RESEARCH REPORT

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Cars and Chargers in the Country: Rural PEV Owner Accounts of Charging and Travel in California

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16. Abstract

Under the Advanced Clean Cars II (ACC II) rule, California must move to 100% zero emission vehicle (ZEV) sales by 2035. To make this transition equitable, it is important to understand how we can support ZEV adoption in all communities–including rural communities. The aim of this study is to explore the experiences and perceptions of current rural plug-in electric vehicle (PEV) owners, identify barriers to charging and ownership, and suggest factors to guide the development of infrastructure in rural areas. (PEVs include battery-electric vehicles [BEVs] and plug-in hybrid vehicles.) Semi-structured interviews were conducted with rural PEV owners and included questions related to travel behavior, at-home and public charging experiences, and motivation for household vehicle purchase. Major themes were extracted from the interviews including that PHEV owners tend to have minimal at-home and public charging requirements, while BEV owners require access to Level 2 charging at home and reliable fast charging in public spaces. Additionally, the magnitude of public charging reliability and availability issues appear to be greater in rural than non-rural areas. Grid reliability issues and specific vehicle requirements were also points of discussion among rural PEV owners. The findings of this report could inform policy makers, car manufacturers, and PEV charging companies to better serve rural communities in the transition to 100% PEV sales.

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Disclaimer

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Under the Advanced Clean Cars II (ACC II) rule, California must move to 100% zero emission vehicle (ZEV) sales by 2035. To make this transition equitable, it is important to understand how we can support ZEV adoption in all communities—including rural communities. The aim of this study is to explore the experiences and perceptions of rural plug-in electric vehicle (PEV) owners, identify barriers to charging and ownership, and suggest how policy and practice can guide the development of infrastructure and support PEV adoption in rural areas. PEVs include battery electric vehicles (BEVs; fully electric) and plug-in hybrid electric vehicles (PHEVs). We conducted semi-structured interviews with rural PEV owners and asked questions related to travel behavior, at-home and public charging experiences, and motivation for household vehicle purchase. We employed a theoretical sampling approach, whereby the number of participants was determined by the point at which information saturation has been met. Seven major interview themes were extracted from the interview transcripts and memorandums:

1. At-home charging potential is very high among rural residents.
2. Rural PHEV owners have a lesser need than BEV owners for public charging and mostly charge at home.
3. Rural BEV owners require Level 2 home charging access to make ownership convenient.
4. Public DC fast charging is needed to support longer trips, high travel demand, and occasional charging needs.
5. Grid reliability, disaster preparedness, and backup power are common concerns of rural PEV owners.
6. The magnitude of problems with public charging reliability and availability in rural areas may be greater than in urban areas.
7. Rural households have some specific vehicle requirements than non-rural households do.

These themes informed five guiding factors for policy makers, car manufacturers, and PEV charging companies to support rural electrification:

1. Provide subsidies for home charging.

Given the heavy reliance on at-home charging in rural areas, subsidies for Level 2 charging infrastructure could be provided, especially for lower-income households.

2. Encourage rural public fast charging developments

Additional incentives could be provided to PEV charging companies to build-out public charging infrastructure in rural areas and to develop a network that has built-in redundancies.

3. Ensure public charging is reliable

PEV charging companies could make system improvements to the functionality of their hardware and software in rural settings to improve charging experiences for rural users. Reliability and interoperability issues may have a large impact in rural areas due to PEV charging infrastructure coverage being less dense.

4. Support PHEV adoption, as well as BEV adoption

PHEVs appear to be well suited to many rural residents as almost all have access to Level 1 charging outlets at home. The ACC II rule allows for a maximum of 20% of ZEV sales to come from PHEVs. This allowance could be important for rural vehicle buyers, especially due to their unique vehicle needs, potential for power outages, and long-distance travel preferences and needs.

5. Incentivize PEV purchase in rural areas

Rural residents tend to have lower incomes on average than urban residents; therefore, to encourage sales in rural areas, additional incentives at point-of-sale may be required, in addition to outreach and engagement activities.

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Introduction

As California moves toward 100% zero-emission vehicle (ZEV) sales by 2035 as required by Advanced Clean Cars II, understanding charging needs across the state is increasingly vital (*1*). To date, little attention has been given specifically to the charging needs in rural California. To support the transition to 100% ZEVs it is important to consider the needs of all communities to provide equitable access to this clean technology. To achieve this goal, we need to understand the experiences of rural ZEV owners and identify any barriers to ownership, including at-home and public charging.

Adoption of ZEV technologies may be more challenging for rural than non-rural communities. On average, incomes in rural areas, compared to non-rural areas, tend to be lower and residents rely more on passenger vehicles, given the nature of rural land planning and the lack of public transit (*2*, *3*). Some rural residents may also need specific vehicle capabilities that are related to land use and the dominant economic sector of the region (e.g., farming). Terrain and weather may also be more extreme in rural areas than in urban areas and consequently reduce the range of plug-in electric vehicles (PEVs) (*4*). These terrain and weather differences combined with longer travel distances could make rural PEV use more challenging. (PEVs include battery-electric vehicles [BEVs; all electric] and plug-in hybrid electric vehicles [PHEVs]). Further exploration is needed to better understand these and other barriers to PEV ownership.

To our knowledge, no studies have employed qualitative techniques to explore PEV adopters' experiences and barriers to PEV use in rural settings. The aim of this study is to explore the experiences and perceptions of rural PEV owners, identify barriers to charging and ownership, and suggest how policy and practice can guide the development of infrastructure and support PEV adoption in rural areas. We conducted semi-structured interviews with rural PEV owners across California to understand the owners' perceptions, preferences and needs for charging, as well as travel behavior and motivation for adoption of the technology. The findings of this study are an initial investigation into charging experiences in rural California. Based on the results, we propose some guiding factors for the development of PEV infrastructure and support for PEV ownership in rural areas.

Literature Review

Previous studies that look at vehicle ownership and travel patterns across urban and rural settings do not focus on alternative fuel vehicle travel and thus do not look at charging infrastructure needs (*5*–*7*). More recently, studies have taken a quantitative approach to compare fuel types across the rural-urban continuum but tend to focus on macro market trends, not individual experiences of PEV ownership. Three studies out of Europe used quantitative methods to look at PEV market uptake across rural and urban areas (*8*–*10*). Wappelhorst (*9*) looked at charging infrastructure deployment across rural areas to determine the relationship between infrastructure and PEV adoption. They determined that public charging infrastructure and home charging correlated strongly with PEV adoption in Germany.

Much of the current literature on qualitative experiences of PEV charging and ownership has an urban focus or counts PEV owners as spatially homogeneous. An early study by Caparello & Kurani (*11*) interviewed PHEV trial participants and identified major themes including charging habits and etiquette, finding that all participants charged at home and mostly at night. Another study held workshops with PEV and non-PEV owning participants from three counties in Northern California (*12*). Amongst other themes, PEV owners broadly discussed their perceptions of public charging infrastructure availability and their process of at-home charging. Kurani & Ogunmayin (*13*) conducted interviews with PEV owners about their experiences of charging. This study found that there was a stark difference between Tesla and non-Tesla owners in their experiences of charging. While these studies provide important insights into the charging experiences of PEV owners, further research could be done to understand the specific barriers and needs of rural PEV owners.

One study from Vermont conducted semi structured in-person interviews with people from urban, suburban, and rural areas, asking participants questions about perceptions of PEVs (*14*). Perceptions were similar across all areas, with participants indicating they would be likely to adopt a PEV if the cost of the vehicles decreases. While that study quantitatively examined perceptions of PEVs in rural areas, it did not examine the lived experiences of current PEV owners in rural areas. To the best of our knowledge, no published studies exist that focus on the charging experiences and perceptions of PEV ownership in rural areas.

Defining Rural

The 2020 United States (US) Census Bureau definition was used to define rural areas in California (Figure 1). Under this definition an urban area is defined as an area with 50,000 or more residents and an urban cluster is an area that has more than 2,500 but fewer than 50,000 residents. All other areas are considered rural. Under this definition, 19% of the US population lives in rural areas, which account for 97% of the land mass. In California, the rural area encompasses 7% of the population and 88% of the land mass (*3*). As highlighted in the literature, the definition used to delineate urban from rural areas has important implications for the vehicle and sociodemographic characteristics captured in this group of people (*3*, *15*, *16*). Additionally, rural areas are not homogenous and thus a large amount of diversity exists within these areas.

Methods & Data

This section provides an overview of the interview recruitment process, as well as the interview themes, and high-level vehicle and demographic data collected.

Participant Recruitment

The Electric Vehicle Miles Traveled (eVMT) survey conducted and managed by the Electric Vehicle Research Center at University of California, Davis was used as the sampling frame for the current study. The eVMT survey gathered responses from 23,682 PEV owners throughout California between 2015 and 2020. The respondents reported home locations, which were categorized as urban or rural, based on whether the home address of the respondent fell into an urban or rural census tract according to the US Census Bureau definitions. Of the 1,199 rural respondents identified in the survey, 1,089 indicated they would be willing to participate in future research and were included in the sampling frame used for recruitment of participants for this study. Recruitment emails were sent out to participants based on income, gender, and age with the aim of recruiting a sample with a cross section of demographic characteristics.

Recruitment emails were sent to 31 email addresses from Marin, Humboldt, Sierra, Placer, Nevada, and El Dorado. Our interview sample is therefore a convenience sample rather than a random sample of California PEV owners. A total of 16 people accepted the request to be interviewed (Figure 1).

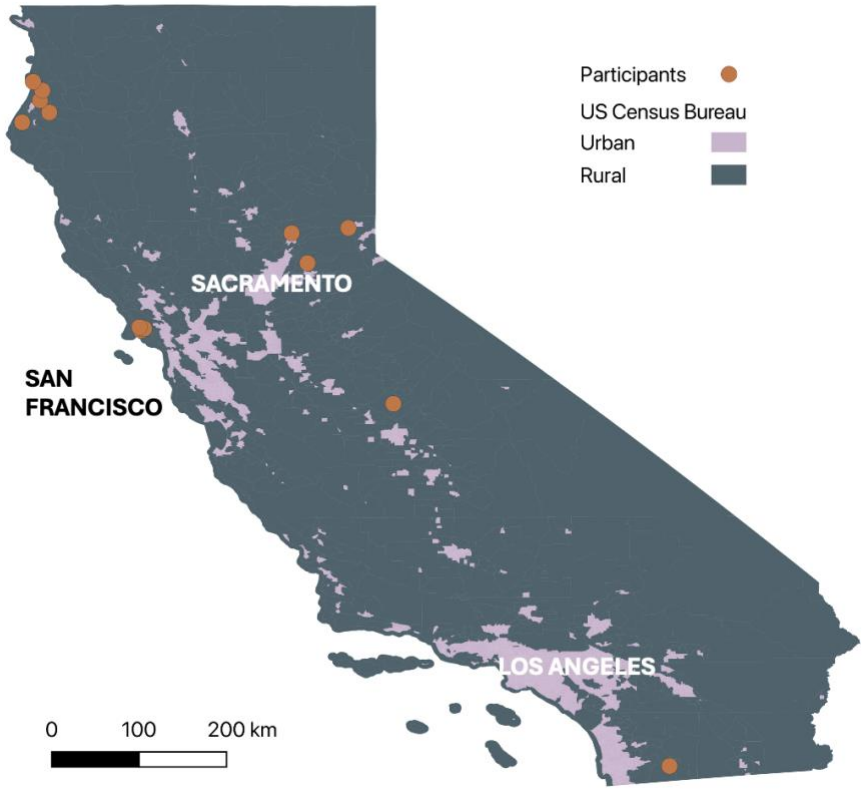

Figure 1. Participant locations overlaid with rural and urban areas as defined by the US Census Bureau

Interviews

The interviews of 16 participants were conducted over a six-month period between July and December 2023. The interviews lasted between 30 to 60 minutes and were semi-structured following an interview protocol (see Table 1 and Appendix A). A theoretical sampling technique, a key part of grounded theory, was employed throughout the interview process. Grounded theory is a general research method whereby a theory is built based on research findings. This approach uses data collection as a way of building a theoretical framework and is iterative in nature, as findings from the previously collected data informs what data to collect next (Brackenridge & Jones, 2009). Therefore, the number of interviews conducted was determined by when saturation of information had been reached. Interview memorandums were used to track interview topics to determine when this had occurred.

An interview guide was created so that each participant was provided with the same contextual information and was asked similar questions covering the same themes (*17*). Pilot testing was conducted prior to the interviews to test for question comprehension and face validity. The interview guide was updated based on feedback from the pilot testing.

Figure 2 outlines the interview process from participant recruitment through interview questions.

Figure 2. Interview process flow diagram

The interview protocol shown in Table 1 provides information on the major themes discussed in the interviews, as well as an example opening question relating to the theme. As these interviews were semi-structured, participants were encouraged to talk about any experiences they felt may be relevant to the topic of discussion and therefore, these opening questions serve as examples to the types of questions asked in the interview.

Table 1. Interview protocol

Theme	Example Opening Question
Travel behavior & vehicle use	One thing we are interested in is how people get around. Could you talk about that?
Household vehicles & decision to purchase	Can we talk about your household's vehicles and why you purchased them?
Electric vehicles & charging experiences	Can you tell us about your experiences with an electric vehicle?
	Do you charge your electric vehicle at home? Can you take me through the charging process?
	Do you charge your electric vehicle at public charging stations? Can you tell me about where you charge and how often?
	When you first purchased your electric vehicle, how did you know where to find public charging stations? Or on long road trips, how do you know where you can charge?
	Do you think you would purchase another electric vehicle in the future? Why/why not?
Feasibility of adoption	Do you think other rural households could incorporate EVs into their households? What issues might they face?
Concluding remarks	Is there anything else you would like to add before we conclude this interview?

Interview Sample

Table 2 presents sociodemographic characteristics of each of the 16 participants, as well as a list of both the PEVs and non-PEVs (internal combustion vehicles) in their household. Seven participants owned BEVs, six participants owned PHEVs, two participants had at least one BEV and one PHEV, and one participant had previously owned two BEVs but no longer owned a PEV. Two participants reported having a BEV and no non-PEV vehicles, while every other participant owned at least an additional PHEV or a non-PEV. Seven of the 16 participants were female, and nine were under 50 years of age. Ten of the participants had a median household income of over US$100,000 per year.

Table 2. Participant characteristics

Participant	Age (y)	Income ($)	Gender	Household vehicle(s)	
				PEV	Non-PEV
1	60-69	150,000-199,999	Female	2017 Tesla 3	Volkswagen Jetta Ford F-350
2	30-39	50,000-99,999	Female	2018 Chevrolet Bolt Chevrolet Volt	
3	70-79	200,000-249,999	Male	2016 Chevrolet Volt	Chevrolet Spark
4	70-79	50,000-99,999	Male	2017 Chevrolet Volt	Subaru Forester
5	30-39	250,000-299,999	Female	2017 Tesla Model S 2017 Model X 2022 Model X 2013 Chevrolet Volt	
6	60-69	100,000-149,999	Male	2018 Tesla Model 3	
7	70-79	50,000-99,999	Male	Subaru Crosstrek	2002 Porsche Boxster
8	60-69	50,000-99,999	Male	Chevrolet Bolt 2017 Honda Clarity Hyundai Kona EV	
9	40-49	150,000-199,999	Male	2017 Chevrolet Bolt	Toyota Tacoma
10	40-49	200,000-249,999	Female	Toyota RAV4 PHEV Toyota Prius PHEV	Chevrolet Suburban
11	60-69	<50,000	Male	2014 Ford C-Max	
12	40-49	100,000-149,999	Male	2018 Chevrolet Bolt	Honda Odyssey Chevrolet Silverado
13	30-39	100,000-149,999	Female	Tesla Model Y	Honda CR-V
14	40-49	<50,000	Female	Kia Soul EV	Nissan Versa Ford F-150

Participant	Age (y)	Income ($)	Gender	Household vehicle(s)	
				PEV	Non-PEV
15	40-49	400,000-449,999	Male	2018 Chrysler Pacifica	2016 Toyota Tundra 2016 Toyota Avalon
16	30-39	100,000-149,999	Female	2018 Tesla Model X (Discontinued) Hyundai Kona EV (Discontinued)	Pickup truck (Discontinued) 2021 Honda CR-V

Results

The major themes, ideas and issues surrounding PEV ownership in rural California from the point of view of the 16 interviewees are presented here. The results of this study represent the views and experiences of the participants in relationship to PEV ownership. Participant names and town names have been redacted to provide anonymity. However, each participant has been assigned a pseudonym.

First, we describe home and work charging access, then experiences of rural PEV charging, grid reliability issues, and vehicle requirements for rural areas.

PEV Ownership and Home and Work Charging Access

Table 3 summarizes key home and work charging information, and the PEVs owned by interviewees. All participants had some form of home charging access, nine reported having access to Level 2 charging at home with the other seven having access to Level 1. Just two of the nine BEV-adopting households reported only having Level 1 charging, one of which has now discontinued PEV ownership. One of the six PHEV households reported having Level 2 charging. Six participants had a home solar system installed and of these participants, three had energy storage systems in the form of residential batteries. One participant had a natural gas backup generator. Six mentioned that they had access to work charging, although use of the work charging varied across participants.

Table 3. Home and work charging summary

Participant	Pseudonym	Electric vehicle(s)	At-home charging	Home energy generation	Residential batteries	Work charging
1	Alex	2017 Tesla 3	Level 2	-	-	-
2	Dylan	2018 Chevrolet Bolt Chevrolet Volt	Level 2	-	-	-
3	John	2016 Chevrolet Volt	Level 1	-	-	-
4	Eric	2017 Chevrolet Volt	Level 2	Solar	-	-
5	Natalie	2017 Tesla Model S 2017 Model X 2022 Model X	Level 2	Solar	Yes	Yes

Participant	Pseudonym	Electric vehicle(s)	At-home charging	Home energy generation	Residential batteries	Work charging
		2013 Chevrolet Volt				
6	Jason	2018 Tesla Model 3	Level 2	Solar	Yes	-
7	Pete	Subaru Crosstrek	Level 1	Natural gas	-	-
8	Charles	Chevrolet Bolt 2017 Honda Clarity Hyundai Kona	Level 1	-	-	-
9	Roger	2017 Chevrolet Bolt	Level 2	-	-	Yes
10	Madison	Toyota RAV4 PHEV Toyota Prius PHEV	Level 1	-	-	Yes
11	Jimmy	2014 Ford C-Max	Level 1	-	-	-
12	Seamus	2018 Chevrolet Bolt	Level 2	Solar	-	Yes
13	Kelly	Tesla Model Y	Level 2	Solar	-	Yes
14	Vivian	Kia Soul EV	Level 2	-	-	-
15	Ray	2018 Chrysler Pacifica	Level 1	Solar	Yes	-
16	Max	2018 Tesla Model X (Discontinued) Hyundai Kona EV (Discontinued)	Level 1	-	-	Yes

Home and Work Charging Experiences

BEV Owners

Participants who owned BEVs or a mixture of BEVs and PHEVs and/or non-PEVs tended to have greater at-home and public charging requirements than owners of PHEVs did. Of the BEV owners, many mentioned that having access to Level 2 charging at home was important, if not essential for owning an all-electric vehicle. One Bolt owner, Roger, spoke of the importance of Level 2 charging when owning a BEV:

> I do think that you need to invest in a home charger [Level 2], because you have to charge your vehicle when it's sitting and it's sitting a lot at home.... You can't rely on a regular Level 1, you know, it's just too slow.

The participants who owned BEVs tended to have more public charging experiences compared with PHEV-owning participants. Nonetheless, they acknowledged that they did most of their charging at home. The motivation behind home charging tended to be financial and convenience-based, with many citing lower at-home charging costs and availability of overnight charging as reasons for home charging. Dylan, a Bolt owner, had this to say:

> We almost exclusively used our home [Level 2] charger because there really aren't that many places [public chargers] out there at all, and it's cheaper to do it at home and just more convenient for my husband, you know. Instead of spending the time waiting for charge, he could just make it home and then just plug it in before he goes to sleep.

Natalie, a Model S owner, purchased her vehicle when Tesla was providing customers with free lifetime fast charging at Tesla stations. Despite being able to charge for free publicly, she did most of her charging for her Model S and three other PEVs at home: “And it [Tesla Model S] also gets, you know, free charging [at Tesla chargers], but we do charge at home most the time.”

Some BEV owners explained that there was a lack of availability of public chargers close to their house, which necessitated their use of home charging. A Bolt owner (Seamus) mentioned that the closest public charging station to his home was a 30 to 40 minute drive. One Model 3 owner, Alex, also mentioned she had to drive a distance to the nearest public charging station: “I charge at home which is good. Here, the nearest charges are over the hill [in the nearest large town].”

PHEV Owners

At-home and public charging demands for participants who only owned PHEVs or a mixture of PHEVs and non-PEVs were minimal. PHEV owners reported a range of public charging use from little to none. Some PHEV owners mentioned that they rarely exceeded the electric range of their vehicle or if they did, the vehicle would switch to using gasoline, so there was no need to charge the battery in public spaces. When asked if she

charged publicly, Madison, a RAV4 PHEV owner, responded: “I've never. There's been the opportunity, but it's rare. I've just never done it.”

Some participants had encountered public charging stations only on a few occasions. When asked how he charged his Volt, John said: “In the garage. I've never charged at a... Only once or twice have I charged elsewhere [publicly].”

Other PHEV owners used public charging infrequently and incidentally. Asked about the proportion of charging done at home, a Subaru Crosstrek PHEV owner (Pete), told of using public chargers when traveling or if the charging cost was inexpensive. Another Volt owner, Eric, mentioned his use of public chargers was mainly incidental as well. He would drive into town and use a free public charger if there were activities and errands to keep him occupied while the vehicle charged:

> Whether I'm going to rehearsal or whether I’m going for whatever trip I can bring my music along, [I] plug-in somewhere and get an extra hour when I'm doing rehearsing that I might otherwise do at home. So I guess what I'm saying is, I will plan to do public charging and have something else to do at the same time...

At home, five of the six PHEV owners plugged into a standard (Level 1 or 120 V) outlet to charge their vehicle. Many PHEV owners mentioned that this level of power was sufficient for charging their vehicle overnight. When asked about his at-home charging process, Pete said:

> I haven't felt too much incentive to install, you know, the company provided charging stations. The only advantage I can see to it is that you can charge faster if you have the stations but these hybrid plugins with the shorter range will charge within three to five hours and that's not anything terrible.

Some PHEV owners mentioned that they would consider installing a Level 2 outlet in their home if they were to purchase a BEV in the future.

Work Charging

Both BEV and PHEV owners discussed the availability and use of work charging stations. Two BEV owners mentioned having commutes of more than 100 miles and relied heavily on Level 2 work charging stations to charge their vehicles. The Model S owner (Natalie) would commute 5 to 6 hours one way, spend two days in the city at work and commute home to spend the rest of the week working remotely. A Bolt owner (Seamus), commuted over 100 miles (total) each day to work and would not have enough charge to make it home each day without work charging. At the time of owning her Hyundai Kona EV, Max relied heavily on a Level 2 work charger as she only had access to Level 1 charging at home. Madison was the only PHEV owner who mentioned charging at work. As there was no designated work charger, she would park her RAV4 right outside her office and thread the charger through the window to a regular Level 1 outlet. A Bolt owner (Roger) had access to Level 2 charging at work but rarely used it because it was cheaper and more convenient to charge at home.

Experiences and Perceptions of Public Charging

Charging Density & Availability

Many PEV owners had positive comments about the change in density of public chargers over time. These participants had owned their PEV for several years and mentioned noticing an increase in public charging infrastructure since purchasing their vehicle. Natalie, who owns the Model 3, had this to say about the Tesla network:

> When I got my Tesla, the Supercharger network was still developing and so it was a little bit tricky to do my commute, as there was no charging station or supercharger on my route between where I live and where I work. So it was challenging at first, but very quickly that changed.

Dylan, a Bolt owner, who relies on other non-Tesla charging networks, noted a similar increase in public chargers: "It [public charging] has totally changed since 2017. Like, it is a different world out there. There're just so many more chargers..."

She went on to explain that while there were more charging stations now, the increase in adoption of PEVs meant that wait times for public chargers had also increased: "...and there're a lot more cars charging at the [stations]... So sometimes you have to wait."

Natalie corroborated Dylan's experience and explained that while broken chargers used to be a problem, the predominant issue now is wait times: "Initially, yeah, there was a state of disrepair with some of the chargers where they wouldn't quite work right or they'd be vandalized. Nowadays, I'd say it's more common that they're too busy."

Despite participants noting an increase in charging stations, many felt that more public charging was needed. In addition to charging wait times, participants cited distance between charging stations, station location, and lack of redundancy to explain the need for more chargers. One Bolt owner, Charles, discussed the desire to have charging stations in similar locations to gas stations:

> Oh, well, first of all, there needs to be more charging easily accessible. I mean you got gas stations, service stations right off the freeway, you know, but sometimes if you need to be charged you have to actually go into town and track down where Walmart is or where Target is. And so it's a little extra driving.

Roger spoke about the longer distances between some of the charging stations and a need for more redundancy so PEV owners didn't get stranded:

> So I think it's good to have like that level of redundancy. If you only have one station that you're relying on, even if there's a, a couple, two, three chargers there, if power supply to that location goes down, you're kind of stuck.

Long Distance Trips

Most of the reported trips made by the interview participants in their PEVs were local except for the two participants who discussed having commutes of greater than 100 miles. Other participants tended to discuss longer trips in their PEVs as occasional and often for the purpose of a vacation or visiting family. Kelly mentioned driving across the United States from California to Alabama to visit her grandmother for her 80th birthday. She had this to say about the Tesla network: "It was really impressive, actually, like Tesla's charging network is very well thought out and well positioned... So we went from California ... into Alabama."

She went on to discuss her charging experience:

> As long as you're on [major highways], like you could charge every two hours. And for us with a dog and a small baby—a baby that had to be fed every like three hours and a dog that needed to run around—the charging actually made it more pleasant because we could stop for 30 minutes. Like everybody stretched their legs.

Charles took a family road trip from California to Canada two years ago in their Hyundai Kona EV, he discussed not being able to charge at a station:

> And so we hit a couple [of charging stations] and it was down. It wasn't working. We ended up doing another slow charge just to get us enough to go to another... to find another fast charger. So we hit a few bumps along the way and we tried to play it as safe as we could but I would guess in the last two years it's gotten better.

Many other participants mentioned taking longer road trips (more than 100 miles) within California in their PEVs, while some mentioned owning a non-PEV for the purposes of driving longer distances as they felt apprehensive about driving their PEV on longer trips.

Charging Station Reliability

Once participants located a public charger, some reported reliability issues with the chargers. Some participants mentioned instances of vandalism, while others reported connection issues. Natalie, the super commuter, said this:

> I've been to a few chargers where someone has like put super glue in the conductor's connector or they've intentionally burned it with like, you know, a propane torch. And you get there, you're like, 'oh look, there's one charging stall left' and you pull up and then you realize 'oh it's broken and it's been vandalized'.

Eric corroborated her story: "I am dismayed at the number of stations where I see that somebody has vandalized them, where the handle is broken or somewhere where the cord has been damaged etc."

Roger mentioned that being in remote areas sometimes meant that charging issues weren't just hardware related but also related to the software and cell phone reception:

> I mean if that communication system goes down, whether it's cellular based or satellite-based or whatever it is, then it doesn't matter if there's still power to the station you can't tell it what to do. And so that can be kind of an issue.

Many participants also reported seeing available chargers on charging applications, going to the station to charge, and finding that the charger was not working for some unknown reason. Dylan had this to say: "And so I looked on the PlugShare app, found an EVgo that was in the WholeFoods in [town]. And so I was like, 'great, I'll do my shopping while it's charging.' And I get there and neither of them work."

Some participants mentioned that there needed to be better reporting on the charging applications about whether the chargers at a particular station were functioning. In rural areas, this is particularly important as the next charging station may be beyond the range of the vehicle. Roger said:

> It's really important on these apps for the different providers that they update and keep up updated information about whether the charges are operating or not. Because if you're relying on the station, you're pulling into it and it's not operable, then you can really be in a bad situation.

Grid Reliability Issues

Many interview participants had experienced power disruptions both at home and in public spaces and discussed PEV ownership in the context of extreme weather events and natural disasters. Participants often spoke about these events affecting their ability to charge. Natalie said: "... Living in a very rural area, you know, we get like large storms, it snows where we live, and trees fall down all the time. There's a lot of power outages."

Many reported that these power outages were frequent, some of which could last hours or days at a time. Kelly expressed concerns about her household having only BEVs, as a lack of ability to home charge during power outages could impede egress during disasters. For this reason, they expressed the need for a backup non-PEV:

> We do get rolling power outages, we had like a five-day stretch where we didn't have power... And so, you know, I think because we have the chance of losing power for that long, it makes us reluctant to, like, give up a gas vehicle. Knowing we'd have no way to get out of here.

When asked about how they charged at home during power outages, Roger reported that it could be a problem but he hadn't personally been caught needing to charge when the power was down. He said that if this scenario were to happen, he too would use his non-PEV: "I have another vehicle I could use. If the EV was my only vehicle and I lived in that setting, I probably would be a lot more concerned about the potential of not being able to travel."

Roger also discussed how a wildfire had caused a power outage in town when he needed to charge:

> ... we were relying on I think the station [in town] to provide [the BEV] the energy we needed to get home. And we didn't have enough energy to get to the next one. And there was a fire and that shut down all the electricity in town and so we just had to wait it out. And we ended up going for a swim and had a couple beers and just kind of waited until it came back online.

Solar and Backup Power

Six participants mentioned having a solar set up at their house, of which three had capacity to store the solar power. When asked about the motivation behind installing solar, Natalie and Jason said it was related to the number of power outages they experienced. Eric, Natalie, and Kelly all said that the motivation was environmental. Seamus and Kelly said they were motivated by reducing the cost of at-home charging and Ray mentioned they installed solar for energy independence from the grid. Pete, the Crosstrek owner, installed a natural gas generator at their home to ensure a power supply during outages.

Rural Vehicle Requirements

Living in rural places can necessitate certain vehicle requirements and travel behaviors. Both BEV and PHEV owners discussed the electric range of PEVs, requirements for all-wheel-drive capabilities, and the need for hauling/towing capacity. BEV owners seemed to express more concern around the range of the vehicle, or the availability and density of chargers compared with PHEV owners who mentioned they would use gasoline if they exceeded their electric range.

Many BEV owners expressed feeling anxious about having enough charge or making it to the next charging station. Charles, a Bolt owner, had this to say about losing battery charge: “I don’t want [my BEV] to end up dead on the side of the road. That’s what I’m worried about.”

Participants mentioned that certain weather conditions could decrease the range of the battery. Cold could decrease the battery capacity, while rain and snow could require certain vehicle traction settings that use additional charge. As well, some PEV owners lived in mountainous areas where the extreme topography required more charge. Despite many BEV owners expressing concern about the range of their vehicles, none of the participants PEV’s had ever ended up ‘dead’ on the side of the road. Although, the anxiety around losing charge was a sufficient motivator for some participants to plan their trips ahead of time and identify public charging locations on longer trips.

Many participants discussed the need for all-wheel drive capabilities because of weather conditions such as snow, ice, and rain, as well as certain terrain conditions. Jason, a Model 3 owner, mentioned that snowfall was common where they lived and that an all-wheel drive vehicle was necessary for the weather: “I wanted to get the four-wheel drive so that going to Tahoe wouldn't be a problem...”

Roger and Seamus (both Bolt owners) mentioned that the vehicle they currently had was at times inadequate for the terrain they needed to drive on. Roger explained that his BEV had inadequate clearance for some of the

off-road and gravel road driving he needed to do. Seamus discussed how a heavy rain year had washed out his driveway so each day when he got home from work, he would have to tow his BEV up to his house with his Chevrolet Silverado:

> And what I had to do is every day when I came home from work, I would park my EV at the bottom of the hill, I would walk up the hill to the house, I'd grab the truck and grab my wife and we'd drive down the hill and I would tow the EV up the hill to get it to my EV charging station.

Many participants mentioned owning additional non-PEVs to fulfill certain hauling and towing needs that their PEV could not do. For example, Seamus and Ray both owned horses and required pickup trucks to tow their horse trailers. While all the participants had purchased their vehicles prior to electric pickup truck models being available to consumers, when asked what their next vehicle purchase would be, four participants (Natalie, Roger, Seamus, and Max) mentioned they would consider an electric truck.

Recommendations to a Neighbor

As a final question, participants were asked if they would recommend a PEV to their neighbors and if they did what challenges their neighbor might encounter. John (a PHEV owner) mentioned that he would be more likely to recommend a PHEV to a rural neighbor than a BEV, due to lack of charging availability away from home: "Plug-in [hybrid] is a little more attractive because [of] the reduced availability of charging other than at home."

Alex mentioned that, while rare, a challenge some rural residents may face is not being able to charge at home due to extreme topography not allowing for driveway access. However, other participants said that owning a PEV without at-home charging was still viable if the range of the vehicle was adequate, if there was access to DC Fast Charging nearby, or if the owner had access to work charging. Most participants agreed that this scenario (a lack of home charging) was more likely to be a challenge faced by urban PEV owners. When asked about barriers to electrification in rural households, Natalie mentioned that rural areas tended to be lower income and therefore the upfront cost of a PEV was a barrier to adoption, and others echoed this sentiment. Respondents also mentioned that rural residents tend to have preferences for larger vehicles, but large PEV models were either not available yet or too expensive. Besides the greater financial barrier in rural areas, Natalie said she felt that it was urban areas that had more barriers to adoption than rural areas: "I actually think that charging in a remote area isn't as much of a problem as charging in the city." She went on to explain that this was because most rural residents had access to at-home charging, while urban residents may have to rely more on public charging to charge their PEV.

Discussion

Across the 16 interviews, PEV owners were asked about travel behavior, at-home and public charging experiences and habits, their motivation for PEV purchase, and feasibility of others to adopt. Out of the 16 participants, seven participants owned BEVs, six participants owned PHEVs, two participants had at least one BEV and one PHEV, and one participant had previously owned two BEVs but had discontinued use of PEVs altogether. The range of experiences were captured in interview transcriptions that were processed to identify shared themes. Five major themes were identified through the interviews which we describe in detail below.

1. At-home charging potential is high among rural residents.

All interviewees reported access to charging at home, perceived others in their community would have access to charging from home, and most rural households live in single family homes, which generally have easier access to at-home charging than multi-unit dwelling do.

2. Rural PHEV owners have a lesser need than BEV owners for public charging and mostly charge at home.
3. Rural BEV owners require Level 2 home charging access to make ownership convenient.

At-home and public charging requirements for PHEV owners interviewed in this study appeared to be minimal compared to BEV owners. Similar to findings by Caparello & Kurani (*11*), PHEV owners were found to mostly charge at home overnight. Some participants charged publicly, but only incidentally. Additionally, once the electric range of the PHEV was depleted, participants were able to continue driving using the car's engine, as would not be possible in a BEV. Given this difference, some of the discussion around at-home charging applies to PHEV owners, but many of the issues around public charging apply mostly to BEV owners.

4. Public DC fast charging is needed to support longer trips, high travel demand, and occasional charging needs.

While interviewees didn't report frequent use of public DC fast chargers, such chargers are still needed to support longer distance trips, instances of high travel demand, occasional charging needs, and could be important in instances of power outages at home.

5. Grid reliability, disaster preparedness, and backup power are common concerns of rural PEV owners.

Some of the themes in this study have also been identified in interviews with non-rural PEV owners. However, the magnitude of the issues may differ across the urban-rural divide. For example, urban PEV owners may have more issues related to at-home charging access given the higher proportion of multi-unit dwellings (*3*). For the most part, our rural participants did not see this as an issue in rural areas, given the high proportion of detached houses with garage access or access to an outlet near the house. On the other hand, Caparello & Kurani (*11*) and Kurani & Ogunmayin (*13*) discussed the routine nature of at-home charging in urban settings, characterizing it as mostly uneventful. However, the rural participants in this study shared experiences of frequent and prolonged power outages that would disrupt routine at-home charging events. This issue

becomes more pronounced in rural areas because of the lack of surrounding public charging infrastructure. Lack of access to public charging also increases the need for at-home Level 2 charging, especially for BEV owners. Additionally, these power outages may be caused by something as banal as a branch falling on a power line or they could be caused by wildfires and other severe weather events. Given the potential need for emergency egress in these situations, rural PEV owners highlight their need for a vehicle that will reliably work in emergency situations. For some participants, power disruptions were significant enough to warrant investment in backup power systems (solar panels and residential battery storage).

6. The magnitude of problems with public charging reliability and availability in rural areas may be greater than in urban areas.

For rural PEV owners, routine public charging events may be more challenging than for non-rural PEV owners due to a lack of chargers. However, on longer road trips with non-routine public charging events, the experiences of rural and non-rural PEV owners may converge. As described by Kurani & Ogunmayin (*13*), being able to charge publicly requires that chargers are available, accessible, and functional. This is true for all charging events. However, if one of these three requirements of charging were to breakdown in rural areas, the the issue would likely be larger. For example, the rural participants in this study discussed issues with charging applications accurately identifying available chargers. The participants told of checking their phone application ahead of time to check for available chargers, only to get there and realize the charger is not working. In an urban setting, the chances of another nearby charging station is high, given the greater density of charging stations (*3*). In rural areas, the next charging station could be prohibitively far away, leaving the driver stranded. For both rural and non-rural PEV drivers, longer non-routine trips would likely take the drivers through rural areas or at least areas that are unfamiliar to the driver. Thus, the experiences of rural vs. non-rural PEV owners during these charging events may be more similar. In these non-routine charging events, some rural participants mentioned they had trouble finding the charging stations. Others recalled not being able to pay for charging through the phone application given the lack of cellular reception. Vandalism of the chargers was an issue faced by rural participants in this study, as well as non-rural participants in other studies (*13*). Again, vandalism of chargers likely has a greater impact on drivers in rural areas than in urban areas because of the lower density of chargers.

7. Rural households have some specific vehicle requirements than non-rural households do.

A theme that appears to be solely experienced by rural PEV owners is the need for certain vehicle capabilities. While urban PEV drivers may hope for longer range vehicles for the occasional long trip, rural PEV owners may be taking longer trips more frequently or need the larger battery capacity for extreme topography or traction settings on icy, wet, or snowy roads. More extreme weather events in some rural areas also require residents to have all-wheel drive capabilities. Participants also mentioned needing a vehicle with higher clearance. Rural participants often had additional non-PEV vehicles in their household fleet that fulfilled these requirements.

Guiding Factors for Supporting Rural PEV Adoption

The following guidelines—based on interviews in this study and findings in other studies—may assist policy makers, car manufacturers, and PEV charging companies in providing support for current and future rural PEV owners.

1. Provide subsidies for home charging.

Given the reliance on at-home charging in rural areas and high potential for home charging access (due to most housing being detached), subsidies for Level 2 charging infrastructure could support further adoption, especially for buyers with low incomes. Additional subsidies could also be provided for at-home renewable energy systems and power storage so that rural PEV owners can charge regardless of grid interruptions.

2. Encourage rural public fast charging developments.

Additional incentives could be provided to PEV charging companies to build out public charging infrastructure in rural areas and small towns in rural regions. This would increase the redundancy of the charging network for rural PEV owners and non-rural PEV owners in the event of power outages or infrastructure reliability issues.

3. Ensure public charging is reliable.

PEV charging companies could make system improvements to the functionality of their hardware and software in rural settings. For example, companies could design payment redundancy at each charging station in cases where cellular reception is low. Additionally, more stringent standards could be implemented for reporting charger functionality on the company applications to reduce likelihood of users being misled to a non-functioning charger.

4. Support PHEV adoption, as well as BEV adoption.

PHEVs appear to be well suited to many rural residents, as almost all have access to at least Level 1 charging outlets at home. PHEV owners are also less likely to need backup energy systems and public charging as they can use the car's engine when power interruptions occur or they use up their electric range. The ACC II rule allows for a maximum of 20% of ZEV sales to come from PHEV sales. This allowance could be important for rural vehicle buyers.

5. Incentivize PEV purchase in rural areas.

Residents in rural areas have lower incomes on average than residents of urban areas, therefore, additional incentives at point of sale may be required to encourage rural adoption. These incentives could be for specific vehicle fuel types (e.g., PHEVs) or specific vehicle capabilities that may be needed in rural areas and should be applicable to used PEVs. For example, incentives in rural areas may specifically be for PEVs with higher ranges, higher clearance, and all-wheel drive capabilities. Education and outreach are also important aspects of this guiding factor as many rural communities may be unaware of PEV technology or the incentives available to them.

Conclusion

This study provides a first qualitative look at the experiences and perceptions of PEV owners in rural California. We found that while overlap exists between the accounts of rural PEV owners in this study and non-rural PEV owners in existing literature, the magnitude of barriers to PEV charging in rural areas appears to be greater in most instances except for access to home charging. As California transitions to 100% ZEV sales by 2035, it is important to acknowledge the unique barriers to PEV adoption faced by rural areas. This study provides five guiding factors that may assist policy makers, car manufacturers, and PEV charging companies in supporting current and future PEV owners. This study is exploratory in nature and is not designed to be representative of PEV ownership experiences generally. It provides an important first step in understanding the road to electrification in rural settings.

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Appendices

Appendix A

Interview Questions for Electric Vehicle Owners

Before starting

- Introductions
- Confirm name of interviewee
- Confirm address of interviewee

Introduction

Good morning/afternoon and thank you for joining me today.

My name is [name here] from the University of California, Davis and the Electric Vehicle Research Center and I will be your interviewer today. This is a study funded by the Statewide Transportation Research Program and led by researchers from UC Davis. Our purpose today is to learn more about your experiences and thoughts about transportation as someone who owns an electric vehicle and lives in a rural area. [Introduce other research team members present.]

We are here for the next 30-60 minutes or so to learn from you. Your input is important as it will help us understand how people living in rural and remote areas travel. I will ask you some questions about how you use your vehicle, your charging habits, and the decisions you make when choosing what vehicle to buy.

I will facilitate this conversation using a topic guide. That means I have a set of questions for you that I want to ask, but this is an open discussion and you should feel free to bring up issues that are relevant to our conversation today. There are no right or wrong answers to any questions we ask today. I will be recording our conversation today and wanted to confirm that you consent to having your answers recorded. Please respond yes or no.

I also want to make you aware that any identifying information you provide me with today is completely confidential and any data that we use in our research will be de-identified to maintain your anonymity. If at any time during this interview should you want to stop or would prefer not to answer a question, please communicate this to me.

Do you have any questions before we begin?

OK, let's get started!

[start recording]

To begin...

- Can you tell me a bit about yourself, what you do for work, how you like to spend your time?

Part I - Travel behavior and vehicle use

- One thing we are interested in is how people get around. Could you talk about that?
  - Thinking about a typical weekday, what trips do you take with your vehicle?
  - Do you use your vehicle during the work day for work purposes?
  - Do you use your vehicle differently on the weekends? And if so, how?
  - Do you ever go on long distance trips with your electric vehicle, for example, more than 200 miles? And if so, what is the purpose of those trips?
  - Other modes

Part II - Decisions to purchase

- Can we talk about your household's vehicles and why you purchased them?
  - Could you tell me what factors you considered when purchasing your vehicles?
  - Do you use different vehicles for different purposes?

Part III - Electric vehicles and charging awareness

- Can you tell us about your experiences with an electric vehicle?
    - Contrast with gas car

One thing we're interested in is how you charge your electric vehicle...

- Do you charge your electric vehicle at home? Can you take me through the charging process?
    - Any issues? E.g. power outages
- Do you charge your electric vehicle at public charging stations? Can you tell me about where you charge and how often?
    - Any issues?
    - Have you ever tried to charge your electric vehicle at a public charging station and it not work? Can you tell me about that experience?
    - What do you think could be done to improve your charging experience?

- When you first purchased your electric vehicle, how did you know where to find public charging stations? Or on long road trips, how do you know where you can charge?

[if they said they took long distance trips]

- Do you think you would purchase another electric vehicle in the future? Why/why not?

If few issues

- If household has few issues:
    - Do you think other rural households could incorporate EVs into their households?
    - Any issues they could face?
    - Thoughts on EV ownership without home charging in rural areas?
    - Would you recommend other rural households to purchase an EV?

Part IV - concluding remarks

- Is there anything else you would like to add before we conclude this interview?

Is there someone