-2.05	0.04
Rural (β_{rural})	-0.8930	0.2721	-3.28	<0.01
Urban (β_{urban})	-0.2682	0.2114	-1.28	0.20

The pseudo-R-squared of this model is calculated to be 0.04, indicating its low predictive power on household-level PEV adoption decisions. This is partially due to the omission of potential predictors, such as environmental values and attitudes toward new technology. Travel demand characteristics, such as commute distance and road trip frequency, can also influence PEV adoption decisions. The skewed distribution of the dependent variable that results from the low PEV penetration rate also contributes to the low pseudo-R-squared. Intuitively, when a very small share of the population is PEV owners, it is difficult for the model to identify specific households as PEV owners with high probability, especially among cohorts of similar demographics.

However, the model performs significantly better across larger geographic areas. We find a higher degree of correlation between modeled PEV ownership and existing PEV registrations[5] when aggregating results from individual households to the county-level ($R^2 = 0.90$). Figure 10 shows the county-level comparison between the actual PEV stock (approximately 1.6 million as of 2021 Q1) and

[5] Derived registration counts by the National Renewable Energy Laboratory, Experian Information Solutions

modeled PEV registrations (assuming the same national total). This level of geographic resolution is consistent with expected future applications (e.g., predictions of residential charging access at the county-level, or similar). While we see general agreement between the actual and modeled county-level PEV registrations, the model tends to favor urban areas, which could artificially depress residential charging predictions by a small amount in aggregate.

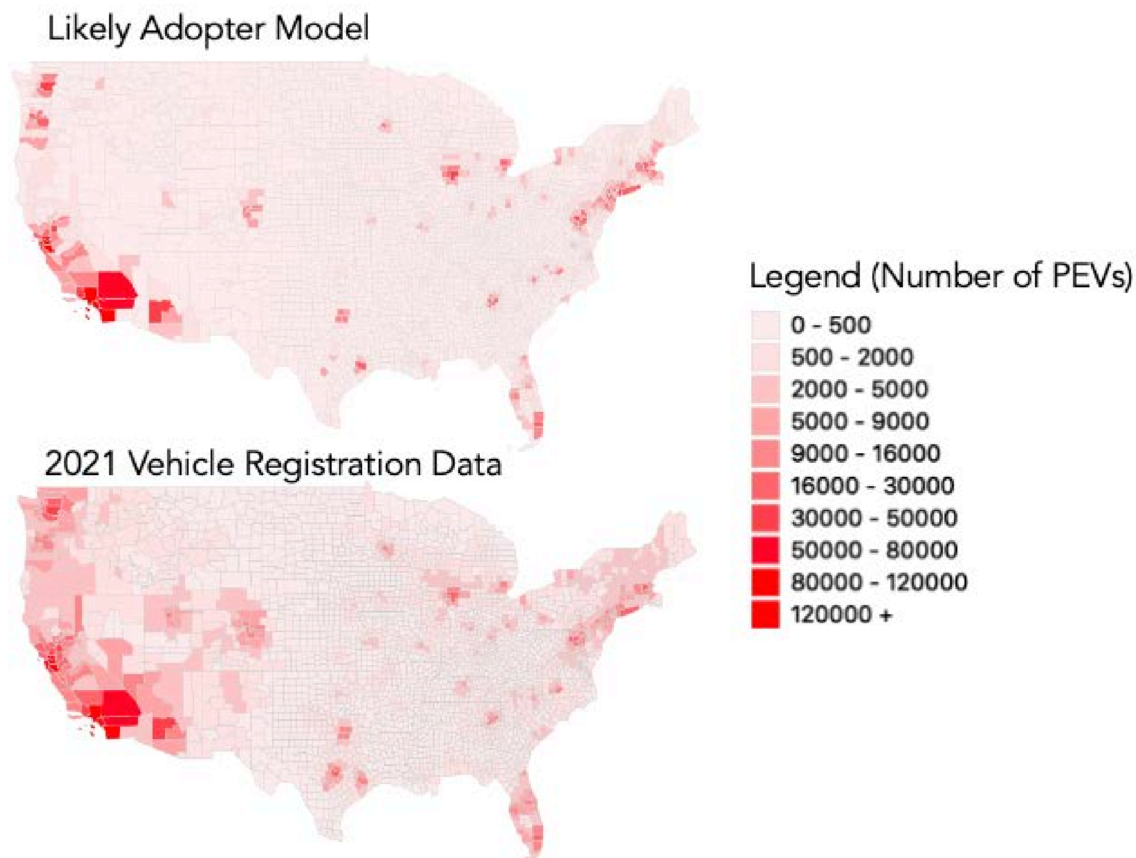

Figure 10. County-level comparison between 2021 PEV registrations and predicted PEV stock by the likely adopter model

The model is also partially constrained by the fact that certain ordinal categorical variables are treated as continuous instead of as factors, which assumes the difference of PEV adoption probability is the same between any two consecutive categories. This is a strong assumption; when income category changes from under \$30k to \$30k–\$50k, the probability of PEV adoption may not increase as much as when it changes from \$75k–\$100k to \$100k–\$150k. Similarly, assuming that ZEV is a continuous variable is not ideal, considering that the difference between California and other ZEV states when it comes to EV adoption is not necessarily the same as the difference between other ZEV states and non-ZEV states. We experimented with models where these variables were discrete factors but made the choice of using income and ZEV as continuous variables. This was a simplification due to the sample size limitation—including multiple levels of these variables is not ideal because the number of PEV owners captured by the survey is very small. Additionally, the effect of income and ZEV status is likely to evolve with the proliferation of the PEV market, and enforcing strict categories reduces the suitability of the model for future PEV adoption projections. For example, assuming that \$100k of household income is the threshold that is appropriate for a PEV adoption decision today, in the future, with more EV proliferation in the market and a PEV price drop enabled by better battery technologies, that threshold might become much lower (for example, \$50k). By using continuous income steps instead of absolute income categories, this model adjusts the coefficients of lower income brackets, and is more appropriate for PEV projection in a future market.

Despite these limitations, we deem this model appropriate for the purpose of likelihood adoption estimation, which will be used for the residential charging availability projection in Section 4.3. This projection uses the likelihood of adoption to generate a relative adoption timeline. The absolute values of the estimates and the predictive capability of the model are not the priorities for this purpose—instead, we emphasize the relative scale of these coefficients (for example, how much influence housing type has on PEV adoption compared with income).

4.2 Residential Charging Access Projection Framework

The residential charging availability for the whole LDV fleet generated in Section 3 is not particularly informative for charging infrastructure planning in the near term, considering it could take decades for the nation to achieve 100% electrification. How does residential charging availability evolve as a function of national PEV fleet size? This is an important question to discuss for the purpose of forecasting charging infrastructure needs for any time before the whole LDV fleet is replaced with PEVs. We applied the following steps to project the residential charging availability for different adoption rates:

- **Step 1: Enrich ACS data.** The dataset used in this analysis is the 2017 five-year PUMS data collected by ACS, which includes 7,539,832 survey records, a sample of approximately 5.9% of the 2016 population of U.S. households. Among the many variables from the PUMS survey, this analysis focuses on household and vehicle ownership traits, including housing tenure, building type, and household income. From the original PUMS data, we used the ACS weight field to multiply the records to generate a population estimate, which we hereby refer to as the *pums_enriched* dataset. To apply the PEV adoption model, two variables need to be generated for each record in the *pums_enriched* dataset: *ZEV* and *density class*. The *ZEV* variable is generated based on the state where a household is located, as defined in Section 4.1. *Density class* is generated according to the thresholds specified in Section 4.1 (i.e., rural, urban, low-density suburban, high-density suburban). Residential charging availability is a random variable generated according to a Bernoulli distribution, with the success rate being the residential charging availability by housing type and tenure listed in Table 1.
- **Step 2: Determine adoption likelihood for each vehicle in the enriched ACS dataset.** Given a set of coefficients, for each record in the enriched PUMS dataset, the utility of PEV adoption can be calculated according to Equation 4.2. Then, the probability of adoption can be calculated using Equation 4.1. In order to account for the variance of the coefficients, for each record, instead of using the estimated mean values, every coefficient is generated as a random variable from a normal distribution. The mean (μ) and standard deviation (σ) of the distributions are estimated using the PEV adoption model, as shown in Table 3.
- **Step 3: Rank adoption likelihood.** Assuming that those with higher PEV adoption probabilities are likely to become PEV owners earlier, by ranking the adoption probability generated by Step 2, we obtain the relative PEV adoption timeline of the records in the enriched PUMS dataset.
- **Step 4: Determine distribution of PEV owner characteristics, including residential charging access, housing type, etc.** Given a specified level of PEV stock (e.g., 25% of all U.S. LDV stock), the ranking generated by Step 3 informs which of the LDVs in the enriched PUMS dataset are estimated to be PEVs. The distributions of the characteristics of these estimated PEVs can then be easily generated.

4.3 National PEV Residential Charging Access Projection Results

In this section, we apply the likely adopter model nationally, and use it to rank household vehicles such that the potential evolution of residential charging access can be visualized. This approach enables a similar inspection of related variables, including housing type distribution, household income, and population density class.

Figure 11 shows the home charging availability projection with the increase of PEV stock for the five residential charging scenarios. In general, with the increase of PEV stock in the United States, the percentage of PEV owners with home charging decreases. The differences between the curves show three gaps for PEV home charging availability: an education gap, an investment gap, and a parking behavior gap.

For example, in a scenario where PEVs account for 50% of the LDV stock, 56% of PEVs on the road are projected to have residential charging access, based on the Existing Electrical Access scenario. This estimate increased to 75% of PEVs in the Enhanced Electrical Access scenario, which assumes new residential-level investment in expanding electrical access. When both investment and parking behavior modification are taken into account, the residential charging availability increased to 92%. Scenario 1, Discounted Existing Electrical Access, is likely to be too conservative, especially considering that as the PEV market progresses, awareness about PEV is likely to increase. This graph showcases the opportunity for improving home charging access through education, investment, and behavior modification.

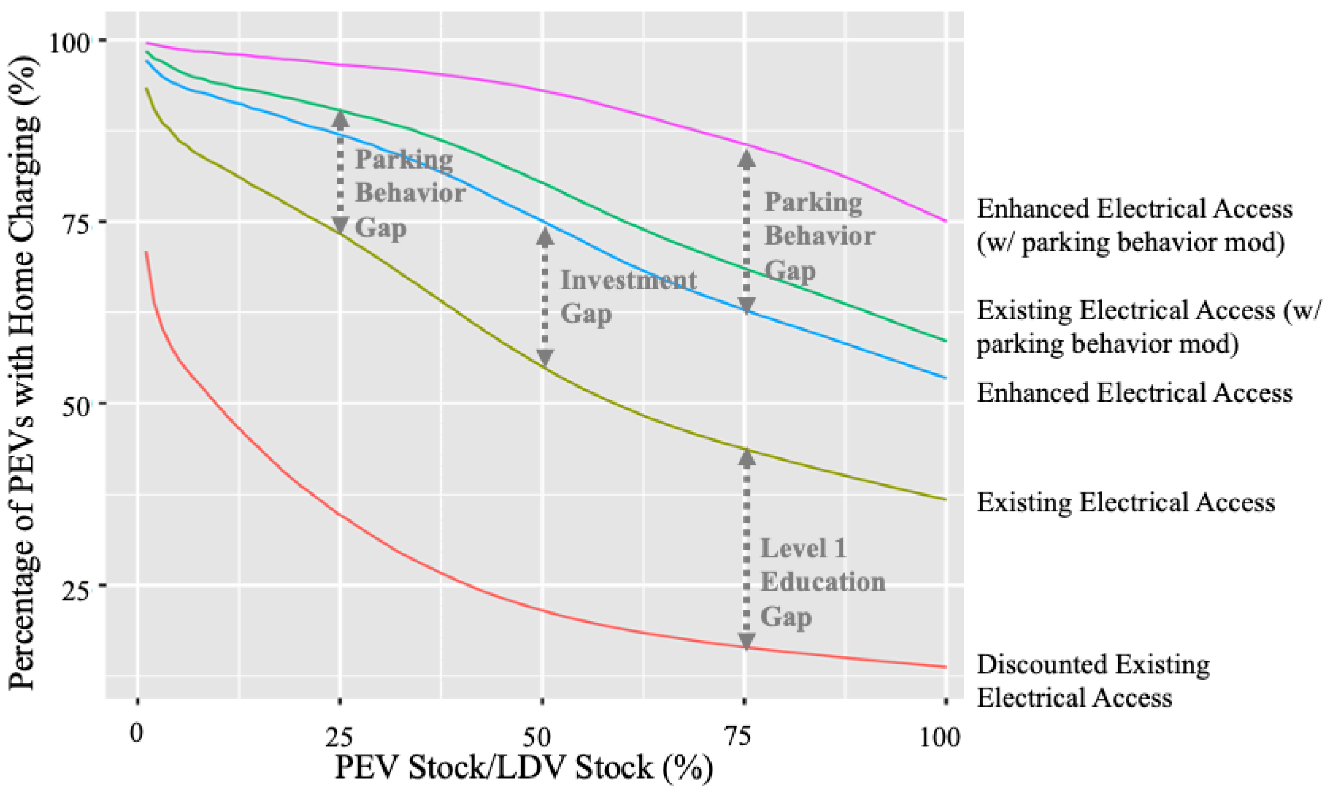

Figure 11. Residential charging accessibility projection with the change of PEV stock share

Looking at the most aggressive scenario (Scenario 5), which has 100% LDV electrification, we estimate that a minimum of 25% of PEVs will not have access to residential charging. This is the most challenging group for which to provide residential access. Among this quarter, approximately 45%

belong to single-family detached homes, and 40% belong to apartments. Although residential access in apartments is more challenging generally, the relative size of the U.S. fleet owned by residents of single-family detached homes is so large that even a small share of PEVs without residential access among this group becomes substantial at the national level. The percentage of LDVs owned by residents of each housing type is listed in the legend of Figure 12. For example, 73.8% of LDVs in 2017 were owned by households in detached SFH. Further, residential access was found to be most challenging among rented households with annual income less than $75,000 (including both single- and multi-family). This raises issues related to equity and charging access, as well as the role of the landlord or property owner in facilitating access.

The two graphs in Figure 12 show the adoption curves of PEVs for households in different housing types. This assumes the distribution of vehicles per household and household type remains consistent in the future. The graph on the left shows how the number of PEVs for each housing type evolves with the increase of PEV stock. The majority of the PEVs are in single-family homes (73.8%). The graph on the right shows the relative adoption speed of each housing type. Single-family homes have the highest adoption speed, followed by mobile homes, and then low-capacity and high-capacity apartments. Mid-capacity apartments have the lowest adoption rate.

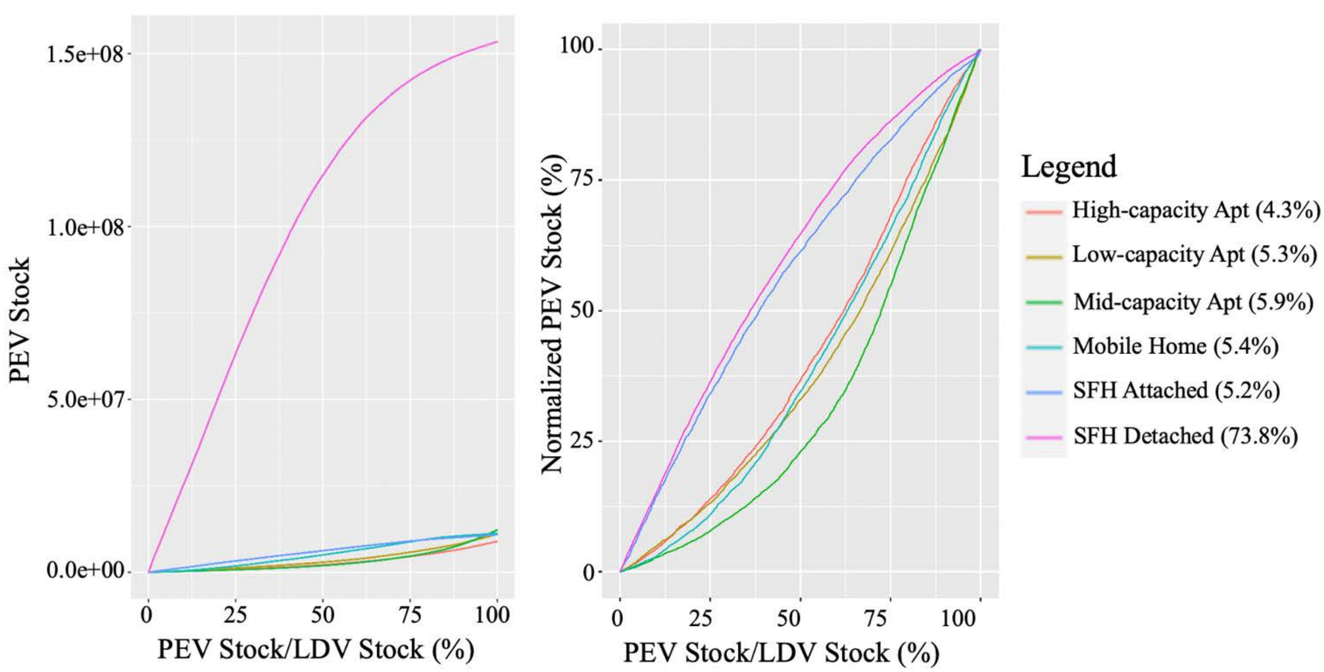

Figure 12. Housing type distribution with the change of PEV stock share

Similarly, Figure 13 shows that PEV adoption speed increases with income. At the early stage of PEV adoption, those in income group 5 ($150k and more) are the majority of PEV owners, but income groups 3 and 4 ($50k–$100k and $100–150k, respectively) subsequently become the majority groups. The majority of LDVs in the United States are owned by medium-level income groups currently.

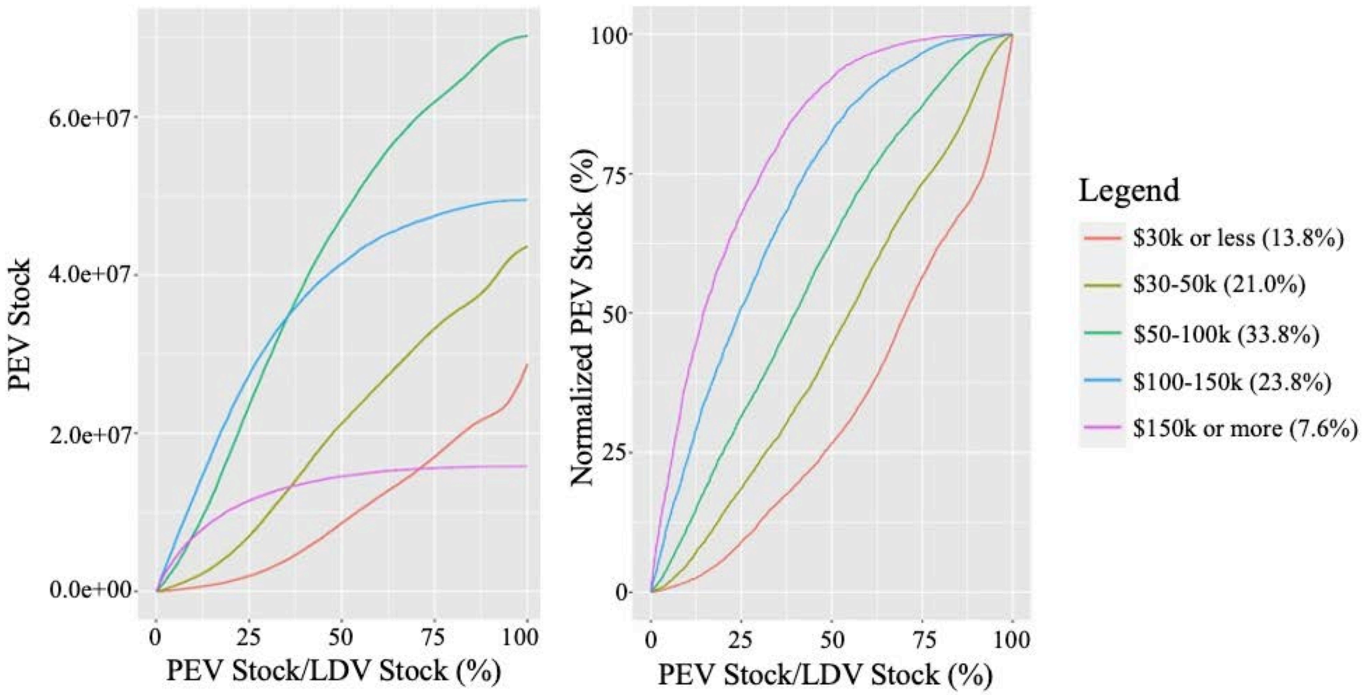

Figure 13. Income distribution with the change of PEV stock share

Figure 14 shows that California has the highest adoption speed early on, but this represents only a small proportion of the LDV fleet (12%). California and other states with ZEV initiatives have a bigger proportion of the national PEV fleet at the initial stage of PEV adoption, but they are soon overtaken by other states without ZEV initiatives, which have the majority of the LDVs (69%).

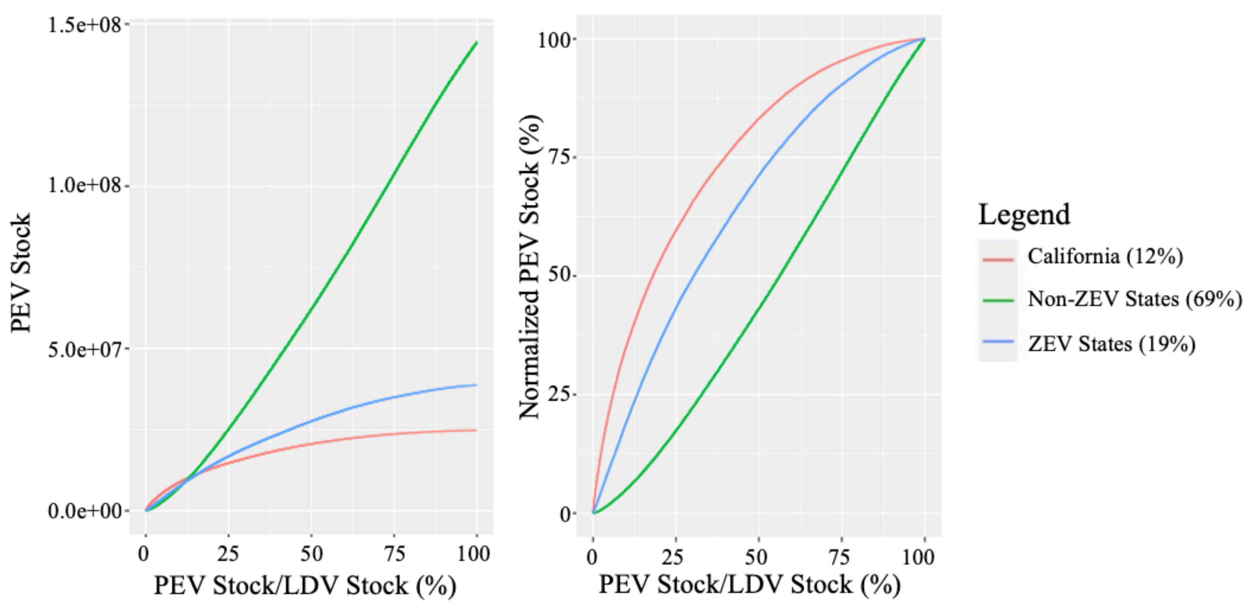

Figure 14. ZEV state distribution with the change of PEV stock share

High-density suburban areas are projected to have the highest adoption speed and a larger proportion of PEV owners until PEV stock is close to half of the LDV stock (Figure 15). Urban areas exhibit fast adoption as well, but only have a small proportion of the LDV fleet (9.6%). Low-density suburban areas have a large proportion of the LDV fleet (30.9%) and will become popular PEV adopters after high-density suburban areas. Rural areas possess the highest proportion of LDVs out of all density classes (36.0%), though adoption speed is the lowest (Figure 15).

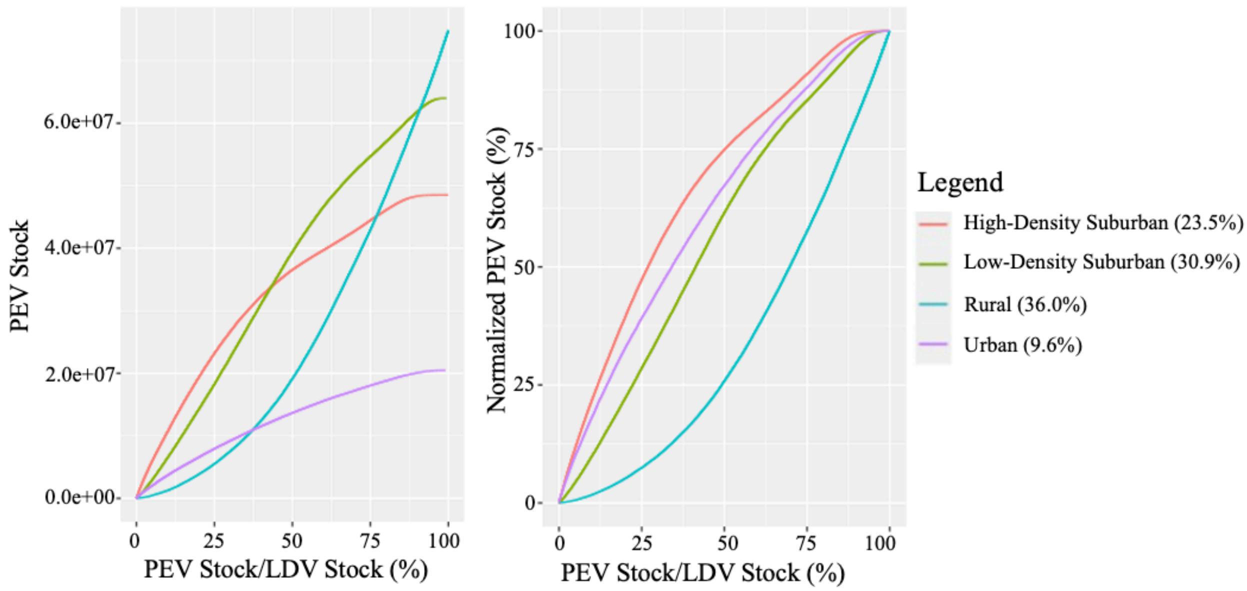

Figure 15. Population density class distribution with the change of PEV stock share

By applying different residential access ratios for the first, second, and third (+) PEVs of a given household according to the values listed for Scenario 2 (Existing Electrical Access) in Appendix A, we estimated the distribution of within-household vehicle order with the evolution of PEV stock share, as shown in Figure 16. The first vehicles of multi-vehicle households are predicted to be replaced by PEVs at the fastest speed, followed by the second and third (+) vehicles of multi-vehicle households. Recall that household vehicle rank is an indicator of charging access potential and not vehicle utilization (the first household vehicle isn't necessarily the one driven most frequently). Vehicles in single-vehicle households will be replaced by PEVs at the slowest rate, which could be due to the combination of the effects of income and housing type, as low-income households living in MFDs are more likely to own one vehicle only (Federal Highway Administration, 2021). Admittedly, the likely adopter model estimated in this study is not able to account for PEV owners' preference that could cause this result to vary. For example, some PEV owners might prefer to have a traditional gasoline vehicle in the household to cover long-distance travel. Therefore, the accuracy of the results on the vehicle ranking is subject to further scrutiny once a more accurate PEV likely adopter model is available.

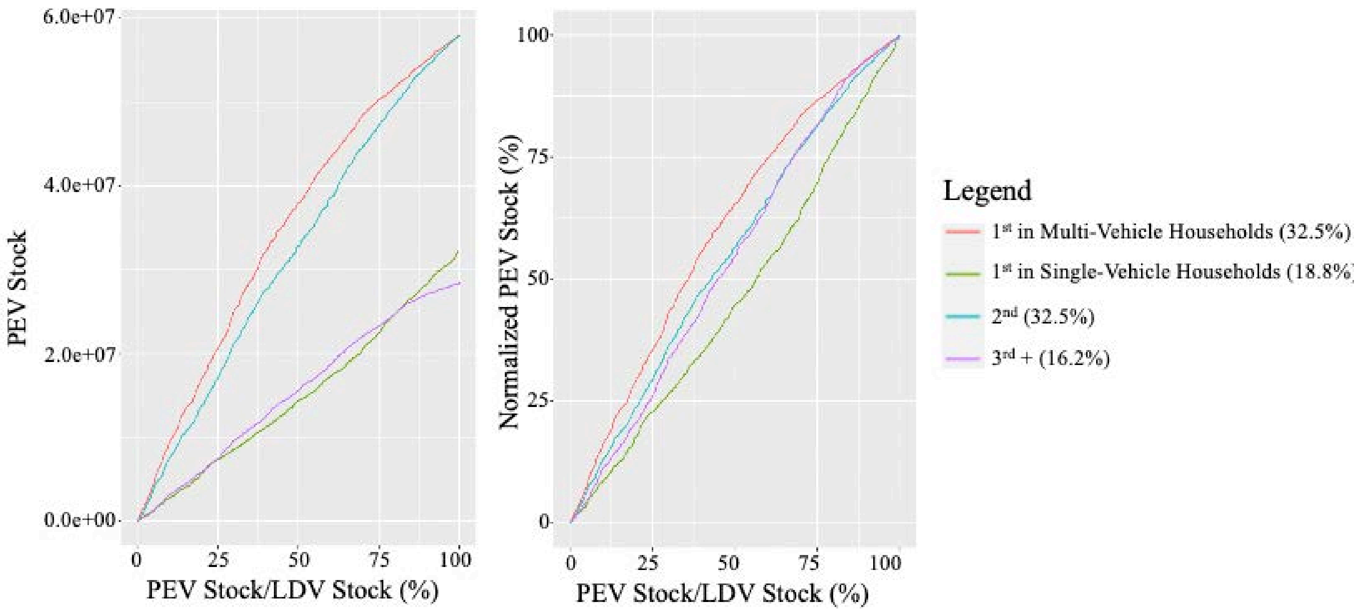

Figure 16. Vehicle Order Distribution with the change of PEV stock share

5 Conclusions and Limitations

Historically, residential charging has been considered the foundation of the PEV charging supply at low levels of PEV adoption. In this analysis, we show that this is an accurate description of the current status; however, vehicle owner access to residential charging is likely to decrease in the future as PEV adoption spreads to different segments of the population (e.g., to vehicle owners living in a wider variety of housing types and geographic locations). According to our analysis, which is based on a novel residential parking and electrical access survey, 33% of the current LDV stock in the United States is parked close to electrical access. Further infrastructure investment and parking behavior modification both show great potential for improving home charging access; both actions combined could increase charging access to 75% of PEVs, assuming a fully electrified LDV fleet. The national residential charging access projection, which is based on a PEV adoption likelihood model using unique survey data, shows that, all things equal, as the level of PEV stock increases, the percentage of PEVs with home charging access decreases dramatically. This finding reinforces the importance of non-home charging options (e.g., workplace, public DC fast charger) as the level of PEV stock increases. In addition, this projection procedure allows us to estimate residential charging availability given a PEV fleet size in one region, which is an essential input of charging infrastructure planning. Not having ample public charging prohibits the broad adoption of PEVs, especially among those living in multi-family dwellings.

There are several limitations to this analysis, and some require future research to improve accuracy. Sampling error associated with a small sample size compared to the reference population is a concern. Because the U.S. population is so large, and the PEV market is still in its infancy, a large sample is necessary to reach enough vehicle (PEV and non-PEV) owners to guarantee an adoption model with results at a high confidence interval. The adoption model suffers from data limitations, such as low goodness of fit and predictive power, due to the omission of psychological variables, which was discussed in detail at the end of Section 4.1. The survey also relied on the respondents' non-technical judgement about the ability to extend electrical access to their home parking option. It is unclear if this subjective assessment over- or underestimates the true potential of enhanced electrical access scenarios.

This analysis assumes *ceteris paribus* conditions. Specifically, we project future results based on historic data. However, due to the early stage of PEV adoption, an adoption model calibrated on the current PEV owners is not ideal for projecting adoption likelihood in the future. For example, PEV prices may decline relative to non-PEV prices, expanding affordability to lower income classes. New PEV model offerings (e.g., pickup trucks) may spark interest in new customer segments, new state level subsidy policies could change the geographic distribution of PEV purchases, and so on. Our model did not consider potential changes in the distributions of the variables, such as income and states with ZEV initiatives, in the future. Similarly, we did not attempt to incorporate changes to future housing stock mix, new construction trends, urbanization trends, or other factors that could impact electrical access and vehicle ownership profiles.

The analysis herein was conducted without a specific time scale in mind. In particular, we did not incorporate a specific timeline associated with achieving different PEV penetration levels. Time-specific factors, such as vehicle replacement, turnover, and scrappage rates, were likewise not incorporated. In addition, we did not address solutions to identified issues. For example, we identified and highlighted the potential of the investment gap and parking behavior gap for residential charging access; however, we did not discuss how to fill the gaps. There is a potential for future research in this area. The national-level results shown here may not be representative of the residential charging accessibility of smaller regions as it does not distinguish location-specific characteristics other than density class. For example, high-capacity apartments in Manhattan may have completely different access ratio than high-capacity apartments in San Francisco. Therefore, region-specific evaluation can be necessary for more localized studies.

Despite these shortcomings, this study leverages recently collected, novel data resources and presents a rigorous methodology for estimating residential charging potential as the share of the LDV stock increasingly electrifies. This analysis presents detailed insights into the future of U.S. residential charging access, significantly contributing to the currently available literature. The framework established in this study can be adapted and improved with higher accuracy PEV adoption modeling and with further increased PEV market penetration.

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Appendix A. Residential Charging Availability Scenarios (the First, Second, and Third + PEVs in the household)

Housing/Tenure	Number of vehicles			Scenario 1: Discounted Existing Electrical Access			Scenario 2: Existing Electrical Access			Scenario 3: Existing Electrical Access (w/ parking behavior mod)			Scenario 4: Enhanced Electrical Access			Scenario 5: Enhanced Electrical Access (w/ parking behavior mod)		
	1st	2nd	3rd+	1st	2nd	3rd+	1st	2nd	3rd+	1st	2nd	3rd+	1st	2nd	3rd+	1st	2nd	3rd+
SFH detached/Own	1363	1096	681	0.21	0.16	0.08	0.58	0.44	0.22	0.71	0.71	0.71	0.76	0.63	0.40	0.88	0.88	0.88
SFH detached/Rent	370	225	106	0.12	0.09	0.04	0.35	0.26	0.10	0.48	0.48	0.48	0.53	0.42	0.18	0.66	0.66	0.66
SFH attached/Own	338	230	106	0.20	0.15	0.07	0.44	0.31	0.15	0.53	0.53	0.53	0.6	0.47	0.28	0.68	0.68	0.68
SFH attached/Rent	220	112	41	0.09	0.05	0.00	0.19	0.14	0.00	0.24	0.24	0.24	0.34	0.29	0.10	0.41	0.41	0.41
High-capacity apt (20+)/Rent	389	150	29	0.06	0.05	0.01	0.15	0.15	0.03	0.17	0.17	0.17	0.25	0.24	0.22	0.26	0.26	0.26
Mid-capacity apt (5–19)/Rent	225	72	12	0.02	0.02	0.01	0.08	0.08	0.06	0.09	0.09	0.09	0.17	0.14	0.11	0.18	0.18	0.18
Low-capacity apt (2–4)/Rent	285	121	35	0.03	0.02	0.02	0.10	0.07	0.06	0.11	0.11	0.11	0.24	0.18	0.09	0.26	0.26	0.26
Other: owned apartments, mobile homes, or households with unknown housing or tenure type	309	191	152	0.10	0.08	0.04	0.29	0.23	0.12	0.38	0.38	0.38	0.46	0.40	0.22	0.55	0.55	0.55