Who can recharge a plug-in electric vehicle at home?

Jonn Axsena,⇑, Kenneth S. Kurani

School of Resource and Environmental Management, Simon Fraser University, 8888 University Drive, Burnaby, BC, Canada V5A 1S6

Institute of Transportation Studies, University of California at Davis, 2028 Academic Surge, One Shields Avenue, Davis, CA 95616, USA

1. Introduction and background

The deployment of passenger plug-in electric vehicles (PEVs) is inherently linked to PEV drivers’ access to electrical infrastructure for recharging. Past PEV use and impact studies make simple assumptions, such as representing all PEV recharging as occurring at home on a nightly basis (National Academy of Sciences, 2010), or estimating charging access based on assumptions about housing stock (Williams and Kurani, 2006). Here we directly elicit recharge access data from households. Two levels of electrical service are assessed: Level 1 (110/120 V) and Level 2 (220/240 V) charging. As battery capacity increases, for example as one goes from plug-in hybrid vehicles to fully electric vehicles, the higher power of Level 2 charging will likely be seen as necessary by potential buyers. To assess residential recharge access, we draw from two recent consumer surveys of new-vehicle buying households.

2. Study 1: Access to Level 1 recharging by US new vehicle buyers

Study 1 is a survey of 2373 new car-buying households completed in December, 2007. Respondents match the population of US new vehicle buyers on geographic, demographic, and attitudinal data.1 In one task, respondents recorded travel data for one of their conventional vehicles for a 24-h period starting with their first vehicle trip of their assigned diary day. Diary days were assigned across the sample to cover all days of the week. Diary information included the timing and distance of each trip, parking locations, and the proximity of those locations to a Level 1 outlet. “Level 1 access” is defined as parking their diary vehicle within 25 ft of a 110/120 V electrical outlet at their home at some point during their diary day. About 52% of the US sample has access to Level 1 recharging at home. This increases to 61% if we allow up to 50 ft distance between the parked car and the nearest adequate outlet, and decreases to 36% if we assume only 10 ft.

Using the 25 ft distance threshold, Fig. 1 depicts differences in Level 1 access by housing type: detached homes, attached homes, apartments and mobile homes. Most respondents lived in detached homes and 59% of these have Level 1 access.
Fewer than half of respondents in all other housing types have access to Level 1: only one-in-six apartment dwellers do so. While residence in a detached home is positively correlated with Level 1 access, it is neither a necessary nor sufficient condition.

The figure also shows that Level 1 access is most likely for respondents who park a vehicle in a garage, whether it is attached to the residence (72%) or detached (62%). Driveway and carport parking locations are less likely to provide access to Level 1 recharging; about 40% in either case. The lowest incidences of recharge access are among respondents parking their vehicle on the street (17%) or in parking lots (5%). As with residence type, parking in home garages increases the likelihood of at-home recharge access, but the condition is neither necessary nor sufficient.

At the scale of large electrical grid interconnections, the data allow us to explore regional differences in home Level 1 access. Such differences may affect regional demand for PEVs and PEV impacts including the grid's adaptability to new
electricity demand. Table 1 reports Level 1 access across five US regions; we condense the US Energy Information Administration’s (2007) 13 grid regions into five: West, Texas, Mid-West, Northeast, and Southeast.

There are statistically significant differences between regions in the distribution of housing type, home parking location, and Level 1 charging access. The Mid-West region has the highest rate of Level 1 access, as well as higher proportions of detached housing and garage use. Level 1 access is 10 percentage points lower in the Northeast region.

3. Study 2: Access to Level 1 and 2 recharge infrastructure in San Diego, California

Study 2 assessed access to both Level 1 and Level 2 recharging among a representative sample of 548 new vehicle buyers in San Diego County, California in 2011. In addition to locations of home vehicle parking and electrical service, the survey also collected data on potential obstacles between the parking location and an existing Level 2 outlet. If a Level 2 outlet was absent entirely, the survey guided respondents through a series of questions that culminated in a cost estimate to install such an outlet. To customize their questionnaires, respondents are first categorized based on three questions. First, do they already have a vehicle charging station available at their home? Second, do they have a reliable home parking space, such as a garage, driveway, carport, or otherwise assigned parking space? Third, if they have a reliable parking spot, do they have the authority to install a Level 2 charger or could they obtain permission from the property owner?

Respondents with a reliable space and authority to install new electrical infrastructure (Type 1) were asked about proximity of existing Level 1 and 2 opportunities, as well as potential to install Level 2. Respondents with a reliable parking space but no authority to install new electrical infrastructure (Type 2) were only asked about existing Level 1 and 2 opportunities. Respondents with no reliable parking space (Type 3) and those with existing vehicle chargers (Type 4) were not sent any further questions.

For Type 1 respondents, we developed a simple cost model for Level 2 installation based on informal conversations with Level 2 installers and data and analysis by the Clean Fuel Connection (Joffe, 2010). Reported installation costs ranged from about $300 to $4000, excluding the cost of the charger itself. Accounting for inflation, the additional cost of the charger, and commercial markup, we assume the installation price for San Diego respondents would range from $2000 to $7000. We base cost estimates on two factors identified by the Clean Fuel Connection:

- Vehicle to electrical supply box distance: higher installation costs are associated with longer distances. We assume a step-function price structure with increases at 25 ft and 50 ft.
- Vehicle to box obstacles: additional costs to surmount any obstacles between the supply box and charger, such as paved ground and multiple walls or floors of the building.

The Clean Fuel Connection study also reports higher installation costs for electricity supply boxes that require upgrade or re-work, as well as inside versus outside box location, and wall mount versus floor mount. Presently, we do not address these additional factors.

![Fig. 2. San Diego new vehicle buyers' residential Levels 1 and 2 access by housing type and parking space.](image-url)
Fig. 2 portrays Levels 1 and 2 access using the 25 foot distance definition used in Study 1. Across the San Diego County sample, 72% report Level 1 access and 35% report Level 2 access. Variations in access by housing type and parking space in San Diego are similar to variations in the nationwide sample. Levels 1 and 2 access are proportionally higher among respondents living in detached homes, and those parking their vehicle in a garage or driveway. However, Level 2 access seems particularly dependent on these factors as it is reported by very few respondents living in apartments and mobile homes or those parking in carports, on the street or in parking lots.

The majority of respondents are classified as Type 1; they have both a reliable parking space and the authority to install a Level 2 charger. Less than one-quarter are Type 2; they have a reliable parking space but not the authority to install new electrical infrastructure. A similar percentage of respondents are classified as Type 3; they have no place to reliably park their vehicle at home and thus no home recharge access. One respondent was classified as Type 4: this person already had a vehicle-specific residential Level 2 charger installed for his or her recently purchased (though not yet delivered) electric-vehicle.

Here we use a second definition for Level 1 and Level 2 access and asked those respondents who identified Level 2 access if they could regularly use it to charge a PEV. According to this definition, 69% have Level 1 access and 28% have Level 2 access; both estimates being slightly lower than the distance based definition. For those with existing Level 2 outlet access, we assume a payment of $1000 is required to buy and install a residential charger approved for vehicle use (with little or no installation required). Forty-five percent of respondents have the potential to install a Level 2 charger; i.e., they do not already have a 220/240 V outlet, they have authority to install, and they can access their electricity supply box. The distribution of installation prices across these respondents is shown in Table 2.

Table 2 also shows the distributions of respondents who want their next new vehicle to be a PEV, and those that would pay for the Level 2 installation. PEVs are desired by 86% of those who already have an existing Level 2 outlet, 76% of those with the potential for Level 2 installation, and 48% of those without Level 2 potential. PEV interest is also related to Level 1 access, where 79% of respondents with Level 1 access would like to buy a PEV, compared to 50% for those without. Twenty percent of the San Diego sample of new car buyers designed their next new vehicle to be a PEV and were willing and able to install a Level 2 charger. Interest in Level 2 installation was generally higher for those facing lower installation costs.

4. Discussion

From Study 1, we estimate that about half the population of new car buying households in the US have the potential to recharge a vehicle at home with at least Level 1 service. This estimate is one-and-a-half to three times larger than previous estimates of home recharging potential for the entire population of American households (Nesbitt et al., 1992). This difference is due to our focus on new vehicle buyers rather than the general population, and the use of information collected directly from the respondents rather than housing stock data. Although access to Level 1 recharging for PEVs is positively correlated with residence in a single-family dwelling and a private garage to park in at home, these conditions are neither necessary nor sufficient to assure Level 1 recharge access. Comparison of Level 1 access between large regions corresponding to the operation of the North American electrical grid shows up to a ten percentage point difference among regions.

While the geographic scope of Study 2 is limited to San Diego County, CA it extends the analysis of household access to PEV recharging by including both Levels 1 and 2. Using the same definition of access to recharging as the national study, access to Level 1 in San Diego appears to be more highly dependent on the household living in an attached or detached home and parking their vehicles in a private garage or driveway. In San Diego County, 28% of respondents faced only the cost of the recharging appliance ($1000) to have access to Level 2; 45% faced additional installation costs ranging from $2000 to $7000—though the vast majority of these face costs of $4000 or less—depending on distance and barriers between the vehicle parking location of the electricity supply box.

<table>
<thead>
<tr>
<th>Price for Level 2 charger</th>
<th>Total</th>
<th>% of sample</th>
<th>% Wanting PEV</th>
<th>% Wanting PEV and wanting to install Level 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Level 2</td>
<td>147</td>
<td>26.8</td>
<td>48.4</td>
<td>0.0</td>
</tr>
<tr>
<td>Existing Level 2</td>
<td>155</td>
<td>28.3</td>
<td>82.5</td>
<td>36.1</td>
</tr>
<tr>
<td>$1000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Install Level 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$2000</td>
<td>78</td>
<td>14.2</td>
<td>77.9</td>
<td>25.6</td>
</tr>
<tr>
<td>$3000</td>
<td>69</td>
<td>12.6</td>
<td>76.2</td>
<td>21.7</td>
</tr>
<tr>
<td>$4000</td>
<td>52</td>
<td>9.5</td>
<td>72.3</td>
<td>21.1</td>
</tr>
<tr>
<td>$5000</td>
<td>33</td>
<td>6.0</td>
<td>69.0</td>
<td>12.1</td>
</tr>
<tr>
<td>$6000</td>
<td>12</td>
<td>2.2</td>
<td>100.0</td>
<td>41.7</td>
</tr>
<tr>
<td>$7000</td>
<td>1</td>
<td>0.2</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Total</td>
<td>547</td>
<td>99.8</td>
<td>70.5</td>
<td>20.3</td>
</tr>
</tbody>
</table>

* We removed the one Type 4 respondent that already has a Level 2 vehicle charger.
5. Conclusions

Consumer-informed estimates of home recharge potential can improve understanding of PEV demand, use, and energy impacts, and prioritizations for developing PEV recharge infrastructure. Information about consumers themselves, e.g., whether or not they buy new cars, can be combined with their observations of their own lives and access to infrastructure generally assumed to be prerequisites to PEV ownership. These observations of their behaviors, e.g., where they park their cars and their actual electrical infrastructure, replace assumptions and proxies. About half of US new vehicle buyers have the Level 1 home access suitable for vehicles with smaller batteries, e.g., plug-in hybrid and neighborhood electric vehicles. About one-third of new vehicle buyers in San Diego County have access to the Level 2 home charging likely required for electric-vehicles with larger batteries and about 20% are willing to pay the costs required to install Level 2 recharging at home.

Acknowledgments

The authors acknowledge funding contributions from the California Energy Commission, and the Social Science and Humanities Research Council of Canada.

References