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Understanding the Impact of Charging Infrastructure on the Consideration to Purchase an Electric Vehicle in California

Kelly Hoogland[1], Kenneth S Kurani, Debapriya Chakraborty, Adam Davis, and Scott Hardman

[1]*University of California at Davis Plug-in Hybrid & Electric Vehicle Research Center 1605 Tilia Street, Davis, CA 95616, United States of America, kmhoogland@ucdavis.edu*

Summary

This research makes explicit and tests an implicit assumption in policies promoting public investment in plug-in electric vehicle (PEV) charging infrastructure: even people who are not already interested in PEVs see public PEV charging. Data from a survey representing all car-owning households in California are combined with per capita counts of public PEV charging locations and PEV registrations to estimate a structural equation model for two central variables: the extent to which participants have already considered acquiring a battery electric vehicle (BEV) or plug-in hybrid electric vehicle (PHEV), and whether and how many places people see PEV charging. The model controls for socio-economic and demographic measures, and participants' awareness, knowledge, and assessments of PEVs. The conclusion is there is no evidence of a relationship between public charging location density and participants reporting they see PEV charging locations. Nor is there a relationship between public charging location density and PEV purchase consideration. The evidence indicates there is little reason to assume building more public PEV charging means more people will see that charging or that more people will consider purchasing a PEV. Rather, awareness, knowledge, and positive assessments of PEVs allow people to see PEV charging in their local environment. In short, interest in PEVs is a prerequisite to people seeing PEV charging.

Keywords: EVSE, consumers, marketing, electric drive, PHEV

1 Introduction

Plug-in electric vehicles (PEVs) are an important technology for reducing energy consumption and emissions from transportation. PEVs are key to meeting greenhouse gas and criteria pollutant emission, human health, eco-system and economic resilience, and renewable energy goals(1). PEVs, which, by definition, can be plugged into the electric grid, include battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs). BEVs must be plugged-in, because they are powered exclusively by electricity from the grid; PHEVs may or may not be plugged-in, as they can be powered either directly by a liquid fuel, usually gasoline, or by electricity from the grid or generated onboard by the gasoline-powered internal combustion engine. In general, we use the collective term PEV but will use BEV and PHEV when the distinction is germane.

Public PEV charging is charging that is open to any PEV driver to use, though some charging stations are not compatible with all PEVs due to the variety of charging connectors and (in)compatibility with different charging powers. Public PEV charging may be located either at "destination" locations—i.e., locations to which people travel to accomplish some activity such as shopping or dining—or along routes to facilitate trips longer than a PEVs range between destinations. Typically, public PEV charging is taken to be charging that is purpose-built for public use and usually provides Level 2 or DC fast charging rather than merely coincidental access to a pre-existing 110V outlet (that might support Level 1 charging).

Billions of public dollars are being invested in PEV charging infrastructure across the US. California has previously spent or committed nearly 1 billion dollars (2,3). Late in 2021, the state committed another $314 million dollars (4) to light-duty PEV charging. The California Public Utilities Commission (CPUC) has authorized electric utilities to spend another $738 million over a 5-year period. Much of the $800 million dollars that Electrify America will spend in California is for PEV charging infrastructure. Large sums are also being spent by other states, e.g., New York State is spending $250 million over 7 years. Electrify America is spending $2 billion nationwide. It is in the public interest that this infrastructure has its intended effect on PEV sales and use. If infrastructure is not having its intended effect, public spending may not be as effective in fostering PEV markets and in creating electric-vehicle miles travelled.

Public PEV charging infrastructure's role is argued to be twofold. First, it may encourage consumers to purchase PEVs (perhaps especially those who haven't already). Second, it may increase the use of PEVs by those who drive them (5). PEV charging infrastructure is frequently cited as a key facilitating condition for PEV market growth—though it is often stated in the opposite sense, i.e., an absence of PEV charging is a primary barrier to market growth (6). Simply, the argument for more PEV charging infrastructure is often stated as, "If you build it, they will charge" (5).

Without necessarily contesting this assertion, this research explores whether building public PEV charging infrastructure is enough or whether other activities such as marketing and promotion of the necessity of a transition to PEVs and PEVs themselves may be required for people who are not PEV owners to be aware of—literally, to see—PEV charging infrastructure around them (7). Whether PEV charging succeeds in encouraging consumer PEV purchase and use depends on consumers, especially those who don't already own PEVs, perceiving (again, *seeing*) charging infrastructure in their environment. It is not enough that charging exists; people must (at least) perceive its existence and form either or both an expectation that PEV chargers are discoverable and a "mental map" (8) of charging opportunities. In this study we test these hypotheses:

1. whether there is a relationship between how much public PEV infrastructure is present and whether people see it, and
2. whether differences in the amount of public PEV infrastructure or whether people see it are associated with those same people's consideration of acquiring a PEV.

We use data from car-owning households (all cars, not just PEVs) from a survey completed in 2021 by nearly 3,000 respondents across California. These data are supplemented by data on the contemporaneous (with the household survey) counts of charging locations and PEV registrations in survey participants' home zip codes. The analysis also controls for density of PEVs in the participants' home zip codes as there is geographic correlation between where there are PEVs and where there is PEV charging infrastructure. Further, the analysis describes who does and does not see PEV charging.

2 Literature Review

Three areas of literature are reviewed:

1. Studies that explore the role of charging infrastructure on PEV sales.
2. Studies that characterize consumer PEV purchase intention based on perception, awareness, and density of charging infrastructure.
3. Studies that characterize consumer awareness, knowledge, and attitudes toward PEVs.

We start by comparing studies that reach different conclusions about the role of public charging infrastructure in PEV sales and use. Cass and Grundoff (5) conclude the diffusion of a visible network of charging infrastructure is necessary for non-adopters to overcome range anxiety. Greene et al. (6) similarly report public charging infrastructure provides benefits to both current and prospective PEV adopters. Ou et al. (9) simulate the impact of public charging infrastructure on PEV sales in China and conclude the impact of public charging on PEV sales varies depending on the battery technology. Narassimhan et al. (10) performed regression analysis on U.S. PEV purchase data from 2008 to 2016, reporting PEV charging infrastructure significantly influenced per capita PEV purchases. Additionally, Sierzchula et al. (11) performed regression analysis of PEV sales data from 30 different countries; the availability of chargers was the best predictor of PEV sales. Mersky et al. (12) also conclude charger availability to be the best predictor of PEV sales in Norway.

In contrast, other studies have found a weak or non-existent relationship between public charging and PEV sales. Nazari et al. (13) report the number of public PEV charging stations was only statistically significant for households choosing PHEVs, but not BEVs. Miele et al (14) used survey data from Canadian new car buyers to simulate the sales impact of increasing charging infrastructure, incorporating both consumer awareness and supply constraints. They report new PEV market share from 2020 to 2030 may not substantially benefit from increased infrastructure. Gnann et al. (15) utilized an agent-based market diffusion model for PEVs and their charging infrastructure in Germany. They concluded that public PEV charging infrastructure is not necessary for PEV market penetration, since many households have accessibility to at-home charging. Lin et al. (16) suggest that widespread access to at-home charging has a greater impact on PEV sales than does access to public and workplace charging. Plotz et al. (17) et al. found that compared with public DC fast charging, public Level 1 and 2 charging stations would need to be subsidized for a long time and do not facilitate PEV sales. They do however suggest public charging may be important for people without access to charging at home. In a literature review of consumer preferences for charging infrastructure, Hardman et al (18) found the most important charging location to convince people to purchase a PEV was at home, followed by workplace, and finally public locations.

While there are differing results in the literature regarding the impact of public charging infrastructure on PEV sales, most of these studies base their conclusions on correlation between PEV charging and PEV sales rather than causation. Chakraborty et al. (19) cautioned against the assumption of causality between PEV charging infrastructure and sales. In a study of factors influencing PEV adoption in California, they found that while there was a positive association between Level 2 public charging and BEV sales, no causal claims could be drawn from the results. It is possible that external factors are what drive both the growth of BEV sales and Level 2 public charging; it may also be the case that causality occurs in the opposite direction, that is, BEV sales lead to more investments in public charging infrastructure.

There are also studies that have examined the impact of charging infrastructure awareness, perception, and density on PEV consideration. These, too, reach contradictory results. Li et al. (20) conclude that situational factors such as insufficient charging infrastructure are major barriers to increasing consumer PEV purchase intention. Similarly, Tiwari et al. (21) report that negative perception of charging infrastructure reliability negatively influences PEV purchase intent. Huang et al (22) conclude higher satisfaction with the amount of charging infrastructure and charging time to be positively associated with purchase intention. In contrast, Hardman et al. (23) found in Sacramento, California in 2018 that awareness of charging infrastructure had a negative impact on consideration, while the density of PEV chargers was not associated with consideration.

Bailey et al. (24) used a sample of Canadian new car buyers to explore whether charger awareness was associated with PEV purchase interest. Their results indicated that when controlling for the availability of Level 1 charging at home, the relationship between public charging awareness and PEV purchase interest was weak or non-existent.

Prior literature has also characterized consumer exposure to and attitudes toward PEV technology and their role in fostering consideration. Kurani et al. (25) found that in California, the state with the highest proportion of PEV sales in the U.S., awareness, knowledge, and experience is low, and consequently, new car buyers' valuations of PEVs remains largely unformed. Additionally, studies such as Kurani et al. (26) and Long et al. (27) have found that these metrics have not been increasing over time from 2013 to 2017. Regarding PEV consideration, Bunce et al. (28), Krause et al. (29), and Franke and Krems (30) find increased PEV familiarity and experience are associated with greater acceptance of PEV technology. In a report detailing American sentiments toward issues surrounding PEVs, Singer (31) concluded through descriptive statistics of survey data that consumers will only purchase PEVs after they are aware of the technology and willing to consider purchasing a PEV. Both Burgess et al. (32) and Kurani et al. (4) found that positive interaction between PEV owners and non-PEV owners led to non-owners having higher valuations of PEVs; PEV owners may therefore be able to act as agents of social influence.

3 Methods

This section describes the data, approach, and analytical tools used to address the hypotheses about the relationship between whether participants living in places with more PEV charging locations report seeing more of these locations than those living in places with fewer charging locations and whether this has a relationship with BEV and PHEV purchase consideration. Structural equations modeling (SEM) is used to test the central hypotheses and several ancillary hypotheses controlling for differences in PEV sales and charging infrastructure that are exogenous to the participants and their households, participants' PEV awareness, knowledge, and assessments, as well as characteristics of participants and their households.

3.1 Data

To build the SEM, data are combined from three sources:

1. A survey of car owning households in California conducted in the first quarter of 2021,
2. Contemporaneous counts of PEV charging locations by zip code, and
3. Contemporaneous counts of PEV sales by zip code.

3.1.1 Household Survey Data

This report draws on data from a large sample survey conducted in California during the first quarter of 2021. It measures consumer awareness, knowledge, assessments, and consideration of PEVs (as well as fuel cell electric vehicles [FCEVs], though they are not included here). The study population was all car-owning households in California. Please refer to the Appendix for descriptive statistics of the survey participants compared to the California average.

The sample was recruited by a professional survey firm. Participants were recruited from panels of people maintained by a variety of commercial firms for the express purpose of participating in research. Because all recruiting is done by the vendor and because these firms typically maintain cooperative relationships with each other allowing them to recruit from each other's panels, the number of initial invitations to the pre-screening questionnaire for this study is unknown. Thus, a traditional response rate cannot be calculated. What is known is the number of people who screened into this study's questionnaire and how many completed it. The completion rate was in the low-70 precents.

3.1.2 PEV Charger Location and Vehicle Registration Data

Counts of PEV charging locations by zip code were produced by combining publicly available charger location information from the US Department of Energy Alternative Fuels Data Center with data from Recaro Plugshare. Charger location data from the two sources were merged using a method described by Xu et al (2021) (33). Counts of PEVs in each zip code were created from a record of privately owned light duty vehicles in California from the California Department of Motor Vehicles. Vehicle Identification Numbers (VIN) in this dataset were processed through a decoder to identify each vehicle's fuel type and power sources.

3.1.3 Model Specification: Variables in the Analysis

The variables central to the main hypothesis of this study are *do people see PEV charging infrastructure* and *to what extent they have already considered acquiring a PEV*. Additional variables provide means to understand who sees PEV charging and who has considered a BEV or PHEV. These include measures of awareness, knowledge, and assessment of PEVs (latent variables) as well as contextual and descriptive variables. Contextual variables account for participants' existing automobile ownership, daily travel, and capability to charge a PEV at home. Descriptive variables include participant and household level socio-economic and demographic measures. Finally, two PEV infrastructure and market related factors, per capita counts of public Level 2 and DC fast charging locations as well as BEV and PHEV registrations within participants' home zip codes are treated as exogenous variables. These variables are informed by prior literature which find these factors to be associated with PEV adoption. All variables used in the analysis are listed and briefly described in **Error! Reference source not found.** and Table 1**Error! Reference source not found.**.

3.2 Model

A SEM is estimated to understand the effects of PEV charging infrastructure and PEV registrations per capita at the zip code level on whether people see PEV charging infrastructure as well as on BEV and PHEV consideration. SEM includes a measurement model and a structural model. The measurement model generates factor scores for the latent constructs. The structural model quantifies the relationships between latent constructs, the other explanatory variables (contextual, descriptive, awareness, knowledge, and assessment.), and the two variables central to the main hypothesis of this study: *do people see PEV charging infrastructure* and *to what extent have they already considered acquiring a PEV*.

3.2.1 Measurement Model

Confirmatory factor analysis (CFA) is employed for the BEV and PHEV assessment factors described in the section "**Error! Reference source not found.**." The CFA is validated using the following measures: construct reliability, convergent validity, and discriminant validity. Construct reliability (CR) should be higher than 0.70 ($CR \geq 0.70$) and average variance explained (AVE) for each latent construct should be greater than or equal to 0.50 ($AVE \geq 0.50$) to achieve convergent validity; lastly the squared inter-correlation between constructs should be lower than average variance explained to satisfy the discriminant validity. Please refer to the Appendix for the PEV assessment factor loadings and fit indices.

Structural Model

BEV and PHEV consideration are considered into two structural models The BEV and PHEV models are structured identically to have an equal comparison of coefficient values and significance levels. The following model fit indices were used to test goodness of fit: root mean squared error of approximation ($RMSEA < 0.08$), squared root mean residual ($SRMR < 0.07$)

Table 1: Variables included in the structural equation model

Variable Group	Measurement Level	Variable Name	Variable Type	Variable Description
Primary Hypothesis Testing	Participant	Seeing charging locations	Ordinal Categorical	Of the parking facilities the participant uses, in how many have they seen PEV charging
		BEV (PHEV) Consideration	Ordinal Categorical	Extent to which participant has already considered acquiring a BEV (PHEV)
PEV Awareness (explanatory variables)	Participant	Number of Incentives	Continuous	Count of sources of PEV Purchase and Use Incentives of which participant is aware
		Advertising Awareness	Continuous	Number of types of media in which participant has seen PEV advertising
PEV knowledge (explanatory variables)	Participant	Fueling a BEV (PHEV)	Dummy	Whether participant knows how a BEV (PHEV) is refueled
		Name a BEV (PHEV)	Dummy	Whether participant can correctly name (make/model) a BEV (PHEV) for sale in the US
		BEV (PHEV) Familiarity	Continuous	Self-rating of familiarity with BEVs (PHEVs)
		BEV (PHEV) Experience	Continuous	Self-rating of driving experience in BEVs (PHEVs)
		PEVInfo Search	Dummy	Whether participant has searched for information on BEVs or PHEVs
		BEV (PHEV) Positive Convo	Dummy	Whether participant has had a positive conversation with a PEV owner about their BEV (PHEV
Contextual and Descriptive (explanatory variables)	Participant	Sex	Dummy	Male = 1; Female = 0
		Age	Continuous	Mid-point of participant's age category
		HOV lane use	Dummy	Whether participant uses HOV lanes
	Household	Number of vehicles	Continuous	Number of household vehicles
		Income	Continuous	Household income
		Electricity access at residential parking spot	Dummy	Whether participant has access to electrical power service at home parking location
PEV infrastructure and market variables (exogenous variables)	Residential Zip Code	Charging locations per capita	Continuous	Number of Level 2 and DC fast charger locations in participant's home zip code
		PEV registrations per capita	Continuous	Number of PEV registrations in participant's home zip code

Table 1. PEV Assessment Factors in the Analysis (Latent variable)

Factor Name	Description	Survey Question	Survey Question Variable Name
BEV (PHEV) Charging Access	Extent to which participants believe they could charge a BEV (PHEV) at home and whether there is enough charging for BEVs (PHEVs)	"My household would be able to plug in a battery electric vehicle to charge at home." "There are enough places to charge battery electric vehicles. "	BEV (PHEV) Plug in at home BEV (PHEV) Enough charging
BEV (PHEV) Safety and Reliability	Safety and reliability of BEVs (PHEVs) compared to conventional gasoline vehicles	"Gasoline powered cars are safer than battery electric vehicles. "Gasoline powered cars are more reliable than battery electric vehicles.	(inverse) BEV (PHEV) gasoline safer (inverse) BEV (PHEV) gasoline more reliable
BEV (PHEV) Marketability	Environmental effects of BEVs (PHEVs) compared to conventional gasoline vehicles and whether BEVs (PHEVs) are ready to be mass marketed.	"Battery electric vehicles are less damaging to the environment than gasoline powered vehicles. "Battery electric vehicle technology is ready for mass automotive markets."	BEV (PHEV) Less damage to environment BEV (PHEV) Mass market
BEV (PHEV) Charging Duration and Range	Perception of charge time and electric range	"It takes too long to charge battery electric vehicles." "Battery electric vehicles do not travel far enough before needing to be charged."	(inverse) BEV (PHEV) range too short (inverse) BEV (PHEV) charging too long
BEV (PHEV) Price	BEV (PHEV) purchase price compared to conventional gasoline vehicles	"Battery electric vehicles cost more to buy than gasoline vehicles."	(inverse) BEV (PHEV) Price

Figure 1 shows the conceptual framework. The two central variables, PEV consideration and seeing charging locations, both control for the following: charging locations per capita (paths 1 & 2), and PEV registrations per capita (paths 3 & 4), demographic factors (paths 8 & 11), PEV knowledge and awareness measures (paths 6 and 9), and assessment factors (paths 7 & 10). Including a relationship between advertising awareness and BEV (PHEV) consideration resulted in multicollinearity and therefore was removed. The covariance defined in the model is denoted as curved double-headed arrows indicating that while the two things are allowed to covary no causal relationship is stipulated: BEV (PHEV) consideration and seeing charging locations (path 5).

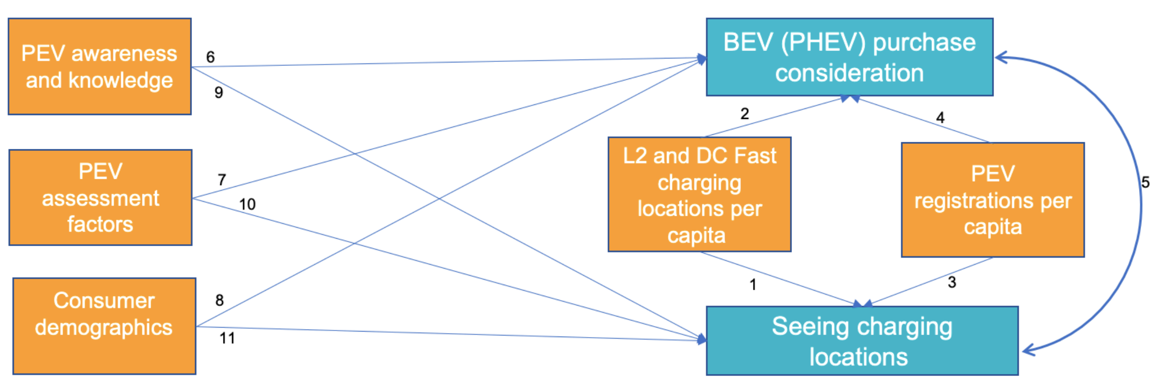

Figure 1: Model theoretical framework

4 Results

Table 3 presents the odds ratios, their standard errors, and their p-values for all estimated relationships for BEV (PHEV) consideration and seeing charging locations. These are interpreted as the increase in the odds of being in a higher rather than lower category of consideration or seeing charging locations rather than not seeing them for a unit increase in one variable while holding all other variables constant. Table 4 presents the covariance between BEV (PHEV) purchase consideration and seeing charging locations, which is interpreted as the increase in the odds of one variable increasing for a unit increase in the other variable while holding all other variables constant. Table 5 presents the goodness-of fit model indices for the two models; all indices exceed their recommended threshold.

4.1 Impact of charging location density

The estimated effect of charging location density (Fig. 1, Path 1) measured per capita at zip code level on whether participants report seeing PEV charging is not statistically different from zero. Additionally, neither the BEV nor the PHEV model identified a significant relationship between charging location density and BEV or PHEV purchase consideration (Path 2). However, the estimated effect for PEV registrations per capita produces higher odds of seeing more charging locations in both models (Path 3).

4.2 PEV purchase consideration

The model results also show that the effect charging location density has on BEV or PHEV purchase consideration is not statistically different from zero (Fig. 1, Path 5). Rather, participants' prior engagement with PEVs is associated with higher odds of both BEV and PHEV purchase consideration (Path 6). Engagement includes PEV knowledge (naming a BEV (PHEV), and PEV awareness (prior PEV information search and having a positive conversation with a BEV (PHEV) owner). In the BEV model, prior PEV information search produces the highest odds ratio of all variables for purchase consideration. Conversely, in the PHEV model, having a positive conversation with a PHEVs owner produces the highest odds ratio for consideration. The effect of the number of incentive sources participants are aware of is not statistically different from zero for either BEV or PHEV consideration.

Engagement measures also include the latent PEV assessments: charging duration and range, marketability, safety and reliability, and charging access. All four produce significant effects; more positive assessments of BEVs and PHEVs increase the odds of higher BEV and PHEV consideration (Path 7). In regard to demographics (Path 8), household income does not produce a result statistically different from zero for either BEV or PHEV purchase consideration. Having HOV lane access, electricity access at a residential parking spot, and being younger do increase the odds ratio of higher levels of BEV and PHEV purchase consideration. The effect size of commute HOV lane access is twice as large for BEV consideration as for PHEV consideration.

4.3 Seeing Charging locations

BEV (PHEV) knowledge and advertising awareness increase the odds of seeing more charging locations in both the BEV and PHEV model (Path 9). The assessment factor for charging access also produces a positive and significant odds ratio for seeing charging locations in both models, while charging duration and range produces a positive and significant odds ratio for seeing charging locations only in the BEV model (Path 10). In regard to demographics (Path 11), the estimated effect of income on seeing charging locations is positive and statistically significant in both models. Having HOV lane access, electricity access at residential parking spot at home, more household vehicles, and being female also increase the odds ratio of seeing more charging locations in both models.

Table 3: Structural equation modelling results for BEV (PHEV) purchase consideration and seeing charging locations

	BEV purchase consideration				PHEV purchase consideration				Seeing charging locations- BEV				Seeing charging locations- PHEV			
	Odds Ratio		Std. error	P-value	Odds Ratio		Std. error	P-value	Odds Ratio		Std. error	P-value	Odds Ratio		Std. error	P-value
Advertising awareness									1.111	***	0.013	0.000	1.118	***	0.013	0.000
Fuelling a BEV (PHEV)	1.050		0.050	.327	1.225	***	0.037	0.000	1.187	***	0.048	0.000	1.131	**	0.044	0.001
Name a BEV (PHEV)	1.25	**	0.055	0.001	1.165	***	0.038	0.000	1.273	***	0.048	0.000	1.030	**	0.048	0.005
Number of incentives	1.017		0.010	0.921	1.006		0.010	0.567	1.026		0.014	0.065	1.040	**	0.013	0.004
BEV (PHEV) familiarity	1.049	***	0.012	0.000	1.053	***	0.008	0.000	1.015		0.011	0.166	1.034	**	0.010	0.009
BEV (PHEV) experience	1.090	***	0.009	0.000	1.071	***	0.010	0.000	0.997		0.015	0.858	0.975	*	0.015	0.011
EV information search	1.675	***	0.040	0.000	1.475	***	0.042	0.000	1.075		0.058	0.218	1.142	*	0.058	0.023
BEV (PHEV) positive convo	1.335	**	0.061	0.001	1.608	***	0.067	0.000	1.332	*	0.083	0.021	1.067		0.086	0.449
BEV (PHEV) charging access	1.177	***	0.021	0.000	1.084	**	0.025	0.006	1.193	***	0.028	0.000	1.211	***	0.032	0.000
BEV (PHEV) safety/reliability	1.173	***	0.018	0.000	1.065	**	0.021	0.004	0.983		0.026	0.508	1.023		0.027	0.401
BEV (PHEV) marketability	1.110	***	0.027	0.000	1.191	***	0.037	0.000	1.020		0.038	0.603	0.975		0.046	0.586
BEV (PHEV) charging duration and range	1.112	**	0.019	0.002	1.109	***	0.022	0.000	1.085	*	0.027	0.043	1.069	*	0.030	0.039
BEV (PHEV) price	0.993		0.011	0.376	0.976		0.012	0.047	0.990		0.013	0.456	0.993		0.015	0.621
Sex- Male	1.02		0.036	0.952	0.990		0.036	0.789	0.801	***	0.045	0.000	0.843	***	0.044	0.000
Age	0.952	***	0.013	0.000	0.938	***	0.014	0.000	1.039	*	0.017	0.011	1.027		0.017	0.114
Income	1.002		0.024	0.581	1.008		0.025	0.753	1.01	***	0.029	0.000	1.144	***	0.029	0.000

	BEV Purchase Consideration				PHEV purchase consideration				Seeing Charging Locations- BEV				Seeing Charging Locations- PHEV			
	Odds Ratio		Std. error	P-value	Odds Ratio		Std. error	P-value	Odds Ratio		Std. error	P-value	Odds Ratio		Std. error	P-value
HOV lane access	1.333	***	0.041	0.000	1.127	**	0.042	0.005	1.205	**	0.057	0.001	1.276	***	0.058	0.000
Number of household vehicles																
Two	1.094	**	0.049	0.006	1.107		0.047	0.031	1.119	*	0.050	0.025	1.087		0.050	0.100
Three	1.077		0.091	0.417	0.967		0.087	0.710	1.243	*	0.087	0.013	1.221	*	0.087	0.027
Four or more	0.843		0.115	0.137	0.913		0.112	0.423	1.515	**	0.136	0.002	1.419	**	0.134	0.009
Electricity access at residential parking spot	1.090	*	0.044	0.049	1.170	*	0.044	0.010	1.125	*	0.048	0.015	1.123	*	0.049	0.018
Charging locations per capita	1.029		0.016	0.064	1.013		0.011	0.267	1.004		0.033	0.892	1.004		0.033	0.892
PEV registrations per capita	0.974		0.162	0.872	1.023		0.015	0.131	1.083	***	0.017	0.000	1.892	***	0.017	0.000

Statistical significance of P-values: 0 '***' 0.001 '**' 0.01 '*'

Table 4: Covariance results

	Covariances: BEV model			Covariances: PHEV model		
	Odds Ratio	Std. error	P-value	Odds Ratio	Std. error	P-value
BEV (PHEV) Consideration ~~ Seeing charging locations	1.008	0.016	0.371	0.987	0.017	0.416

Table 5: Structural equation model fit indices

Model specification	Model summary	RMSEA	RMSR
BEV model	Test-statistic = 7.300 df = 1 N = 2,553	0.050	0.000
PHEV model	Test-statistic = 1.107 df = 1 N = 2,530	0.003	0.000

5 Discussion

5.1 Impact of charging infrastructure on PEV adoption

Prior research has indicated there is a relationship between PEV sales and PEV charging infrastructure (2,3,10). Based on this, some stakeholders posit that the benefits of a growing PEV charging network, and public charging in particular, are two-fold: it overcomes an impediment to PEV market growth by reducing consumers' fears about the lack of charging infrastructure, and increases the proportion of electric miles that are driven for PEV owners (2, 33). Early investment in charging infrastructure has been recommended as a solution to "range anxiety" and to achieve a multiplier effect on PEV sales (10). Both these lines of argument assume people see PEV charging locations when and where they are installed, and that this leads to buyers considering and ultimately buying a PEV.

This research indicates this assumption is not true. We find there is no relationship between public charging location density and participants reporting they see PEV charging locations. Nor is there a relationship between public charging location density and PEV purchase consideration. Further, we find the relationship between seeing charging locations and PEV purchase consideration is also not statistically different from zero.

Taken together, these show there is little reason to assume that building more public PEV charging locations means more people will see that charging or that more people will consider purchasing a PEV. These results extend those of Bailey at al. and Krause et al. (24,29) which also found a weak relationship between public charger awareness and PEV interest. We do find that consumers living in regions with more PEV registrations per capita are more likely to see charging locations in the parking lots and facilities they use.This could be the result of a social network effects (e.g., coworkers, friends, acquaintances etc. owning PEVs), or perhaps reflect more PEV drivers living in these areas and having more utilization and awareness of their surrounding charging network.

5.2 PEV purchase consideration

Our findings indicate positive assessments of BEV and PHEV charging accessibility—both at and away from home, rather than the density of charging locations, leads to higher levels of PEV purchase consideration. This further suggests perceptions of PEV charging access may be formed independent of actual PEV charging density. We also find that higher awareness, better knowledge, and more positive assessments increase the odds of higher PEV purchase consideration. The exception is awareness of sources of incentives which has no effect on either BEV or PHEV consideration. Krause et al. (29) similarly found the availability of incentives did not impact interest in PEVs but argue that more accurate knowledge of PEV incentives would likely lead to an increase in consumer interest.

We find demographic and contextual factors such as being younger, having electricity access at the residential parking spot, and using HOV lanes to be positively associated with PEV purchase consideration. Prior studies have shown that access to charging from home is the most influential charging location in the decision to purchase a PEV, and home is the most frequently used charging location (18). Canepa et al. (35) found that for residents of multi-unit dwellings, a key barrier to PEV adoption is a lack of access to public or private charging. For the PEV market shares to increase from predominantly owners of single-family homes, to include more renters living in apartments, more efforts may be needed to increase charging access for consumers without electricity access at their residential parking spot. Our finding on age aligns with some stated preference studies (36, 37), but is in contrast with most studies on actual EV buyers (38). Lastly, our finding on HOV lane use aligns with studies that find access to HOV lanes has a strong positive association with PEV sales (39).

5.3 Seeing Charging Locations

The factors associated with more people seeing more public PEV charging locations include their prior engagement with PEVs. This "engagement" includes being able to correctly name a PEV make for sale, knowing how PEVs are refuelled, seeing PEV advertising across multiple media, and having a positive assessment of charging accessibility. In other words, the people who report they see public PEV charging locations are the people who are interested in seeing them, and who already have a positive assessment of charging accessibility. People who see PEV charging locations report seeing them across the range of actual PEV charging densities observed in 2021 at the time that survey data was collected from households.

Our findings indicate that interest and engagement with PEVs leads to PEV purchase consideration and seeing signs of PEVs (such as charging), not the other way around: the mere presence of the signs does not appear to prompt purchase consideration. Increasing awareness, cultivating knowledge, enhancing experience, and improving assessments of PEVs may be at least useful if not necessary prerequisites for leveraging ongoing PEV charging infrastructure investments. In short, investing in both engagement and increasing awareness of PEV charging infrastructure alongside developing charging infrastructure may be a more effective way to grow the PEV market. In particular, engagement methods that focus on increasing interest to look for PEV charging locations may be an effective strategy to improving consumers' assessment of charging accessibility, and therefore achieving the desired multiplier effect on PEV sales.

6 Conclusion

In this study, we find households living in areas with more public PEV charging locations per capita are not more likely to report they see PEV charging locations than those living in regions with fewer such locations per capita. Further, whether people report seeing PEV charging is not associated with the consideration they have given to acquiring either a BEV or a PHEV. The implication of this result is that building PEV charging alone may not lead to more people seeing PEV charging, and even if people see charging this alone may not lead to increased purchase consideration of a PHEV or BEV.

Investments in PEV charging alone are unlikely to lead to increased PEV sales. The factors which are positively associated with whether people report seeing public PEV charging and higher levels of consideration are measures of peoples' prior engagement with PEVs: are they aware of incentives and advertising, do they have knowledge of available PEVs and how they are fuelled, and what are their assessments of PEV charging availability. In short, the people who see public PEV charging are those who are engaged enough with PEVs to see public charging—independent of how much charging there is in their local environment. Since prior research showed these measures of PEV awareness, knowledge, and assessment have not been improving over time (26,27) more efforts may be needed to engage car buyers in the transition to PEVs, and based on the results of this study, deploying EV charging is not a strategy to do this.

While public charging access does not appear to influence PEV consideration, the same is not true for home charging. We find access to charging at home is significantly correlated with considering purchasing a PHEV or BEV. People living in multi-unit dwellings may have a higher demand for public PEV charging, therefore, developing an interest to see public PEV charging may be even more important for them. This research emphasizes the need to prioritize targeting consumer engagement with PEVs to help meet PEV milestone goals.

The results gained from this analysis provide new insights into how consumers perceive PEV charging, and the factors which influence PEV consideration and PEV charging awareness and may caution against developing PEV charging infrastructure as an engagement approach. Further research should explore the effectiveness of broad engagement strategies on encouraging PEV adoption, such as marketing, social marketing, and social movements.

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Appendix

Table 6: Socio-demographic Profile of Survey Participants Compared with Respondents to the California Subset of the 2019 American Community Survey (ACS)

Demographic	Category	Survey participants, percent	2019 ACS, percent
Sex	Male	47.7	49.7
Age (closest ASC age category in parentheses)	19 to 29 (20 to 34)	16.2	22.1
	30 to 39 (35 to 44)	22.7	13.4
	40 to 49 (45 to 54)	17.4	12.6
	50 to 59 (55 to 64)	15.5	12.1
	60 to 69 (65 to 74)	16.2	8.6
	70 or older (75 or older)	12.1	6.2
Household income	Less than $50,000	24.9	34.4
	$50,000 to $99,999	34.2	27.9
	$100,000 to $149,999	19.8	16.6
	$150,000 or more	21.0	21.1
Education level	Did not graduate high school	2.0	16.7
	High school graduate	12.3	20.5
	Some college	26.4	21.1
	College graduate	32.1	21.2
Education level	Masters, Doctoral or Professional degree	21.2	12.8
Number of household vehicles	1	48.4	32.8
	2	39.1	40.0
	3+	12.5	27.2

Demographic	Category	Survey participants, percent	2019 ACS, percent
Home type	Detached house	62.2	57.7
	Apartment	13.4	23.5
	Attached house	12.7	7.0
	du-,tri-,or four-plex	5.7	7.9
	Other	6.0	3.9
Home ownership	Own	62.4	54.8
	Other	37.6	45.2

Table 7: BEV Assessment Confirmatory Factor Analysis Results

Latent Construct	Indicator	Factor Loading	Standard Error	P-value
BEV charging duration and range	(inverse) BEV range too short	0.750	0.000	
	(inverse) BEV charging too long	0.775	0.041	0.000
BEV safety and reliability	(inverse) BEV gasoline safer	0.786	0.000	
	(inverse)BEV gasoline more reliable	0.834	0.034	0.000
BEV charging access	BEV plug in at home	0.630	0.000	
	BEV enough charging	0.821	0.053	0.000
BEV marketability	BEV less damage to environment	0.530	0.000	
	BEV mass market	0.893	0.095	0.000

Table 8: PHEV Assessment Confirmatory Factor Analysis Result

Latent Construct	Indicator	Factor Loading	Standard Error	P-value
PHEV charging duration and range	(inverse) BEV range too short	0.782		
	(inverse) BEV charging too long	9.756	0.030	0.000
PHEV safety and reliability	(inverse) BEV gasoline safer	0.821		
	(inverse)BEV gasoline more reliable	0.871	0.029	0.000
PHEV charging access	BEV plug in at home	0.671		
	BEV enough charging	0.747	0.045	0.000
PHEV marketability	BEV less damage to environment	0.548		
	BEV mass market	0.862	0.090	0.000

Table 9: BEV Assessment Factor Reliability and Validity

BEV Assessment Factors	BEV Charging Duration and Range	BEV Marketability	BEV Charging Access	BEV Safety and Reliability	Composite Reliability
BEV charging duration and range	0.58				0.73
BEV marketability	0	0.54			0.69
BEV charging access	0	0.39	0.52		0.68
BEV safety and reliability	0.38	0.01	-0.02	0.65	0.79

Table 10: PHEV Assessment Factor Reliability and Validity

PHEV assessment Factors	PHEV Charging Duration and Range	PHEV Marketability	PHEV Charging Access	PHEV Safety and Reliability	Composite Reliability
PHEV charging duration and range	0.59				0.74
PHEV marketability	0	0.53			0.68
PHEV charging access	-0.02	0.44	0.5		0.67
PHEV safety and reliability	0.47	0	-0.01	0.716	0.83

Authors

Kelly Hoogland is a PhD student at University of California, Davis, as a part of the Transportation Technology and Policy Graduate Group. She earned her M.S., also at UC Davis, in Energy Systems as part of the Energy Graduate Group. She is interested in consumer adoption of plug-in electric vehicles (PEVs), including researching topics such as consumer finance method, perception of incentives, and purchase intention. The overarching goals of Kelly's research are to investigate the barriers to widespread consumer adoption of PEVs, and the role of policy levers in guiding the transition to a more sustainable transportation system.