Customer Experience at Public Charging Stations and Its Effects on the Purchase and Use of Electric Vehicles

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Working Group 1: Defining the Charging Experience

CHARGEX consortium

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DISCLAIMER

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Executive Summary

To support the ChargeX Consortium's mission to measure and significantly improve the reliability and usability of public charging infrastructure in North America, researchers in the consortium from the University of Washington (UW) reviewed the published literature and data from consortium members to evaluate how the consumer experience at public fast charging stations influences electric vehicle (EV) adoption.

Figure ES-1 presents a conceptual model of the different factors that influence consumers' decisions to purchase their first EV, to use an EV they own for a particular trip, and to purchase a subsequent EV. This study is focused on the dark purple arrows that represent the effects of public charging on the behavior of consumers.

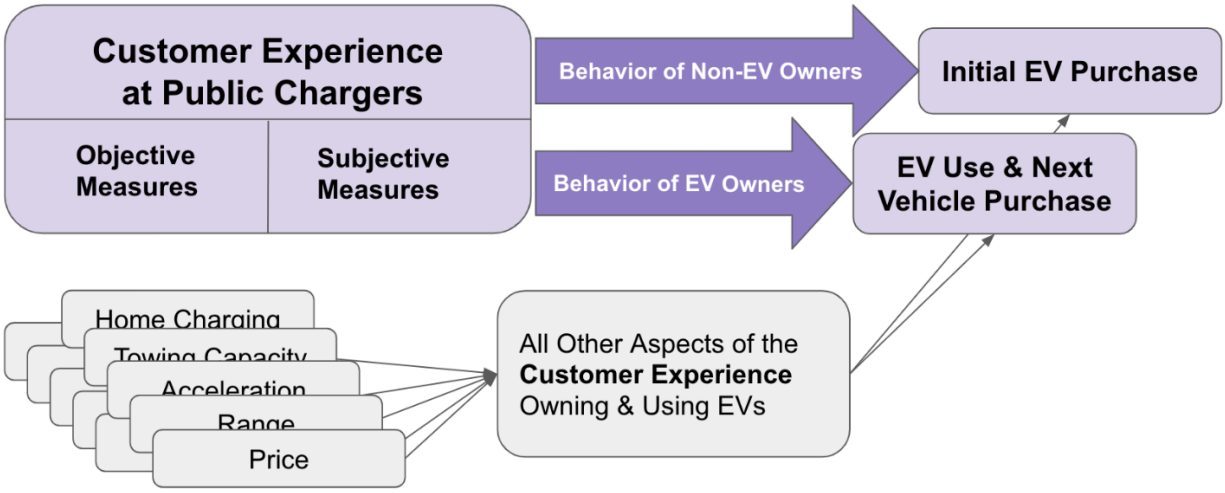

Figure ES-1. Conceptual model of how the customer experience impacts EV adoption.

The study found a large body of published information on customer perceptions of the public charging experience and separate data on EV adoption but relatively little data covering the purple arrows on how the first affects the second. Surveys show that a growing share of EV owners have significant concerns about public charging stations involving non-functional or broken chargers, long charging times, distance between chargers, long waiting times, and high charging costs (Plug In America 2023). Consumer willingness to purchase an EV depends on a wide range of factors, including first cost, operating cost, acceleration, towing capacity, styling, range, and attitudes about climate change and vehicle emissions. However, among all these factors, a 2022 study by Consumer Reports found that concerns about charging logistics was the **most frequently cited reason** that first time buyers would not purchase an EV (Consumer Reports 2022a).

Moreover, a 2023 consumer survey from Plug In America, which collected data from over 3,300 EV owners, showed that existing owners with significant concerns about their experience at public charging networks were nearly **twice as likely** as those without such concerns not to purchase another electric vehicle (Plug In America, 2023). Researchers at the Institute for Transportation Studies found that dissatisfaction with the convenience of charging was a highly significant factor in causing owners to

discontinue EV use. In fact, the evidence for this effect was stronger than that for any other factor, including those related to concerns about safety, recharging costs, reliability, or range among those who discontinued EV ownership (Hardman and Tal 2021).

The 2023 Plug In America survey showed that the first wave of electric car buyers were strongly motivated by environmental concerns and are willing to tolerate difficulties when accessing public chargers. As EV adoption becomes more widespread, the next wave of EV drivers may be less forgiving of a poor public charging experience, which would tend to increase its negative impact on future EV purchases.

This study's review of the available data underscores the pivotal role of satisfaction with the overall charging experience in propelling the widespread adoption of electric vehicles. Moreover, the Plug In America data show that dissatisfaction with public charging has a large impact on willingness to purchase another electric vehicle. However, there is still a lot to learn to better understand how the quality of public charging affects EV adoption, including:

- How do objective measures of charging-station performance (e.g., the percentage of charging sessions that are completed successfully) affect subjective measures of the customer experience?
- How do subjective measures of customer experience affect the intent to purchase, use, and continue owning EVs?
- How do the above relationships vary across different customer segments?
- Which aspects of the public charging experience have the largest influence on EV market growth?
- What are the implications of answers to these questions on the development of key performance indicators and their targets for public charging stations?

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List of Abbreviations

Abbreviation	Description
CSO	Charging Station Operator, also referred to as Charge Point Operator
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
OEM	Original Equipment Manufacturer

Acknowledgements

We acknowledge helpful guidance and review from Idaho National Laboratory staff as well as the contributions of ChargeX Consortium members including representatives from ChargeHub, ChargePoint, Consumer Reports, Cool the Earth, Electrify America, EVgo, EVSession, General Motors, JD Power, New York Power Authority, Plug In America, and University of California, Davis

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1. Introduction

The market for EVs has grown rapidly, driven by a combination of technological change, market acceptance, and public policy. Motor Trend magazine named EV startup Lucid's Air sedan as its 2022 Car of the Year, Hyundai's IONIQ 5 its 2023 SUV of the year, and Ford's F-150 Lightning electric pickup as 2023 Truck of the Year (Evans 2022, Markus 2021, Seabaugh 2022), signifying EVs' arrival in the mainstream vehicle market. Prior to a small hike in 2022 due to supply-chain constraints, the price of lithium-ion battery packs had declined steadily for more than a decade (BNEF 2022, Goldie-Scot 2019). This has led to falling prices for EVs, causing some analysts to project price parity of EVs and gasoline cars in the next two to three years (Reuters 2022). EVs grew from 3.2 to 5.8% of new cars in the US from 2021 to 2022 and surpassed 10% of vehicles sold worldwide (Boston 2023). In addition to these consumer trends, 15 states, led by California (which constitutes 36% of the US market), will require all new light-duty vehicles sold to be zero emissions by 2035 (CARB 2022), and the European Parliament recently approved a similar phaseout of CO2-emitting vehicles (Das 2023).

Despite these trends, a rapid and durable transition to EVs is not assured, due in part to issues with access and reliability in America's network of public fast chargers (Krishna 2021, Slowik and Lutsey 2017). Poor reliability at public chargers has garnered attention in the automotive and popular press, particularly with consumers' tales of woe encountered on long road trips. Dvorak's (2023) account of her family trip with a rental EV in Nevada has been coined "fire valley" due to their unsettling experience. Despite her initial enthusiasm for electric vehicles, Dvorak's encounter with public charging, first hindered by a lack of available charging stations and, later, by issues of station reliability, left her with reservations about committing to an EV herself. Wolfe (2022) echoed a similar narrative, highlighting a common sentiment among enthusiasts turned skeptics of EVs after trying one. Following a series of frustrating charging experiences on a road trip, Wolfe found solace in returning to his own gas-powered car. Motor Trend's (2023) report documents the experiences of its own staff members with EV charging during winter road trips. Despite their ability to transform frustrating situations into opportunities for curiosity, a common thread of inadequate and undependable charging stations, as well as the time-consuming nature of frequent stops, ultimately left drivers dissatisfied. This notion has also been explored in the published literature, for example, by Karanam and Tal (2023), who found that unreliable charging—during long-distance travel, in corridors of low charger density, or when users do not have access to home charging—leaves EV owners stranded and in need of a lengthy tow.

The establishment of the Joint Office of Energy and Transportation under the Infrastructure Investment and Jobs Act signifies a concerted federal effort to accelerate vehicle electrification and address these barriers. The Joint Office is a collaborative initiative between the United States Department of Energy and the United States Department of Transportation to improve EV infrastructure with four programs: the National Electric Vehicle Infrastructure Formula Program (NEVI), the Charging and Fueling Infrastructure Discretionary Grant Program, the Low or No Emission Vehicle Program for Transit, and the Clean School Bus Program (Joint Office of Energy and Transportation n.d.). The Biden-Harris administration has also launched the Electric Vehicle Charger Reliability and Accessibility Program, allocating $100M in funding improve public charging reliability (Joint Office of Energy and Transportation 2023). These programs represent a significant federal commitment to developing robust EV charging infrastructure and thereby reduce one of the key barriers to widespread EV adoption.

The Joint Office has also funded a team from three national laboratories to lead the National Charging Experience Consortium (ChargeX Consortium). Argonne National Laboratory, Idaho National Laboratory (INL), and the National Renewable Energy Laboratory are convening organizations representing a cross-section of the EV industry to address charging challenges. The Consortium has three different working groups, including one led by INL focused on identifying the pain points in the public charging experience and developing key performance indicators to provide specific targets for improvement.

While the notion that a robust public charging infrastructure is necessary to support vehicle electrification seems obvious, the public and policymakers do not have ready access to information about the magnitude of the effects of a poor public charging experience on EV adoption and use. To remedy this situation, INL, in its role as one of the convenors of ChargeX Working Group 1, contracted with the University of Washington's (UW's) Sustainable Transportation Lab to summarize current knowledge on the topic and identify fruitful areas for additional research in this white paper.

2. Conceptual Model

Figure 1 presents a conceptual model of the different factors that influence the decisions of non-EV owners to make an initial purchase of an electric vehicle and of EV owners to use their vehicle and to purchase another. The purple shaded boxes show the topic areas addressed in this study, with particular emphasis on how the customer experience of charging affects the behavior of EV owners and prospective buyers regarding EV purchase and use. This review covers both the objective measures of the charging experience, such as the percentage of charging attempts that fail on the first try, and subjective measures, such as customer perceptions of reliability. This review did not delve into the published data on all the other aspects of the customer experience of owning an EV that influence the purchase and use of EVs—e.g., vehicle price, range, and model types.

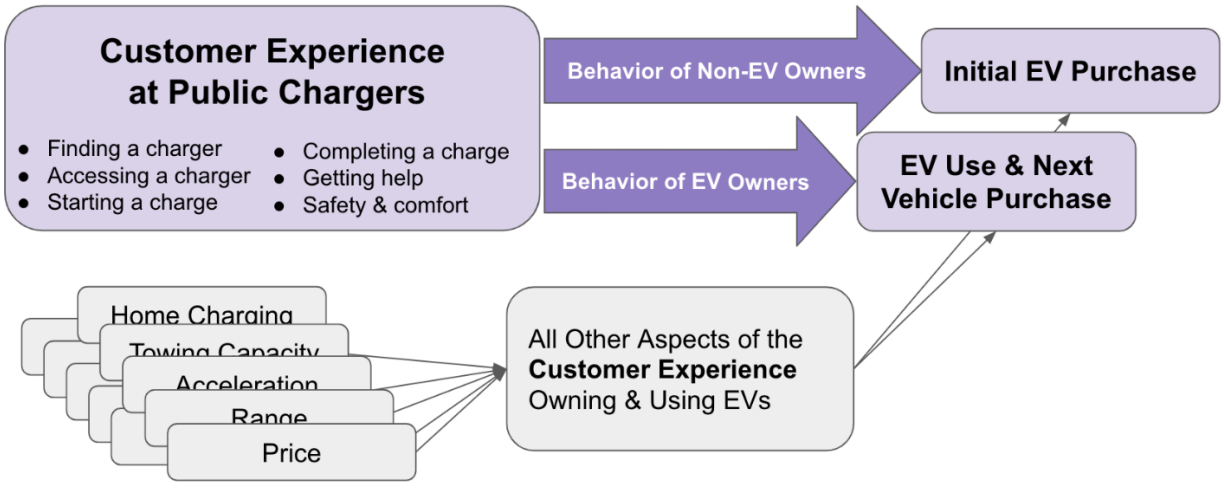

Figure 1. Conceptual model of how public-charging pain points impact EV adoption.

The ChargeX consortium has worked to develop a comprehensive list of customer pain points associated with public charging and has organized the customer experience into six categories that map to the customer journey for public charging:

- Finding a charger
- Accessing a charger
- Starting a charge
- Completing a charge
- Getting help
- Feeling safe and comfortable.

Each named step in the journey contains objective measures of a charging station's performance, subjective measures of consumer perceptions of those same attributes, and a relative impact on attitudes towards EV purchase and use.

This model helped this study focus on the review of available evidence and to avoid conflating one measure with another. For example, some surveys pose questions about charging in general, which combine EV owners' home and public charging experiences. Other studies have evaluated the number of charging stations and their distance from users without any measures related to reliability once EV owners arrive at a station. Counts of complaints about difficulty resolving problems with payment or unsafe charging locations were sometimes mixed with complaints about inoperative charging equipment or vandalism.

Other working groups in the ChargeX consortium are focused on resolving the technical challenges of reliably starting and completing a charge across a range of different charging equipment and vehicle makes and models. That work is essential to improve the overall customer experience at public chargers. This conceptual model also provides a reminder that objective measures of charging-session reliability are a subset of a broader set of measures that characterize the performance of a public charging station that shape customers' subjective perceptions. These, in turn, shape their behavior regarding the purchase and use of EVs. With this conceptual framework in view, the remainder of the document will now focus on the different measures of customer experience that emerged from the literature review.

3. Measures of the Customer Experience at Public Charging Stations

EV manufacturers, charging-network operators, and public agencies have not yet converged on a set of consistent metrics for evaluating the public charging experience. Precise definitions of measures, the methods for collecting them, and results by station location are viewed as proprietary by the charging networks. Studies of consumer perception conducted by private research firms also pose different questions, and many results are not made public. Indeed, it is this lack of clarity and consensus on what constitutes a measure of reliability in the charging experience that motivates the work program of ChargeX Working Group 1 to develop standard key performance indicators.

Table 1 shows measures of the different attributes of reliability and the charging experience defined by eight recent studies and organized into the categories developed during the summer of 2023 by ChargeX Working Group 1.

Table 1. Customer experience measures at public chargers identified in eight recent studies.

Elements of the Customer Experience	Measure of Charging Experience Identified in Review	Source
Finding a charger	Reviews and feedback from ChargeHub customers	1
	Price	2, 3, 8
	Price transparency	2
	Ease of finding the charger	3, 4, 7, 8
	Availability	2, 3, 7, 8
	Number of ports	1
	Diverse payment options	5
Accessing a charger	Charger accessibility (clear pathways, weather protection, manageable cables, etc.)	6
Starting a charge	Hardware issues	5, 6
	Charging issues	6
	Payment (initiation, options, ease)	3, 4, 5, 7, 8
	Ease of use	2, 3, 8
Completing a charge	Functionality	2, 3
	Charging efficiency	3, 5, 7, 8
	Uptime	4
	Failure rate (number of failed charge cycles)	4
	Utilization (number of sessions per month, charging hours per month, plug-in time, etc.)	4, 6
	Mean time between failure	4
	Vehicle failure rate (vehicle fails, EVSE okay)	4
Getting help	Mean time to repair	4
Feeling safe and comfortable	Comfort	2, 8
	Location (convenience, things to do at the charger at charger, etc.)	3, 5, 7, 8

Sources:

1. Mogile Technologies, Inc., 2021
2. Fabianek and Madlener, 2023
3. J. D. Power, 2023
4. Alexander et al., 2023
5. Okoma, 2023
6. Mogile Technologies, Inc., 2022
7. Plug In America, 2023
8. Consumer Reports, 2022b

4. Public Charging for Many EV Owners is a Pain and Getting Worse

The public charging experience as measured across the preceding categories is poor for many current EV owners. A 2022 audit in the San Francisco Bay Area found that nearly 28% of public fast charge stations were unusable: 23% had "unresponsive or unavailable screens, payment system failures, charge initiation failures, network failures, or broken connectors," while another 5% had cables too short to reach the vehicle's charging port (Rempel et al. 2022). In its 2022 EV Experience survey, consumer research firm J. D. Power named "operability and maintenance a key issue," concluding that "the industry needs to do a better job of maintaining existing charging stations . . . one out of every five respondents ended up not charging their vehicle during their visit. Of those who didn't charge, 72% indicated that it was due to the station malfunctioning or being out of service" (J. D. Power 2022). Based on a series of interviews with industry stakeholders, Keith and Womack (2023) concluded that "network operators appear to have limited appetite for investment in maintenance, which may be explained by the challenging unit economics of public fast-charging stations when utilization is low."

Consumer satisfaction with public fast charging networks declined sharply in the last year, according to surveys by J. D. Power (2023) and Plug In America (2023). For example, Figure 2 and Figure 3 from Plug In America demonstrate a notable decrease in satisfaction with public direct current fast charging (DCFC) and the Tesla Supercharger networks due to breakage or malfunction between 2022 and 2023 (Plug In America 2023). Nonfunctional or broken chargers were the most-widely cited issue for public DCFC networks in both years and exhibited the largest year-over-year increase: more than 20 percentage points. Although the baseline satisfaction was much better for Tesla Superchargers than for other charging networks, satisfaction also decreased for the Tesla network from 2022 to 2023. Given Tesla's higher customer satisfaction with public charging, it is noteworthy to consider a 2022 Consumer Reports study that featured a 54% higher proportion of Tesla users than the Plug In America survey and reported over 85% customer satisfaction with public charging reliability.

Kurani and Ogunmayin (2023) observe that, while early adopters are willing to endure the inconvenience of searching for a charger that may be "unavailable, inaccessible, or non-functional," the next wave of EV buyer may not have the same tolerance. The Plug In America report speculated that the entrance of these more-mainstream customers had contributed to the decline in satisfaction. Similarly, it is possible that EV drivers embarked on more road trips in 2022 than in 2021 because pandemic concerns began to recede, and all this resulted in a heightened usage of public charging networks (Plug In America 2023). The fact that performance got worse on every single measure of public charging satisfaction, for both Tesla and public networks, suggests a change in the composition of the survey sample towards less-forgiving customers rather than across-the-board declines in performance, especially with factors such as cost to charge, which did not change significantly from 2022 to 2023. If these changes in satisfaction are indeed due to a changing customer mix, they likely will only accelerate as EVs push further into the middle of the market.

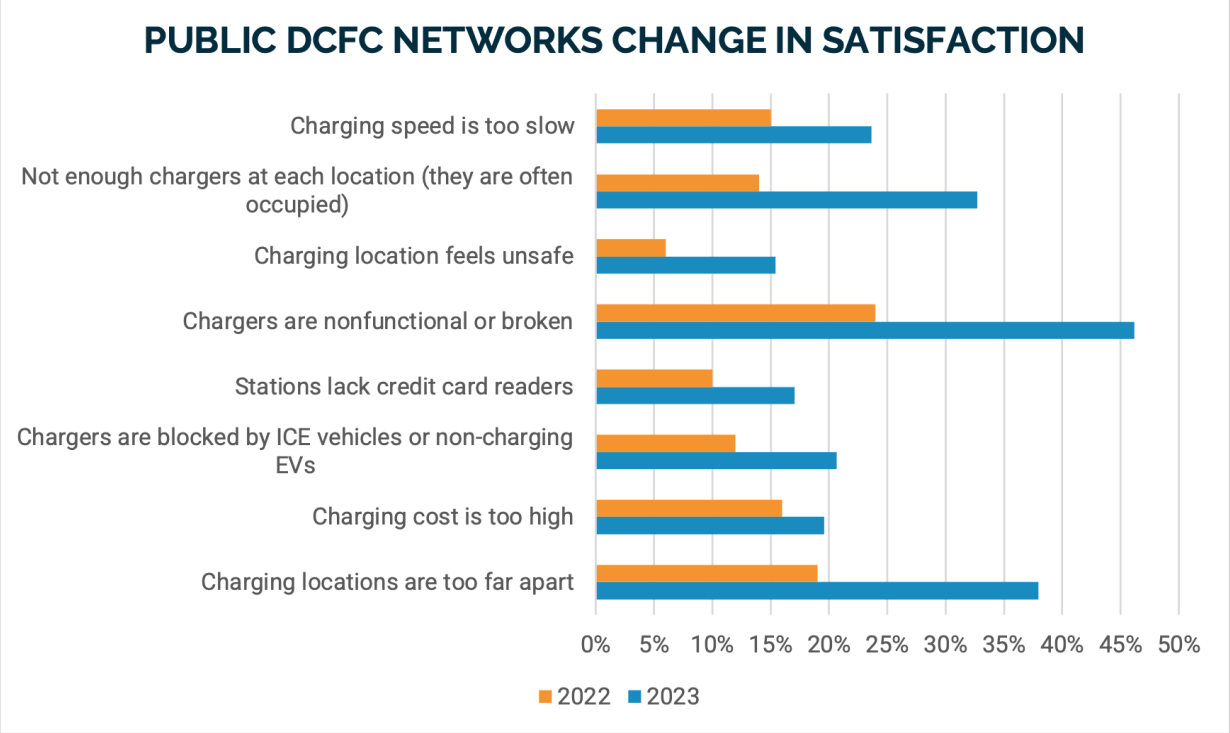

Figure 2. Public DCFC networks change in satisfaction (Plug In America 2023).

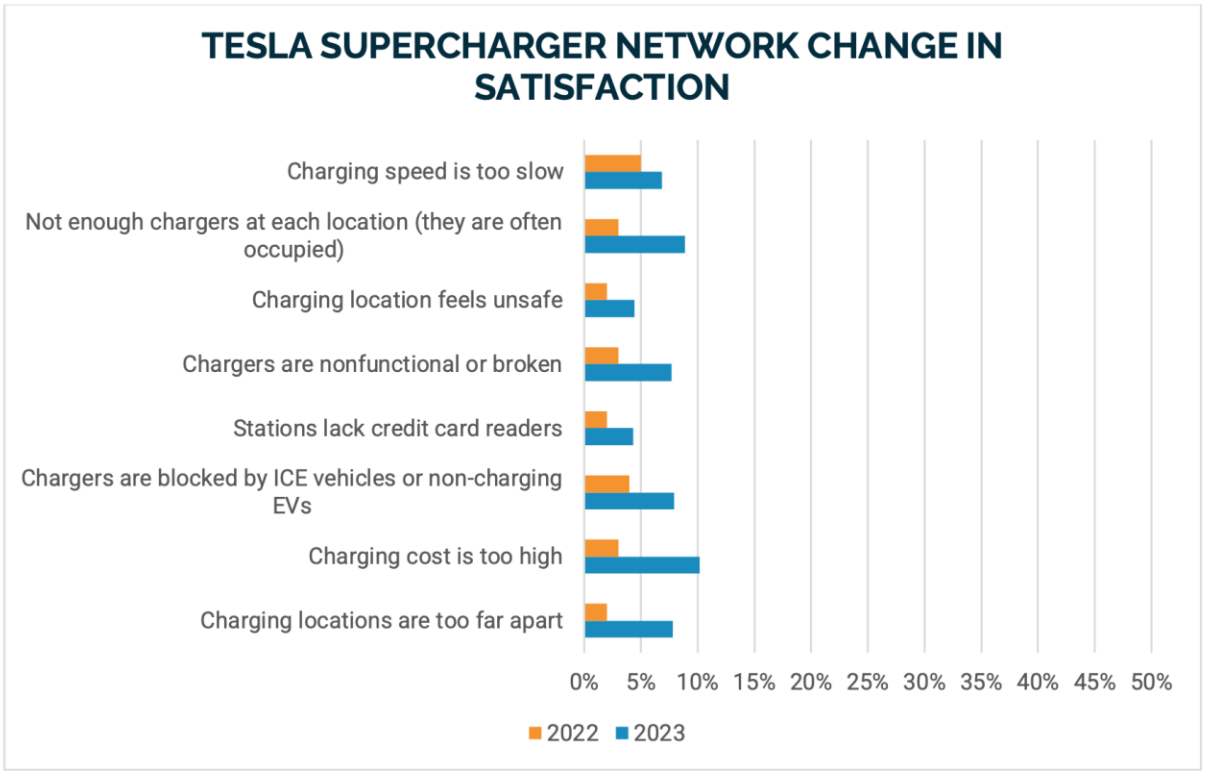

Figure 3. Tesla Supercharger network change in satisfaction (Plug In America 2023).

5. How Poor Public Charging Affects Willingness to Purchase

A lack of access to public charging stations reduces consumers' inclination to purchase their first electric vehicle. Much of the existing published research on this relationship has focused on the geospatial density of charging stations or their proximity to the respondent's home or workplace rather than their reliability, and most have not distinguished between slow- and fast-charging stations (Liao et al. 2017). According to J. D. Power (2023), for two consecutive years, nearly half of potential EV buyers cited the lack of public charging stations as their primary reason for rejecting EV ownership. Cox Automotive in 2022 made similar findings, reporting that 32% of individuals considering an EV purchase identified insufficient charging stations in their area as a significant barrier to making the purchase, ranking second only to concerns about vehicle cost (Cox Automotive 2023). Furthermore, multiple studies have identified a substantial positive correlation between charging infrastructure and EV-adoption rates at various scales, including the national level (Sierzchula et al. 2014), regional or state level (Mersky et al. 2016, Okoma 2023), and the municipal level (Egnér and Trosvik 2018). An increased number of public chargers offers practical improvements to the utility of driving an EV and also signals a change in social norms that makes purchasing an EV more acceptable to prospective buyers (White et al. 2022)

Although access to public charging is necessary, access to an unreliable public charging station is unlikely to sustain growing market adoption. The AAA Consumer Attitudes Electric Vehicles report revealed that 92% of the survey respondents who are likely to buy an electric or hybrid vehicle consider overall reliability somewhat or very important (AAA 2018). While this survey addresses overall reliability, rather than public-charger reliability, together with the data on how charger accessibility affects new customer purchases, it seems safe to infer that charger availability and reliability are important to customers considering their first EV purchase.

In response to a request for this study, staff at Plug In America ran custom analysis of their survey data to explore how their data on owner satisfaction with charging networks influenced their willingness to purchase another EV. Their analysis revealed that the EV owners with at least one major concern about public charging networks (n = 1,365) were almost twice as likely (Figure 4) as those with no major concerns (n = 1,151) to indicate that their next car would not be electric. This large effect of poor public charging on willingness to purchase another EV is among current EV owners, a group that includes many early adopters who are motivated by the environmental benefits of EVs and are more tolerant of challenges with charging (Plug In America 2023). As the next wave of EV customers interacts with public charging systems, the effect of negative charging experiences on reducing future EV purchases may increase. If this were to occur, more first-time EV owners would likely return to internal-combustion engine vehicles and thus a flattening of the curve of EVs as a percentage of the vehicle fleet over time.

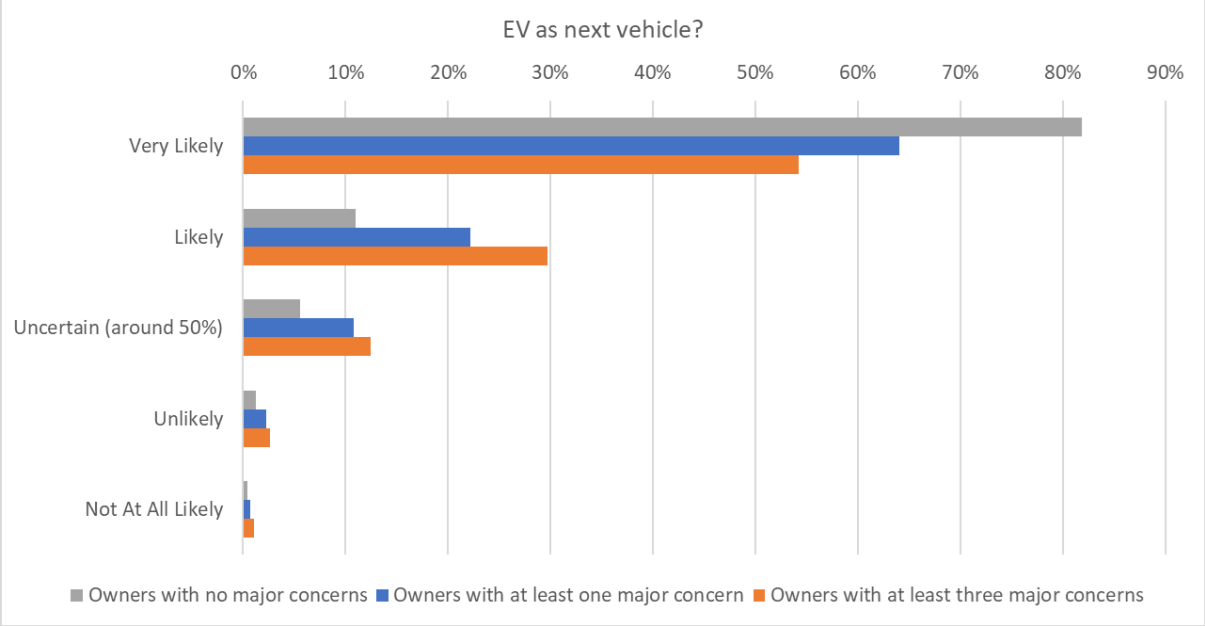

Figure 4. Likelihood of EV purchase based on concerns about public charging. (Plug In America custom analysis). Separately, researchers at the Institute for Transportation Studies explored the reasons EV owners returned to internal-combustion engine vehicles using data from five questionnaire surveys of EV owners in California between 2015 and 2019. From among the sample of 1,672, Hardman and Tal (2021) found that dissatisfaction with the convenience of charging among those who discontinued EV ownership was a highly significant factor in causing owners to discontinue EV use. In fact, the evidence for this effect was stronger than that for any other factor, including those relating to concerns about safety, recharging costs, reliability, or range. While the survey question did not distinguish between public charging and at-home or at-work charging, the research provides supporting evidence that a poor public charging experience had a significant effect on the discontinuance of EV use among early adopters in California.

6. Areas for Additional Research

This study did not locate any publicly available reports that estimated how changes in measures of the customer experience at public charging stations affect the willingness to purchase and use electric vehicles among existing and prospective EV owners. This study did find research that shows a lack of accessibility to public chargers matters to new EV buyers, but there are no estimates of the separate effects of perceptions of accessibility, charger reliability, customer service, safety and station amenities on the willingness to purchase and use an EV. This study has shown that EV owners who are dissatisfied with public charging are twice as likely not to purchase an EV and that dissatisfaction with charging convenience outweighs other all factors in motivating discontinuance of EV ownership. However, it is unknown how the effects of a poor public charging experience will change among the next waves of EV buyers, nor can it be disaggregated from the different aspects of the public charging experience to determine which factors matter most.

Additional research could address wide range of questions including:

- How do objective measures of charging-station performance—e.g., precisely defined charging-session success rates from data generated by charging equipment—affect the subjective measures of the customer experience (e.g., customer-satisfaction metrics)?
- How do subjective measures of customer experience affect the intention to purchase, use, and continue owning EVs?
- How do the above relationships vary across different customer segments?
- Which aspects of the public charging experience have the largest influence on EV market growth?
- What is the relationship between key performance indicators—under development by the ChargeX Working Group 1—and EV purchase and use for different customer groups?

7. Conclusion

While studies and reports characterize the customer experience at public chargers, and other studies evaluate factors influencing EV adoption, there is a notable gap in the data and literature linking the two. ChargeX Working Group 1 is developing key performance indicators as one mechanism to help improve the public charging experience. Better and more consistent metrics on the customer experience at public charging stations could also help inform how unreliable public charging affects consumers' willingness to purchase and use EVs. Improving the public charging experience will undoubtedly increase the pace of EV purchases and use. Among the current generation of EV owners, this study had found that those with at least one major concern about the public charging networks are twice as likely to revert to an internal-combustion vehicle for their next vehicle purchase. The next generation of EV owners may prove even less forgiving of a poor-quality public charging experience. A better understanding of how the quality of the public charging experience affects the propensity to adopt EVs could help set performance metrics for charging stations and ensure that EV adoption meets state and federal goals in the coming years.

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