Analyzing the Business Case & Consumer Preferences for

FAST CHARGERS IN CALIFORNIA

A PROJECT OF

NEXT 10

UC DAVIS Electric Vehicle Research Center
Institute of Transportation Studies

September 2024

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September 2024

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Acknowledgements:

Thanks to Stefan Mabit (Technical University of Denmark) for their work on designing the choice experiment used in this questionnaire survey, thanks to Matthew Favetti (UC Davis) for programming the survey used in this study.

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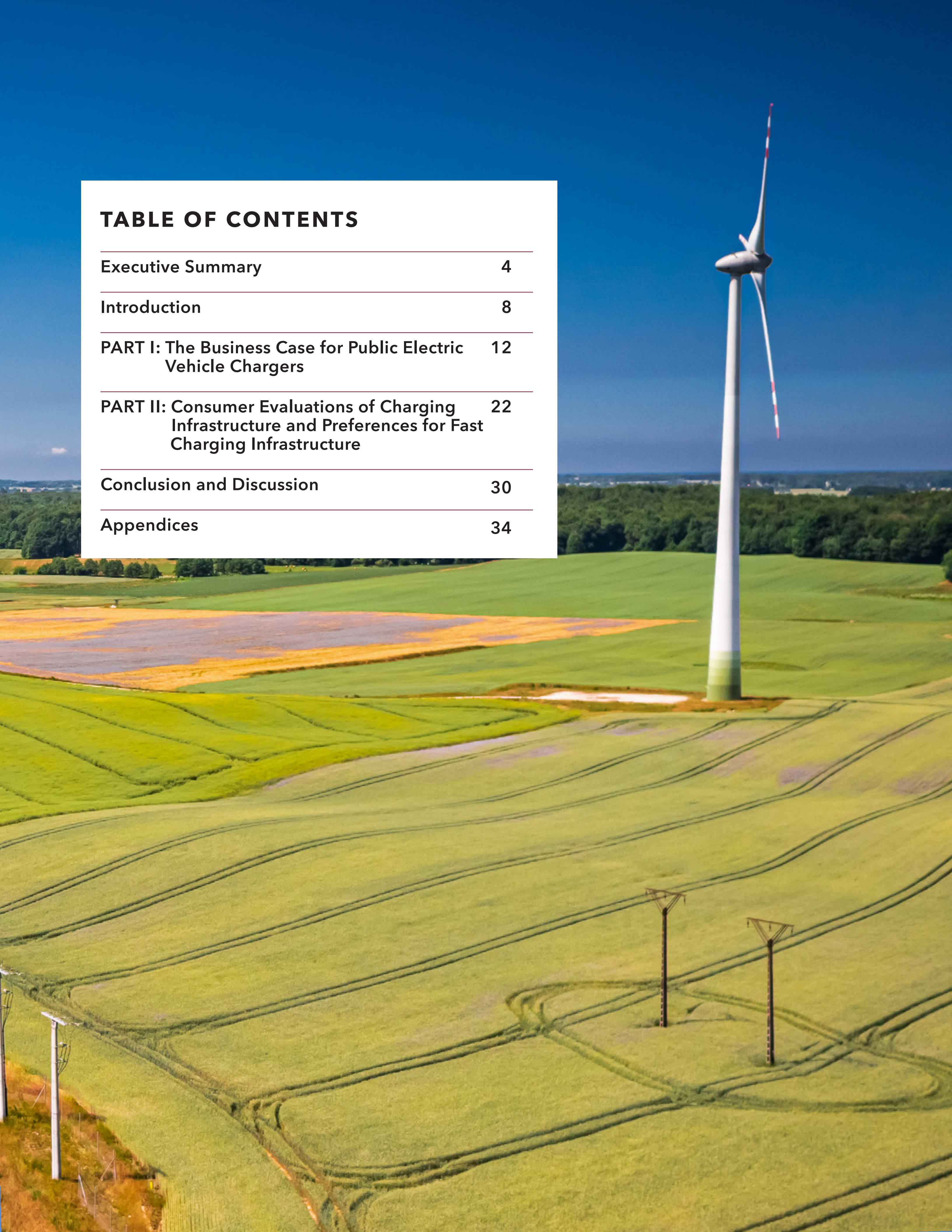


TABLE OF CONTENTS

Executive Summary

Electric vehicle charging infrastructure is currently heavily subsidized in the United States at local, state, and federal levels. The future success and growth of charging infrastructure to meet future electric vehicle (EV) demand will likely require chargers to become a sustainable business independent of government intervention. Public funding alone is unlikely to be sufficient to build the necessary network of charging to meet the needs of drivers, without funding or a viable business model providers could be less likely to deploy electric vehicle supply equipment (EVSE), and if chargers are not profitable, providers may have no reason to continue to operate and maintain the infrastructure.

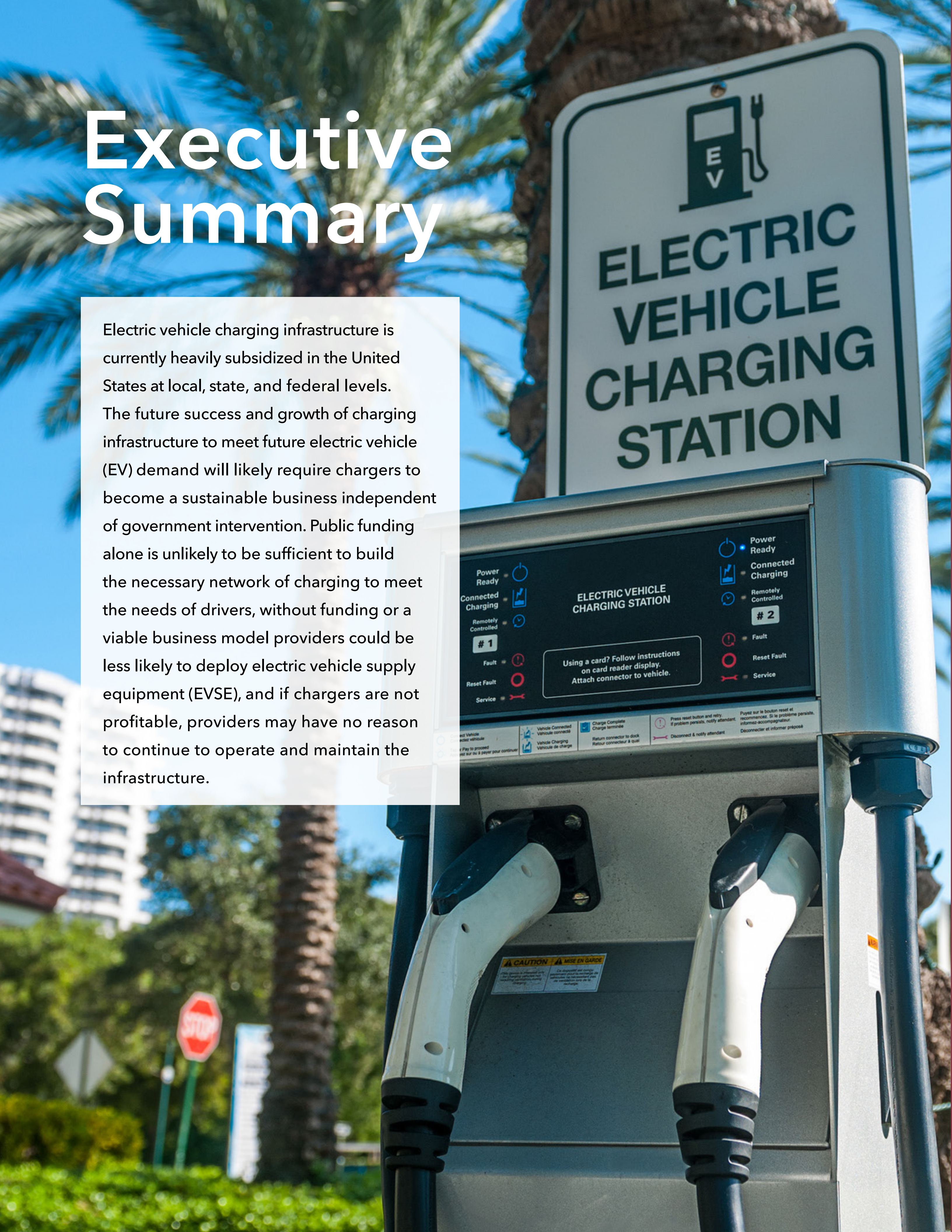
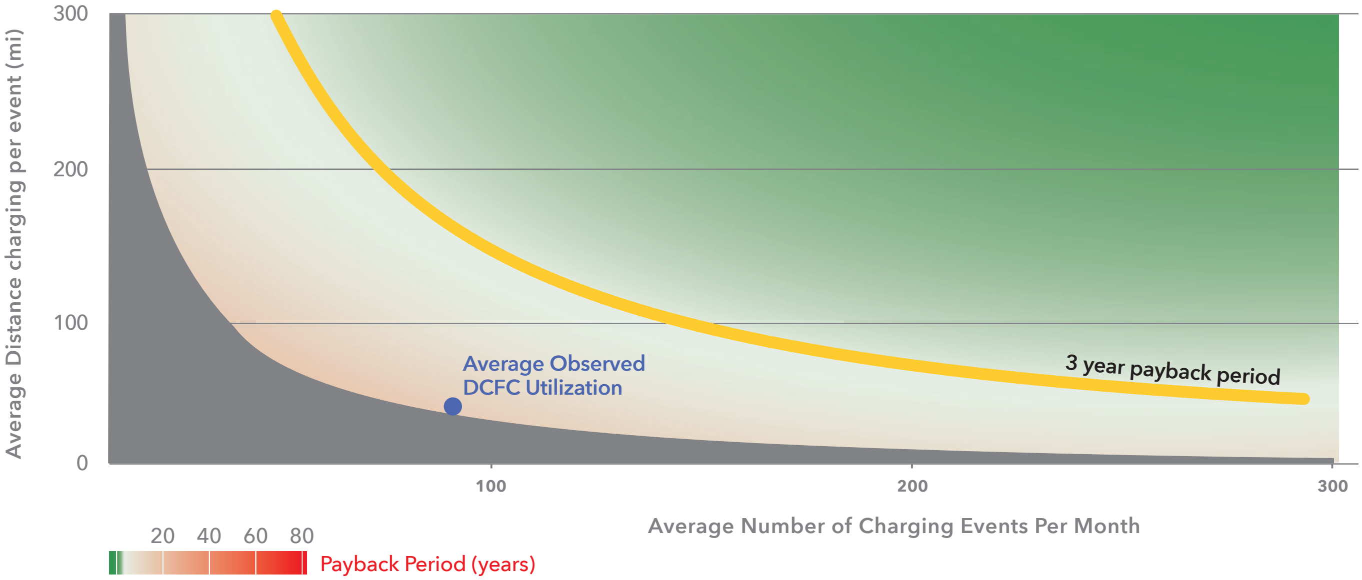


FIG ES.1

Time to Payback a DC Fast Charger Based on Station Utilization and Duration of Charging Sessions



Note: Assumes a $30,000 capital cost, a $0.1065/kWh electricity rate paid by the service provider, and a 10% discount rate. The grey portion of the graph represents DC fast charging never recovering costs.

This study examines the business case of electric vehicle chargers, focusing specifically on DC fast chargers and investigates EV driver charging behavior and preferences for charging. This analysis employs empirical datasets, with rate plans down to the charging plug level and utilization data representing several major charging networks with over 5 million individual charging events across 1,300 DC fast chargers in California. Then, the report explores EV driver charging behavior and preferences for public DC fast charging (DCFC) based on survey responses of 1,086 electric vehicle owners in California. The purpose of this report is to analyze both the demand and supply sides of EV charging infrastructure to understand the business case for DCFC and understand where chargers could be cited so they are most useful to consumers while also providing potential additional revenue for businesses to help make them more financially feasible.

Analysis of EV Charger Utilization and Investment Payback

The analysis of business cases finds that for charging rates based on energy [$/kWh] or a combination of energy and time [$/kWh and $/hr.], customers pay an average of about $0.124/mi and $0.129/mi, respectively. Rates based solely on time (dominated by the Tesla Supercharger network) are substantially cheaper at $0.084/mi. However, when coupling these findings with utilization data and comparing it to costs associated with charger deployment, the analysis finds that the revenues are nowhere near able to pay back the capital and operating costs of the even DC fast chargers with the lowest installation cost over a three-year period, a commonly used payback period for businesses—even when doubling the average number of events and amount of energy dispensed to charge vehicles (Figure ES.1).

Even under these favorable assumptions, the required utilization of the charger is quite high—especially relative to the average observed utilization of the charging infrastructure which is nearly unable to recover its initial capital costs at the assumed discount rate much less than reach a 3-year payback. The average observed utilization is far over a 10-year period and close to the grey area which indicates the investment never paying off because utilization and the difference between energy sold and energy purchased by the provider isn't sufficient to cover costs.

This report also conducted a spatial analysis of local businesses and services co-located with EV chargers. This analysis shows public chargers experience more utilization when they are located within 500 meters of both dining services (with an average increase of 2.7 charging events per month per nearby restaurant) and grocery stores (with an average increase of 5.2 charging events per month per nearby grocery store). The relationship between service availability and station utilization point to compounding evidence that drivers prefer stations with amenities. Chargers could therefore bring more customers to businesses (improving business revenue) or DCFC could be located with amenities also owned by charging providers to provide a viable source of alternative revenue to help breakeven on EV charger costs.

Questionnaire Survey Results

Results from the survey of 1,086 electric vehicle owners in California finds drivers charge at a variety of locations including at home and away from home, though most charging occurs at home (2/3 of respondents charge at home 90 percent of the time or more). Drivers appear to prefer home charging over public charging, perhaps due to perceiving public charging as more costly and less convenient than home charging. About 1/3 to 2/5 of drivers report that they would likely discontinue EV ownership in the absence of home charging, which underscores the importance of increasing home charging access.

Nevertheless, public DC fast charging is needed to facilitate long distance travel, occasional charging needs, and to support electric vehicle adoption for those without home charging access. Therefore, the authors designed a choice experiment to understand preferences for public fast charging of EVs on long distance trips. This experiment finds drivers prefer faster chargers, chargers that are closer to travel routes, chargers with no chance of waiting or a shorter wait time, chargers that are cheaper, and chargers with amenities such as restrooms, cafes, and restaurants. Table ES.1 shows willingness to pay for reductions in charging time, detour time, the chance of waiting, and wait time.

TABLE ES.1

Estimates of Willingness to Pay for Reductions in Charging Time, Detour, Charge Wait, and Wait Time per 100 Miles of Charging

	Willingness to pay ($/100 miles)
1 minute reduction in charging time	0.66
1 minute reduction in detour time to charger	0.48
No chance of waiting at charger	0.94
1 minute reduction in wait time at charger	0.39

These values can be converted to a $/kWh basis. The results show drivers are willing to pay an additional:

- $0.184 more per kWh for an increase in charger power of 100 kW
- $0.034 more per kWh for a 1-minute reduction in detour time to the charger
- $0.014 more per kWh for a 1-minute reduction in wait time at the charger
- $0.034 more per kWh to use a charger with no chance of waiting

Consumers therefore value reductions in charging time (or increases in charger power) and detour time to a charger and prefer not having to wait for a charger.

In addition, drivers are 37 percent more likely to choose a charger with additional amenities (for example restrooms and convenience stores). The presence of these amenities will increase charging station utilization, contributing to station revenue, and could be an additional source of revenue to offset infrastructure costs which could improve the business case for DC fast charging. The analysis of long-distance trips also finds that the presence of additional amenities at a charge location is significantly related to charging choices, with a relatively high estimate.

The highest percent of respondents indicated that would choose to charge at rest stops, which may indicate a preference for on-travel route charging. After rest stops, charging at malls, parking garages, and restaurants were the most commonly selected, indicating that drivers also prefer charging at destinations they frequently travel to or have opportunities to do other activities while they charge.

This analysis highlights the importance of home charging and shows which attributes of DC fast electric vehicle chargers are most valued, and how these influence drivers charging choices. The results also highlight that additional amenities at charging locations would significantly increase charging station utilization (aligning with the data on station utilization) and could provide additional revenue to infrastructure providers. This study shows that the current model of public DCFC may not be profitable in absence of public funding. However, business models of DCFC that co-locate DCFC with amenities may be a route to the profitability of DCFC.

Policy Implications

Given the current challenges in achieving a return on investment for DC fast-charging stations, a comprehensive policy framework is crucial for sustainable development and operation. The final section of the report outlines a range of policy options and recommendations aimed at mitigating financial risks, promoting utilization, reducing costs, and educating stakeholders. These actions include the following, with further detail in the last section of the report:

- *Continued Subsidy Support for Infrastructure:* This should include balancing subsidies to not over incentivize organizations installing EVSE only because of subsidies and with no consideration of the sustainability of EVSE locations. Subsidies could also include operation and maintenance subsidies to lower the cost of maintaining EVSE. Decision-making about who receive subsidies should include metrics that encourage grantees to consider the long-term sustainability of EV charging locations.
- *Measures to increase EV charging utilization:* This should incentivize the strategic placement of chargers (including locating them in areas with amenities) as well as the development of charging stations with faster chargers and higher quantities of chargers in order to reduce wait times.
    - » *Collocating chargers with amenities:* Charging locations should be located close to travel corridors, be co-located with amenities (stores, restaurants, etc.), and have enough fast charging outlets per location to reduce wait times.
- *Decreasing Charging Installation Costs:* This could be through cost reductions in construction methods and charging equipment, and universal charging standards. Developing and adopting universal charging standards (including for equipment) can decrease manufacturing and maintenance costs.
- *Education on Charging Infrastructure Opportunities:* Policymakers should actively demonstrate the revenue-generating potential of hosting charging stations to local businesses. A focus can be placed on research and data that shows increased dwell times at charging stations leading to higher local retail sales, thereby presenting a win-win scenario for both EV drivers and businesses. Policymakers can also initiate partnerships with educational institutions and develop public outreach campaigns.

Results from the survey analysis highlight the importance of home charging access. Home charging is cheaper, more convenient, and highly influential in the decision to buy an EV. Support for home charging could include the following measures.

- *Allocating a portion of public funding to support home charging efforts:* This could include allocating funding to home charging programs in government programs. This could focus primarily on households who cannot afford home charging installation or households with difficulties installing a home charger (e.g. renters or those living in apartments, or who park on street), and could include incentives to cover charging installation cost, installation of charging in charged parking lots, or wherever drivers park their vehicles.
- *Providing incentives for charging equipment and installation costs:* Governments should consider continuing and expanding programs that already exist to help households obtain home charging access.
- *Requirements for installation at existing buildings:* Some State and Local governments have introduced requirements to install charging at new buildings or prepare new buildings for charging installation. Policymakers could explore these regulations, potentially requiring charging installation in existing multiunit buildings at a rate like the rate of EV adoption among vehicles on the road (current EV adoption is around 5% in California).

Introduction

Electric vehicles (EVs) are a crucial technology for the decarbonization of the transportation sector. Governments around the world have enacted policies supporting EV market growth from ambitious fuel efficiency standards (Corporate Average Fuel Economy standards[1] in the US and the EU CO_2 emission performance standards[2]) to mandating their sales (Zero Emissions Vehicle regulation in the US,[3] Canada,[4] and Korea,[5] as well as the New Energy Vehicle regulation in China[6]) and even as far as banning the sale of gasoline vehicles.[7,8]

Thanks in part to these policies, electric vehicle sales have grown substantially, reaching 14 million sales in 2023 alone, an increase of 35 percent compared to 2022.[9] The advent of EV technology has simultaneously led to the deployment of electric vehicle charging infrastructure, which is sometimes also called electric vehicle supply equipment (EVSE) and includes the associated infrastructure necessary to charge EVs. As seen in Figure 1, the relationship between the number of chargers and the number of EVs on the road varies from country to country, but given the rapid growth in sales of EVs, there will almost certainly be an associated rise in charging infrastructure deployment. The effect of public charging infrastructure on the adoption of electric vehicles cannot be overstated.

Several studies have shown that infrastructure is needed to support electric vehicle market, though perception of density appears to be more important the actual number of stations.[10,11,12,13] Due to the often-ambiguous terms related to charging infrastructure, we explicitly define the terms charging stations, EV chargers, and plugs. An "EV charger" is the term we will use throughout this work to describe the technical term Electric Vehicle Supply Equipment (EVSE), the above-ground appliance that is often associated with the "box" of hardware containing electrical conductors, related equipment, software, and communications protocols that delivers energy to the vehicle. A charger can have one or more connectors and plugs, and a charging station consists of all the chargers at a single location. A charger is characterized as alternating current (AC) at Level 1 (1 kW) or Level 2 (commonly 6-7 kW, theoretically as high as 20 kW), or as a direct current fast charger (DCFC, 50 kW-350 kW).

Unlike the current model of conventional vehicle fueling at gas stations, EV charging can occur in a much wider variety of locations including at home, at the workplace, and in public locations. While most charging currently happens at home,[14] public charging can play an important role to provide supplemental charging, corridor charging, support long distance travel, provide confidence in EV technology, and even boost the adoption of EVs. As electric vehicles continue their market growth, this must be accompanied by a rapid deployment of charging infrastructure to meet their charging demand. This is reflected in policies such as California's Executive Order requiring 250,000 charging stations by 2025 and a federal US mandate to install a charger every 50 miles across the national highway network.

Fortunately, the installation of charging stations around the United States has enjoyed strong government support, especially with monetary incentives including the California Electric Vehicle Infrastructure Project (CALeVIP), California's Low Carbon Fuel Standards, and the National Electric Vehicle Infrastructure (NEVI) program which

1 National Highway Traffic Safety Administration. Federal Register Vol. 87, No. 84. May 2, 2022.

2 Regulation (EU) 2019/631 of the European Parliament and of the Council of 17 April 2019.

3 California Air Resources Board. Zero-Emission Vehicle Program. https://ww2.arb.ca.gov/our-work/programs/zero-emission-vehicle-program

4 Government of Canada. 2030 Emissions Reduction Plan: Clean Air, Strong Economy.

5 Clean Air Conservation Act Chapter 4 Article 58-2 "Deployment of low-emission Vehicles".

6 China's Ministry of Industry and Information Technology (MIIT). New Energy Vehicle mandate. September 27, 2017.

7 Governor Gavin Newsom. Executive Order N-79-20. https://www.gov.ca.gov/wp-content/uploads/2020/09/9.23.20-EO-N-79-20-Climate.pdf

8 Nick Carey and Christoph Steitz. "EU proposes effective ban for new fossil-fuel cars from 2035". Reuters. July 14, 2021. https://www.reuters.com/business/retail-consumer/eu-proposes-effective-ban-new-fossil-fuel-car-sales-2035-2021-07-14/

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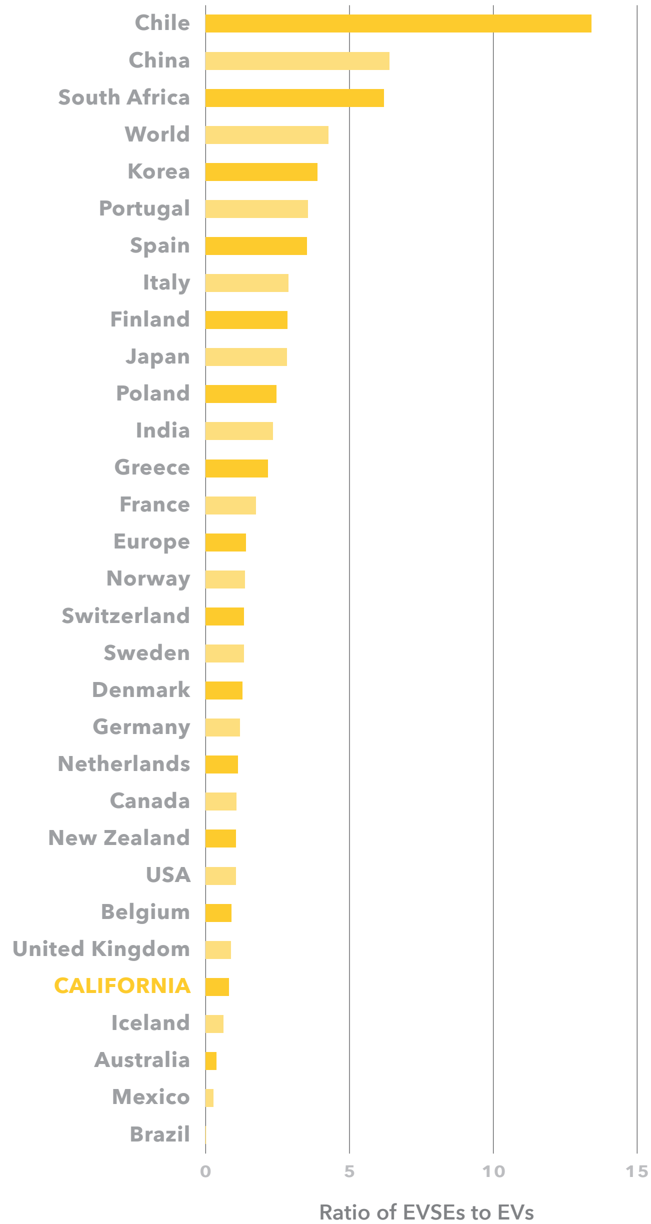
will provide $5 billion in funding for the deployment of charging stations. Yet, the landscape of charging infrastructure continues to rapidly evolve, especially with recent developments pointing to a transition towards the North American Charging Standard (NACS)—traditionally a standard only being used by Tesla. Since the beginning of 2023, Ford, GM, Rivian, Volvo, Fisker, Honda, Nissan, Polestar, and Mercedes-Benz have all announced their intentions to migrate away from the Combined Charging Standard (CCS) for their vehicles to NACS beginning with 2025 model year vehicles.[15] While this has implications for vehicle manufacturing and access, the overall cost of infrastructure is unlikely to be substantially affected because the change in connector is a minute component of the total cost of infrastructure. While the analysis in this study does not include government incentives, it should be noted that support from the NEVI program is unlikely to change either, as the incentives do not preclude the ability of installers to include additional NACS connectors, though they do require a minimum of four CCS chargers per location.

The value of additional public infrastructure to support electric vehicle adoption has been demonstrated as a necessity to meet future charging demands.[16,17] This need has been estimated to be at a minimum one DC fast charger for every 1,000 EVs on the road,[18] a threshold that the US is currently meeting at about 20 DCFCs per 1,000 BEVs. California is even further ahead at 10 DCFCs per 1,000 BEVs. Several studies have also shown that populations of EV drivers place a high value on public fast chargers, particularly in cities and along highways[19] with willingness-to-pay values from drivers as high as $6,500 per additional charger.[20] A California based study found that even from the perspective of economic impact from emissions reductions, the benefits from charging infrastructure deployment already offset

FIG 1

Number of Publicly Available Fast Charging Stations per 100 BEVs in 2023



Data Source: Global EV Outlook, 2024

15 Caranddriver, 2024, Tesla Charging Network: All the Upcoming Compatible EVs, https://www.caranddriver.com/news/a44388939/tesla-nacs-charging-network-compatibility/

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the costs in the majority of counties in California.[21] However, for the technology to be successful, the infrastructure must also ultimately become economically viable without government intervention. This study examines real-world operation and pricing of public charging infrastructure to determine the extent that current day charging infrastructure have viable business cases, and explores what factors related to EV drivers' choice of EV charging station using results from a questionnaire survey.

In this report, we first investigate the business case for public DCFCs by considering charging station utilization rates, which shows DCFCs in California may not be profitable at current utilization rates, among other findings. After that, the report presents survey findings in an effort to understand the factors that influence EV drivers' choices of charging stations, and how the presence of amenities (that could be an additional source of revenue) impacts EV drivers charging station choices. The purpose of this report is to understand first whether EV fast charging stations are profitable, something that may be necessary to ensure the long-term sustainability of public EV charging (and the EV market), and to explore how EV charging station utilization could be increased, which is something that can support station profitability. This issue is investigated from both the perspective of charging station use data and the survey of EV drivers in California.

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PART 1

The Business Case for Public Electric Vehicle Chargers

To understand the business model of electric vehicle charging infrastructure, the report examines a combination of factors related to both chargers and charging behavior. Fortunately, many of these factors have been investigated in the literature. Beginning with charging behavior, this is a critical factor to determine the utilization of charging infrastructure. While earlier studies in this area relied primarily on modeling charging behavior, often drawing analogies to traditional gasoline vehicles, there are several pitfalls that must be avoided to accurately simulate EV specific behavior.[22]

Other approaches have been taken to elicit behavior in stated preference surveys to understand how drivers currently charge their vehicles[23] or to understand how critical factors such as location, pricing, and demographics may affect behavior.[24,25] However, the availability of empirical data has allowed for substantive revealed preference studies to determine real-world charging patterns[26,27] and even enabled detailed price responsiveness studies.[28,29] This study falls in-line with the latter body of work that leverages real-world data, as described in more detail later in this work, we employ a combination of millions of charging events across several charging network service providers.

Behavioral elements point to driver-side levers that affect the economics of public infrastructure. On the other side of the equation, technical elements of chargers related to power of charging and strategic planning of locations of deployment are both critical aspects of costs that ultimately also affect the economics of chargers.[30,31] However, the combination of these two elements has not been well researched across the body of literature related to the economics of public charging infrastructure and the necessary business case needed to support them. A review paper provides a qualitative assessment of the necessary factors needed to support deployment of infrastructure, though one of their key conclusions is that government support is necessary for initial deployment which is not necessarily a sustainable solution in the long run.[32] The closest analogies to this study is work which models potential business models to support the installation and deployment of charging stations[33] and another study which uses real utilization data but estimates feasible pricing schemes that allow for financial stability of charging services.[34] Unlike these previous works, our study conducts a business feasibility analysis entirely with empirical data on charging rates and utilization—we do not rely on assumptions modeling either behavior or pricing rates. This allows us to examine feasibility of current service plans and gain insight on the financial viability of charging stations absent government subsidies.

This section of the paper is organized as follows: an overview of the data and the analytical approach in the "Data and Methods" section. Following this, an overview of results including a summary of pricing rates throughout California, an in-depth view of utilization of DCFC public chargers, an analysis of the financial recovery rates for existing business models, and finally discussion of alternative revenue sources to support charging as a sustainable business within the "Results" section. Lastly, the report includes a discussion of the primary takeaways from the analysis.

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2.1. Data and methods

2.1.1. Pricing Rate Data

The analysis in this report focuses specifically on the state of California, which enjoys a relatively high volume of electric vehicles and a greater buildout of charging infrastructure across the state compared to the U.S. overall. For pricing, data was gathered from several major charging network provider plans, including Tesla Superchargers, EVgo, and Electrify America (Table 1). These prices are up to date as of June 2023 and will likely change as electricity rates change. For example, Electricity America pricing is currently around $0.56/kWh—an increase from the values used in the analysis. However, since the results depend on the difference in cost between commercial electricity rates and the price of EV charging per kWh (along with utilization rates and kWh per event), the results would be the same assuming this difference is unchanged.

Despite the plethora of charging stations represented by these service providers, they still represent a minority fraction of all public charging infrastructure available to Californians, as can be seen in Figure 2. The data in Figure 2 is collected from two sources: the Alternative Fuels Data Center (AFDC, a repository of public information about electric vehicles and EV infrastructure managed by the Department of Energy) and from PlugShare (a service that provides information about charging infrastructure from crowd-sourced data). While the data sources are not entirely consistent, they are relatively close in aggregate counts of number of plugs in California with AFDC reporting 37,348 and PlugShare reporting 39,302. However, it should be noted that these counts may be an underestimate of the true number of public charging chargers.[35]

In addition to the pricing plans from several major networks, both AFDC and PlugShare provide information on pricing for individual chargers in their data. While neither service has pricing information on many chargers in their respective systems, PlugShare has data on just about half of their listed chargers while AFDC is substantially more limited with just 16.5 percent of charger locations containing pricing information. To further confound the issue, pricing rates and structures can also be complicated. Besides differences in services charging by energy ($/kWh) or by time ($/hour), there are further nuances in rates that include: dynamic energy prices at different times of the day, free or discounted charging for a period before energy/hourly rates change, combinations of different rates, connections fees, and membership dues

TABLE 1

Pricing Plans in California of Major DC Fast Charging Networks Used in the Analysis

Network Provider	Pricing Plans
Tesla	• Tier 1 (≤60 kW): $0.17/min • Tier 2 (>60 kW & ≤100 kW): $0.45/min • Tier 3 (>100 kW & ≤180 kW): $0.84/min • Tier 4 (>180 kW): $1.35/min
Electrify America	• Guest: $0.43/kWh • Member: $0.31/kWh + $4 monthly fee
EVgo	Varies by location • Bay Area » Pay-as-you-go: $0.34/kWh » EVgo Member: $0.29/kWh + $4.99 minimum monthly » EVgo Plus: $0.25 + $6.99 monthly fee • Los Angeles » Pay-as-you-go: $0.32/kWh » EVgo Member: $0.28/kWh + $4.99 minimum monthly » EVgo Plus: $0.29 + $6.99 monthly fee • San Diego » Pay-as-you-go: $0.43/kWh » EVgo Member: $0.39/kWh + $4.99 minimum monthly » EVgo Plus: $0.29/kWh + $6.99 monthly fee

Note: 2024 charging prices in California are higher. For example, Electricity America pricing is currently around $0.56/kWh.

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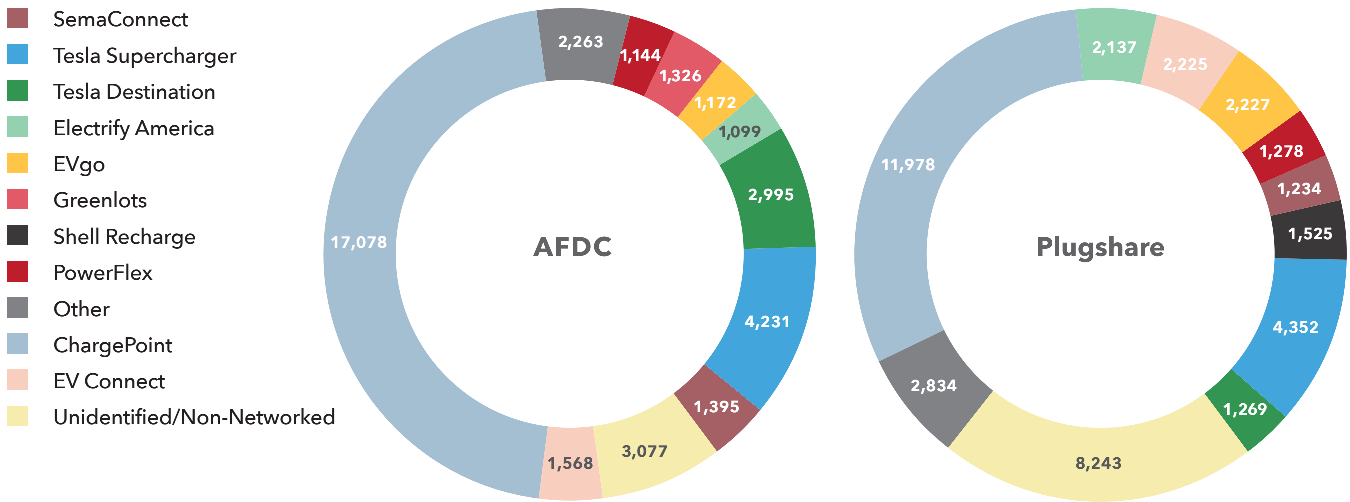
FIG 2

Comparison of the Number of Charging Plugs in California Broken Down by Charging Provider



Data Source: 2023 data from the Alternative Fuels Data Center (Department of Energy) and Plugshare (a crowd-sourced charger location app).

to name a few. With some simplifying assumptions, the categories of rate structures are generalized into those seen in Table 2.

To provide some context on the range of costs that drivers observe, Figure 3 provides distributions of costs extracted from the PlugShare data. For hourly charging rates (left panel), Level 1 and Level 2 charging have relatively similar hourly pricing rates ranging from $1 to $6 per hour with Level 2 having slightly higher-end pricing rates compared to Level 1. Even though Level 2 provides six to seven times more energy over any given interval of time compared to Level 1 charging, this is not reflected in pricing rates. However, when it comes to DC fast charging, hourly charges range from $40 to above $60 per hour—which better reflects the order of magnitude larger amount of energy dispensed by these chargers compared to Level 2 chargers. It should be noted that DC fast chargers have a much broader range of power levels varying from 50 kW to 350 kW—and while the pricing on an energy basis would be most sensible for a 50 kW charger, we observe that these prices are still observed at higher power levels indicating that hourly rates might be a better deal for drivers at these chargers. For pricing rates on an energy basis (right panel), there is still a very wide distribution of prices. Within Level 2 chargers, most prices range from $0.20/kWh up to $0.40/kWh (though the tails of the distribution extend farther in both directions). DC fast chargers have higher average prices at $0.40/kWh up to $0.60/kWh, representing premiums paid by drivers for faster charging speeds.

TABLE 2

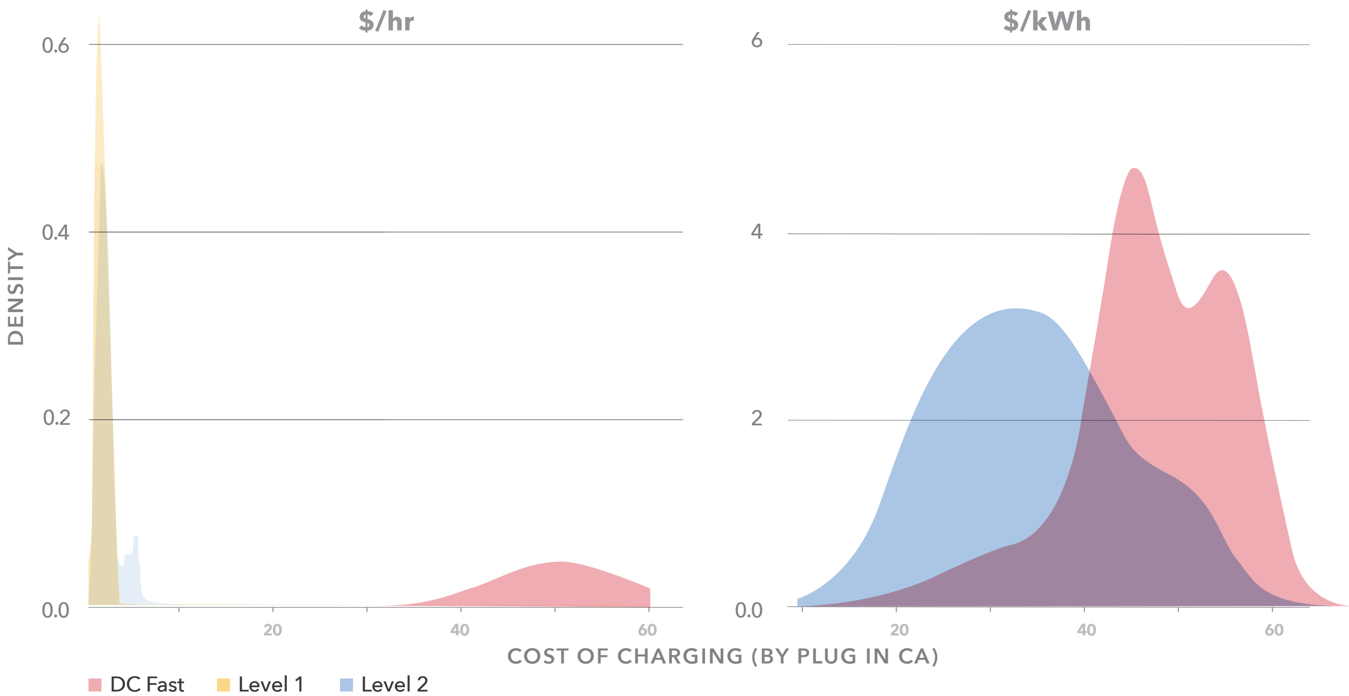
Counts of Payment Categories for California EV Chargers for PlugShare vs. AFDC

	PlugShare	AFDC
Flat connection fee only	50	-
$/kWh only	7,248	-
$/hr. flat	7,824	-
$/hr. dynamic	276	1,283
Combo $/kWh and $/hr.	1,420	107
Free	2,930	4,745
Unknown	19,554	31,213
Total	39,302	37,348

Note: Reflects 2023 data.

FIG 3

Pricing Rates for Both Hourly and Energy Pricing Schemes for EV Chargers in California



Data Source: 2023 data from AFDC and PlugShare.

2.1.2. Utilization Data

This analysis employs charger utilization data based on over 5.6 million charging events from DC fast chargers across a combination of networks including EVgo, ChargePoint, and Tesla Superchargers in California from 2014 through 2019. The charging event data provide data down to the plug level, with corresponding locations of chargers. Crucially, the data provides individual event information on the kilowatt-hours of charging associated with each charge but does not contain any information on the vehicle associated with the event. It should also be noted that the evolution of model availability may change charging behavior over time due to the differences in vehicle battery capacity and corresponding range over time, as well as changes in EV driver charging behavior. Unfortunately, the data from Level 1 and Level 2 are not consistent and, therefore, our analysis focuses on evaluating the business case for DC fast chargers.

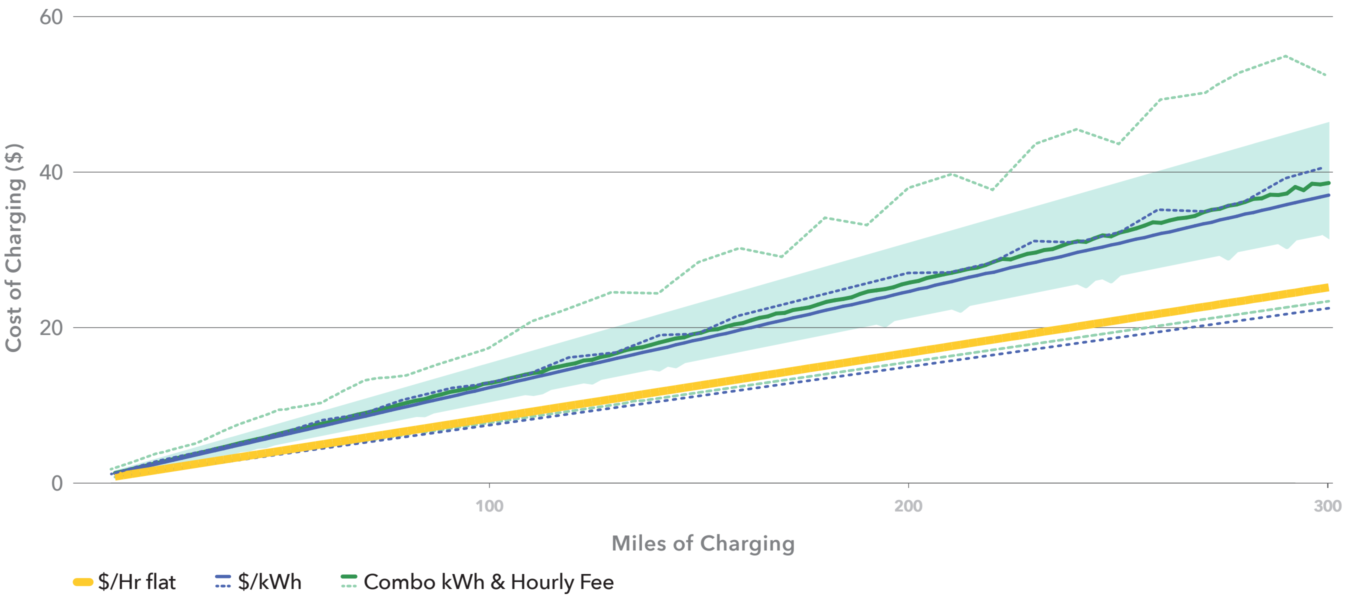
Calculating Charging Revenues

Given the especially high costs of DC fast charging infrastructure relative to Level 1 and 2 chargers, this study of business plans focuses primarily on public DC fast chargers. We leverage the pricing rate data combined with public infrastructure utilization data to determine distributions of total prices paid by EV drivers when charging. We bootstrap utilization data to generate a representative correlated distributions of energy and time associated with individual charging events which are then coupled to draws of pricing rates which can be used to calculate total costs in the equation shown in the Appendix

The approach assumes independence of the energy draw and the charging rate plan draw, which maybe an oversimplification of charging behavior (it is probably reasonable to assume that charging behavior of drivers using 50 kW chargers may differ from 150 kW chargers). This assumption could bias the overall shape of the distribution, but the range of the distribution will remain unchanged. Additionally, this analysis focuses on the most optimistic scenarios—if it is the case that economic sustainability is unable to be achieved under our assumed conditions, it is unlikely that honing in on more` accurate assumptions would result in financial stability for the analyzed business plans of public infrastructure.

FIG 4

Bootstrapped Cost to Customers to Charge their Vehicles Across Varying Ranges of Miles



Note: Assumes an EV efficiency of 0.3 kWh/mi. Solid line represents the mean cost to charge, shaded ribbon represents the 25th to 75th percentile of the costs, dotted lines represent the 5th to 95th percentile of the costs. Flat, time-based pricing plans are consistently the cheapest to charge, though this is an underestimate as EVs do not charge at the maximum rated capacity of the EVSE at all times.

2.2. Results

Two pieces of analysis are included in this section. The first is an examination of the revenue generated from charging stations and their ability to break even given their installation and operation costs. The second part of this section investigates the possibility of alternative sources of indirect revenue to support the costs of charging infrastructure.

2.2.1. Revenue Analysis

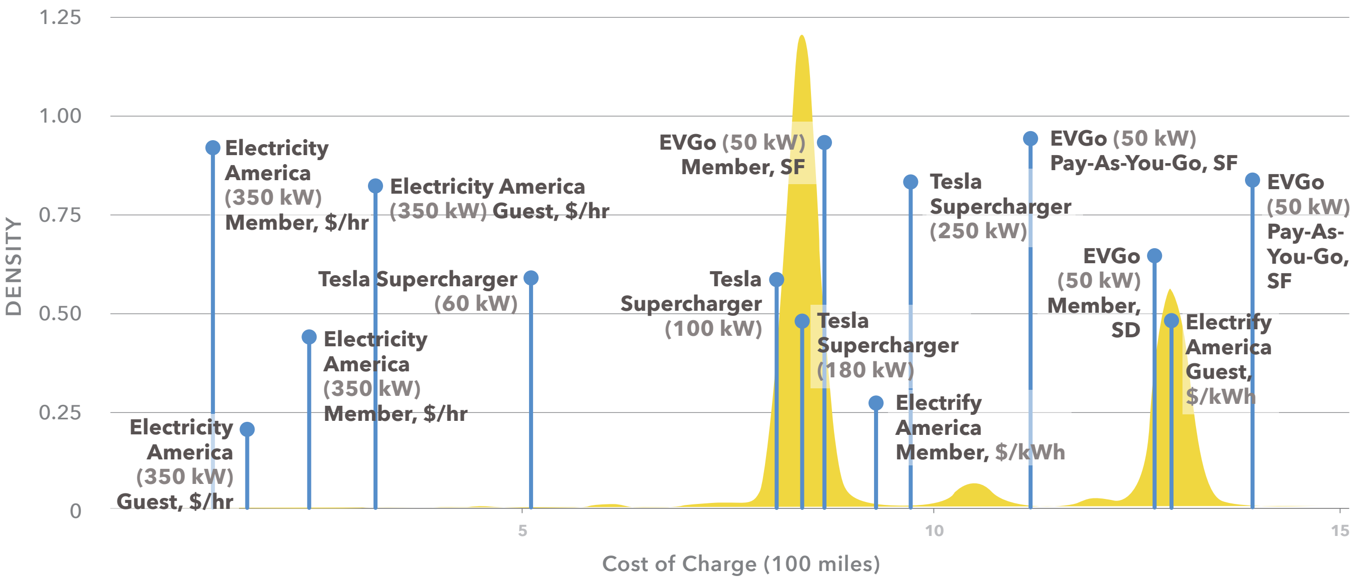
Based on the bootstrapped results from Equation 1 in the Appendix, the next step is to convert kilowatt-hours of charging to miles of range based on an assumed EV efficiency of 0.3 kWh/mi. This makes it possible to plot a distribution of possible revenues for a given number of charged miles with the observed pricing rate structures for DC fast chargers from the PlugShare dataset, as seen in Figure 4.

This analysis finds that pricing rates based on energy ($/kWh) or rates based on a combination of energy and time ($/kWh and $/hr.) tend to generate very similar amounts of revenue across the range of miles charged, costing drivers on average $0.124/mi and $0.129/mi respectively. Despite the massive variety in pricing plans (across a total of 607 unique pricing plans), for DC fast charging the variance of the cost of charging to drivers is not very wide. However, flat hourly rates for DC fast charging are substantially cheaper than rate plans based on energy. The vast majority of these plans are from Tesla's Supercharger network, which is the primary driver for these results. Nevertheless, Tesla owners can take advantage of these rates, which average to about $0.084/mi which is approximately one-third cheaper than the energy rates. Whether drivers of other BEVs will have access to the same rates when more BEVs have access to Tesla superchargers is not clear.

Taking a vertical slice at 100 miles along the x-axis in Figure 4, we can observe the distribution of the total costs to drivers in greater detail based on the different rates observed by drivers charging their vehicles as seen in Figure 5. The distribution of prices is not normally distributed, but rather is dependent on the count of plans corresponding to specific plugs. The largest peak in Figure 5 is centered on Tesla Supercharger Tier 2 and 3 plans corresponding to chargers operating between 60 kW and 180 kW, representing the bulk of Tesla's Supercharger network. The second largest peak is characterized by both EVgo and Electrify America's energy-based rates. Despite the variety of plans, the bootstrap on empirical

FIG 5

Bootstrapped Pricing from PlugShare Data to Charge 100 miles of Range



Note: Examples of major DCFC service providers are shown with corresponding prices based on advertised plans. Within the bootstrap, each service provider is only assumed to have one plan (we assume "pay-as-you-go" rather than member plans and 180 kW rates for Tesla). Most costs range from about $8 to $13 to charge 100 miles of range. Across the range of prices, this compares very favorably to the average gasoline car which would pay approximately $18.50 for 100 miles of range.

data suggests that the range of costs to charge 100 miles of range primarily falls between $8 to $13—providing evidence that service providers have settled on a similar range of prices to their customers for charging vehicles. Across the range of prices, this compares very favorably to the average gasoline car which would pay approximately $18.50 for 100 miles of range.

To assess the economic viability of charging stations, the cost of deploying DC fast charging infrastructure is necessary to compare the revenue streams from earlier portions of our analysis. Costs for DC fast chargers differ between studies, but the body of literature has indicated a wide range of $30,000 on the low end to as high as $150,000,[36,37,38,39,40] with one study finding costs for corridor charging up to $440,000.[41]

This analysis found that even under the most optimistic scenario (lowest cost, $30,000) for DC fast chargers, current utilization patterns of chargers are unable to successfully payback costs within a 3-year timeframe at a 10% discount rate. As can be seen in Note: , the average observed utilization of DC fast chargers in terms of number of charging events and the amount of charging that happens per event is well below the requisite threshold to meet a 3-year payback. Even if both the number of charging events and the average amount of energy dispensed were to double, charging infrastructure would still barely be unable to meet a 3-year payback. The average observed DCFC utilization in the figure is at a point of over 10 years payback. Our results suggest that in the absence of government subsidies, fast chargers would likely be an unsustainable business without a change in charging behavior and/or a drastic increase in electricity prices seen by consumers.

36 Hawaiian Electric, Maui Electric, Hawai'i Electric Light. Electrification of Transportation Strategic Roadmap. 2018;68:1–159.

37 Francfort J, Salisbury S, Smart J, Garetson T, Karner D. Considerations for Corridor and Community DC Fast Charging Complex System Design. Inl/Ext-17-40829. 2017;(May):1–51.

38 Nelder C, Rogers E. Reducing EV Charging Infrastructure Costs - Rocky Mountain Institute. January 2019.

39 Miller JF, Howell D. The EV everywhere grand challenge. World Electric Vehicle Journal. 2013;6(4):1008–13.

40 Nicholas M. Estimating electric vehicle charging infrastructure costs across major U.S. metropolitan areas. 2019;(14):11.

41 Gamage T, Tal G, Jenn AT. The costs and challenges of installing corridor DC Fast Chargers in California. Case Studies on Transport Policy. 2023 Mar;11:100969.

2.2.2. Alternative Sources of Revenue

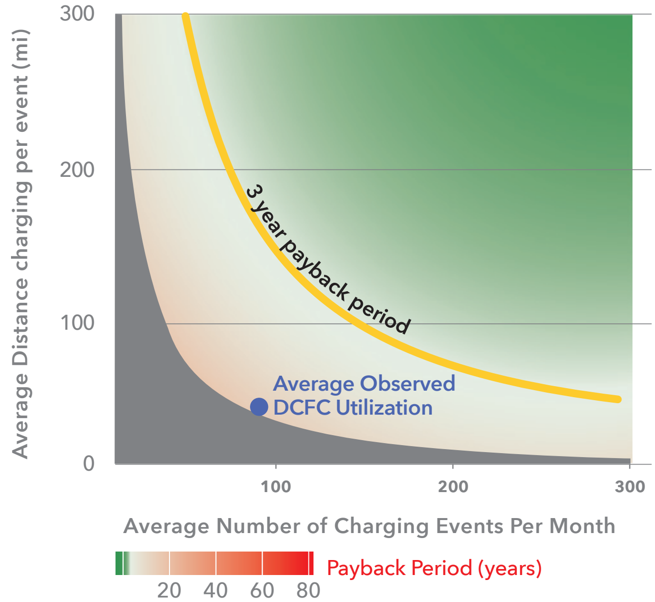
One area of study that remains unaddressed by the literature at large is alternative sources of revenue revolving around businesses that may indirectly benefit from the presence of public infrastructure. The profit margins for selling gasoline at traditional fueling stations are very low.[42] If the analogy for electric vehicles is that stations will similarly be unable to be financially viable from the low profit margins from selling electricity, there is another analogy where gasoline stations can make substantial revenue to supplement their fuel sales from concessions (drinks, snacks, and other amenities offered within the gas station store).

Likewise, for EV charging infrastructure, businesses located near these chargers may attract more business and sales that have higher profit margins. In fact, there are already many examples of businesses where EV charging is employed as a loss leader to bring customers into their stores—such as Target's deployment of Tesla, ChargePoint, and Electrify America chargers.[43] Whole Food's partnership with EVgo,[44] and Volta's unique offering of free charging to display ads in strip malls.[45] Whereas many gasoline stations are located on traffic corridors (e.g., freeway exits), electric vehicle charging stations have been increasingly deployed in locations with an abundance of desirable services. As an example, Figure 7 shows an example of the plethora of services surrounding an EV DC fast charger in Santa Monica, California. Within 500 meters of the charger, 20 restaurants, 15 hotels, 5 grocery stores, 4 movie theaters, and 8 retail shopping businesses are observed. This charger enjoys relatively high utilization with 1,500 visits in a 2-year period.

The density of services around the charger seen in Figure 7 is not a unique occurrence either. This study mapped five categories of services (dining, grocery stores, hotels, movie theaters, and shopping) within a ten-minute walk (500 meters) of 1,300 DC fast chargers around California with counts of each of the services. As can be seen in Figure 8, almost all chargers have some services located near them, with the highest counts for dining, followed by shopping and hotels.

FIG 6

Time to Payback a DC Fast Charger based on station utilization and duration of charging sessions



Note: Assumes a $30,000 capital cost, a $0.1065/kWh electricity rate paid by the service provider, and a 10% discount rate. The grey portion of the graph represents DC fast charging never recovering costs. Even under these favorable assumptions, the required utilization of the charger is quite high—especially relative to the average observed utilization of the charging infrastructure which is nearly never able to recover its initial capital costs at the assumed discount rate, much less than reach a 3-year payback.

Across the 1,300 chargers seen in Figure 8, we conducted a simple linear regression to examine the correlation between services and the number of events experienced at a given charger plug. This analysis is not a causal analysis of the driving force behind why drivers choose to charge at specific locations, rather the regression is simply observing the number of charging events as it relates to the number of different services in the vicinity of the charger. This finds that public chargers tend to experience more traffic near both dining services (with an average increase of 2.7 events per month per nearby restaurant) and grocery

42 Austin Chegini. "How Much Do Gas Station Owners Make?". Eposnow. April 29, 2021.

43 "Target's Charging Up Its Electric Vehicle Program to Reach More Than 20 States". Target: A Bullseye View. April 23, 2018. https://corporate.target.com/article/2018/04/electric-vehicles

44 "EVgo and Whole Foods Markets partner in California to reduce carbon through EV Fast Charging!". EVgo Press Release. November 5, 2015. https://www.evgo.com/press-release/evgo-whole-foods-markets-partner-california-reduce-carbon-ev-fast-charging/

45 Bill Howard. "Volta Offers Free EV Charging, With Caveats". ExtremeTech. October 2, 2019. https://www.extremetech.com/extreme/299467-volta-offers-free-ev-charging-with-caveats

FIG 7

Local Businesses Near a DC Fast Charger Located in Santa Monica, Los Angeles

Note: This charger enjoys relatively high utilization with 1,500 visits in a 2-year period. The station is conveniently located to a large number of amenities including restaurants, grocery stores, hotels, movie theaters, and retail shopping within a 10-minute walk (500 meters).

stores (with an average increase of 5.2 events per month per nearby grocery store).

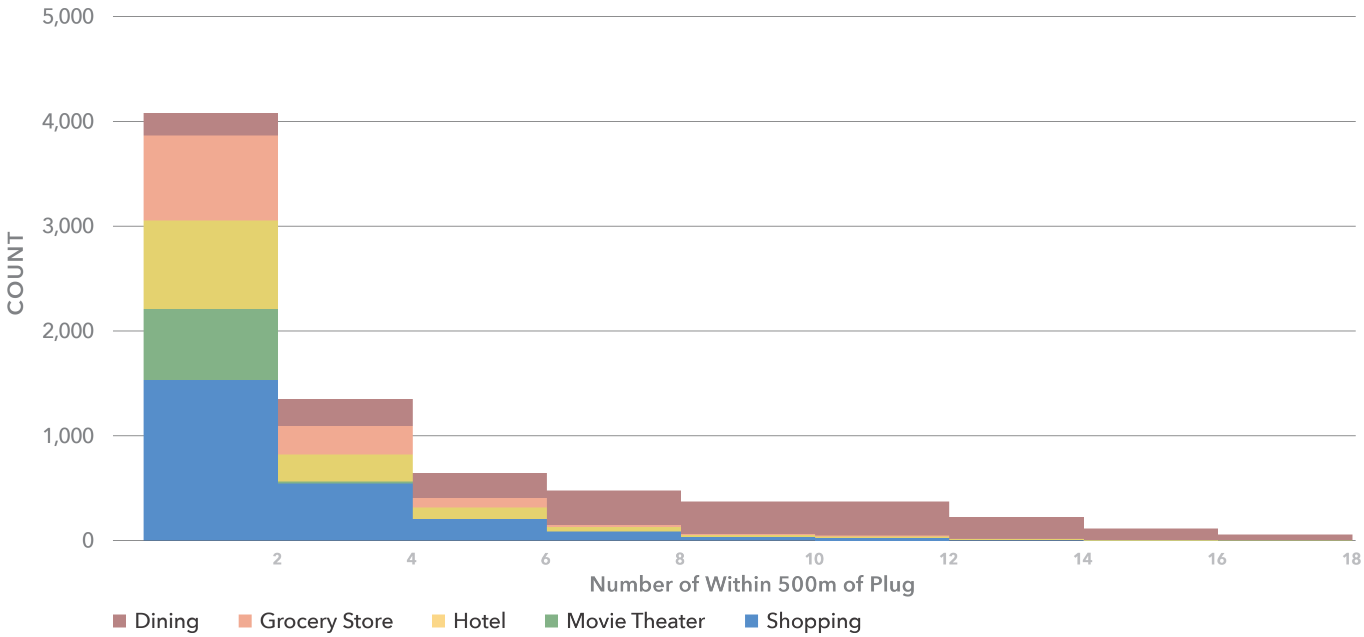
Our examination of alternative revenue sources, à la nearby businesses, is preliminary and meant to incite further research on the topic. The regression analysis is not a robust examination of causal factors, and the question remains how added revenue to surrounding businesses can help to supplement charging infrastructure costs. Nevertheless, the combination of service availability, examples of existing partnerships (Target with Chargepoint, Whole Foods with EVgo, and Volta), and utilization in relation to service availability all point to compounding evidence that leveraging nearby businesses may be a viable source of alternative revenue to help breakeven on EV charger costs.

2.3. Summary

This analysis indicates that even in the most optimistic utilization scenario and with the lowest possible charger costs observed in the literature, EV DC fast chargers are currently unable to achieve payback of their initial costs within a 3-year timeframe. In fact, even if utilization were to double both the average number of events and the amount of energy dispensed to vehicles, chargers would still be unable to achieve a payback in the same period. This financial assessment worsens substantially when considering higher costs for the installation and deployment of charging infrastructure. Unfortunately, this likely means that infrastructure deployment will still rely on government intervention for the foreseeable future unless prices

FIG 8

Count of Amenities Located Next to a Sample of 1,300 DC Fast Chargers in California



as substantially increased, charging behavior drastically changes, or alternative sources of revenue are identified.

This study also conducted a preliminary investigation of alternative revenue sources for charging infrastructure. Like gas stations that supplement their fuel sales with higher profit margin concessions, it may be possible for chargers to partner with local businesses such as restaurants and grocery stores to help bridge the gap in costs compared to revenues. Not only are chargers in California already co-located with useful services, but the use of chargers is also highly correlated with the density of these services in proximity to the chargers.

TABLE 3

Linear Regression Results of Average Monthly Counts of Charging Events per Charger Plug on Number of Services Located within 500 meters of Charger

Variable	Estimate
Constant	58.9*** (3.18)
# of dining services	2.74*** (0.32)
# of grocery stores	5.24*** (1.17)
# of hotels	-1.72* (0.85)
# of movie theaters	6.86* (3.36)
# of retail shopping stores	-1.20 (0.92)
Adj. R2=0.0336, n=3,347	

Significance codes: * = p<0.1, ** = p<0.05, *** = p<0.01

PART 2

Consumer Evaluations of Charging Infrastructure and Preferences for Fast Charging Infrastructure

3.1. Introduction

A substantial portion of public fast charging infrastructure is subsidized by public funds and, as the analysis in Part 1 shows, many public fast charging stations may not be profitable. This section of the report investigates battery electric vehicle (BEV) drivers’ choices and preferences for public DC fast charging to understand their willingness to pay for several charging attributes and understand how the presence of amenities (that could be a potential source of revenue) impact DC fast charging station choices.

This section also explores BEV owner charging behavior, including home charging access, use of public chargers, how a lack of home charging would impact adopter behavior, and what amenities drivers prefer the most at DC fast charging locations. This section of the paper is organized as follows. First, an outline of the survey methods used, then results from the survey and analysis of the choice experiment, and finally a summary of the findings.

3.2. Methods

The questionnaire survey was administered to 4,120 existing plug-in electric vehicle owners in February and March 2024. Of these, 1,265 respondents started the survey and 1,086 completed the survey. The first 1,000 participants to complete the survey were offered a $5 Amazon gift card for completing the survey. Existing electric vehicle owners were recruited to the survey to understand their preferences for fast charging and their experiences using charging stations. Electric vehicle drivers are more familiar with charging and their responses to the choice experiment may be more presentative of real choices compared to drivers who do not own BEVs. Prior research shows behavioral intentions do not always align with behavior[46] potentially due to non-adopters being psychologically distant from any technology they have not adopted, therefore they have abstract ideas about that technology.[47] Theoretically, existing adopters will have more concrete ideas on their preferences for charging, which may provide more behaviorally accurate results.

Since home is the dominant charging location used by electric vehicle owners and fewer future buyers will have home charging access, survey respondents were asked several questions considering the scenario in which they did not have home charging. The aim with this is to understand more about difficulties in electric vehicle use without home charging access and preferences for public charging locations.

A choice experiment was developed to understand BEV owner choices for fast chargers on long distance trips. The experiment included charging type (Fast (100kW to 125 kW) or Ultrafast (250kW to 400 kW)), charging cost, charging time, detour time to the charger, whether there is a chance of having to wait at the charger, the typical wait time, and whether there were different amenities available at each charging location.

Table 4 shows the choice experiment attributes and the different attribute levels. Based on these attributes survey takers were shown four separate choice scenarios (for example, see Table 5) which each included two charg-

TABLE 4

Choice Experiment Attributes and Attribute Levels

Attributes	Attribute levels
Charger Type	Fast (100-125 kW)* Ultrafast (250-400 kW)**
Charging cost ($ per 100 miles)	4: $4 8: $8 18: $18 25: $25
Charging time Minutes per 100 miles	5: 5 minutes 10: 10 minutes 15: 15 minutes 20: 20 minutes
Driving detour from route (minutes)	2: 2 minutes 5: 5 minutes 10: 10 minutes 12: 12 minutes
Chance of waiting for charger	0: No chance of waiting 1: Possible chance of waiting
Typical wait time	0: No chance of Waiting 4: 4 minutes 8: 8 minutes 12: 12 minutes
Facilities	1. No amenities 2. Restrooms only 3. Restrooms + Convenience Store 4. Restrooms, Coffee shop/ restaurants, play area/ green outdoor space

Note: * if charge time is 15 or 20 mins per 100 miles. ** if charge time is 5 or 10 mins per 100 miles.

46 Arts JWC, Frambach RT, Bijmolt THA. Generalizations on consumer innovation adoption: A meta-analysis on drivers of intention and behavior. International Journal of Research in Marketing. 2011;28(2):134–44.

47 Trope Y, Liberman N. Construal-Level Theory of Psychological Distance Yaacov. Psychological Review. 2010;3(2):3–23.

TABLE 5

Example Choice Experiment Set Up

Assume you are making a long-distance trip (a "road trip") in your [Volkswagen ID4], you started your journey with 80% charge and have driven [162 miles] and the battery is now at 20% capacity (you have [54 miles] miles left). You must charge to reach your destination, and the following are two options with Fast Chargers nearby. Which one would you choose? (Reminder: You are charging from 20% to an 80% charge. That is, you are adding [162 miles] to reach a new range of [216 miles].

	Charging Location A	Charging Location B
Charger Type	Fast (100-125 kW)	Ultrafast (250-400 kW)
Charging cost	$4 per 100 miles	$18 per 100 miles
	$6.58 total cost	**$29.16 total cost**
Charging time	15 min per 100 miles	10 min per 100 miles
	24.3 total minutes	**16.2 total minutes**
Driving detour from route (minutes)	12 minutes	2 minutes
Chance of waiting for charger	Possible chance of waiting	Possible chance of waiting
Typical wait time	12 minutes	0 minutes
Facilities	Restrooms only	Restrooms only

Note: Fields in square brackets (e.g. "[162 miles]") were tailored to each respondents BEV.

ing choices, generated based on the attributes shown in Table 4. The design allows us to understand preferences for charging speed, time, detour distance, waiting time, and facilities at charging locations.

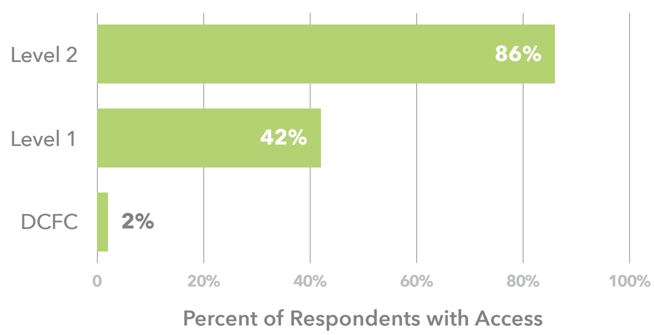
3.3. Results

3.3.1. Charging Behavior and Access to Charging

Figure 9 shows the percent of survey respondents with access to Level 1, Level 2, or DC fast charging where they park their vehicle at home. Overall, 94.5 percent have access to charging from home, with 86 percent of respondents reporting access to Level 2 charging, 42 percent with Level 1 charging, and 2 percent reported access to DC fast charging at home. Note: Overall, 94.5 percent reported access at or near their home.

FIG 9

Home Charging Access



Note: Overall, 94.5 percent reported access at or near their home.

Figure 10 shows where these charging locations are—most charging (66%) is in a garage attached to the household's unit, with 27 percent of access being in uncovered driveways. Single digit percentages of electric

FIG 10

Location of Home Charging Access

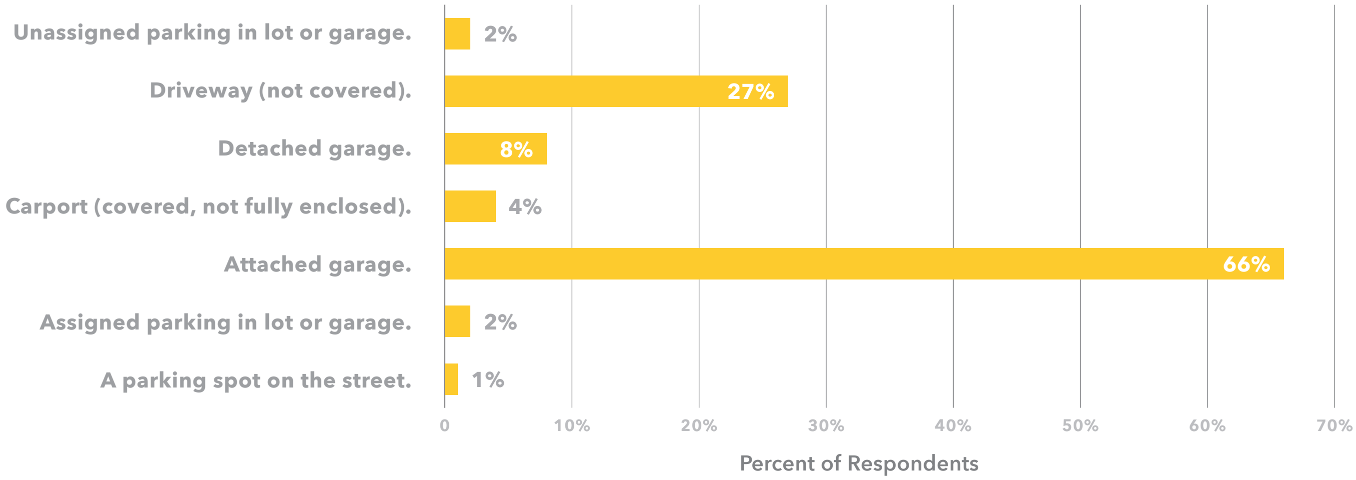
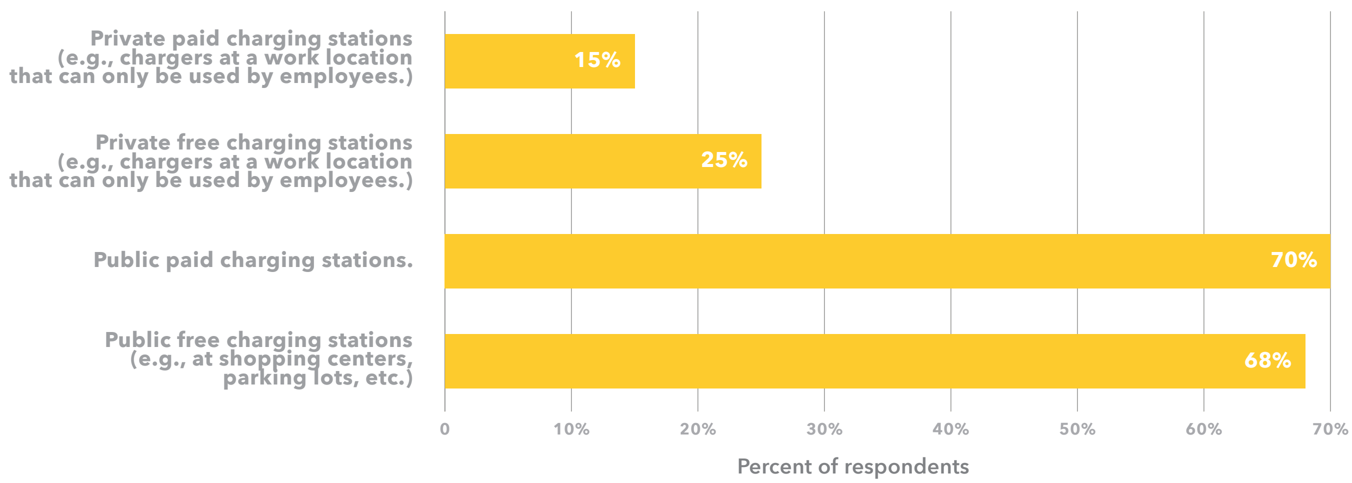


FIG 11

Location of Home Charging Access



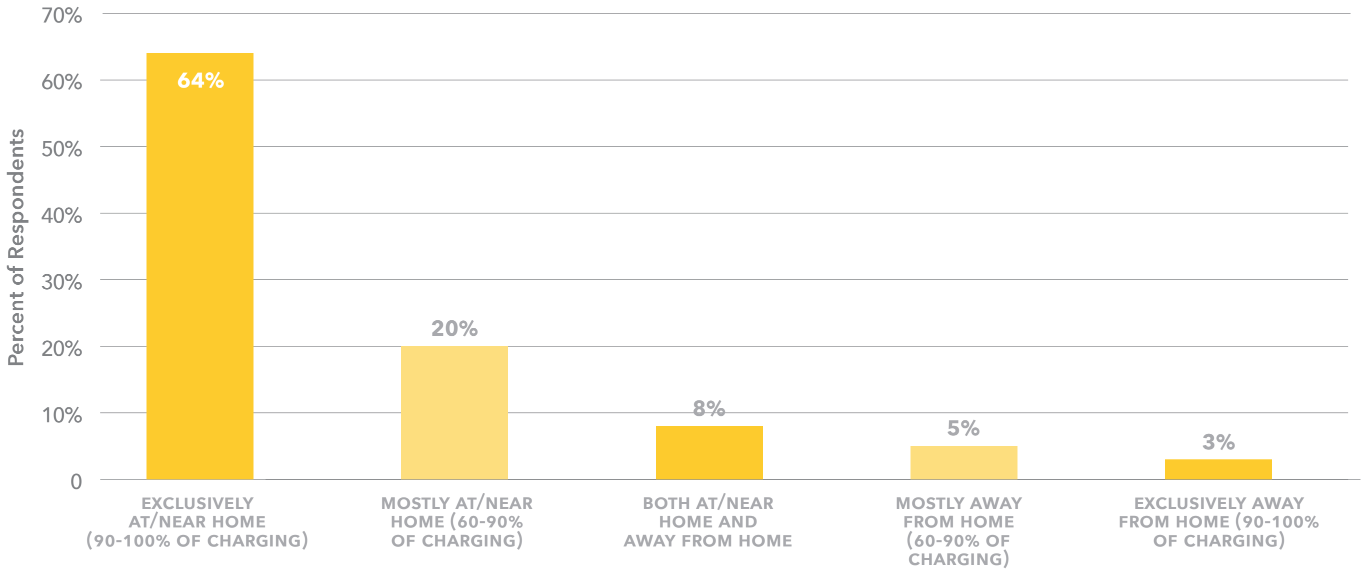
vehicle drivers charge in unassigned parking spaces in parking lots, in carports, detached garages, on the street, or in an assigned parking space in a parking lot.

For use of charging away from home, 70 percent of respondents reported having used public paid charging stations and 68 percent reported using free public charging stations (Figure 11). 25 percent reported using private free public charging (for example, at workplaces), while 15 percent reported using private paid public charging. Despite a high proportion of respondents reporting having used charging away from home, most charging occurs at home. Figure 12 shows respondents reported charging behavior on an ordinal scale ranging from almost all of charging being at home to almost all charging being completed away from home. Most survey respondents (64%) reported charging exclusively at or near home, with 20 percent reporting mostly charging at or near home, and 8 percent reported charging equally at both home and away from home. Only 8 percent of respondents reported charging more away from home than at home.

We also asked survey respondents how a lack of home charging access would impact their BEV ownership experiences. Figure 13 shows whether respondents agree with

FIG 12

Participants' Reported Charging Behavior



different statements in the scenario that they did not have home charging. While respondents mostly agree that there are plenty of options to replace home charging, about 25 percent disagree with this statement. Despite respondents perceiving there are other options, they believe that losing home charging would affect their behavior—69 percent disagree that losing home charging would have little effect on what they are doing. 53 percent of drivers also report that continuing to use their BEV would require changes to our routine, but it would be doable, in the event they lose home charging. Next, 43 percent reported that they would rethink their decision to own a BEV, with 48 percent reporting that they would not have to rethink their decision to own a BEV. A large proportion (66%) of BEV owners are also concerned with the high cost of non-home charging, and 84 percent are concerned about the inconvenience of non-home charging options.

We also asked respondents about any potential changes in travel behavior if they no longer had access to home charging. Figure 14 shows what electric vehicle buyers may do in the event they did not have home charging. Few respondents (6%) reported choosing a different travel mode (transit or ridesharing). 35 percent of respondents reported that without home charging they would replace their BEV with a traditional vehicle, while 38 and 41 percent of respondents would replace their BEV with a PHEV or a traditional HEV, respectively. The largest proportion of respondents indicated that they would use more Level 2 charging away from home (60%). Tesla BEV owners and owners of non-Tesla BEVs were asked separately about supercharging and DC fast charging. 91 percent of Tesla owners reported they would do more charging at Tesla superchargers, compared to 58 percent of non-Tesla owners (non-Tesla owners were asked about DC fast chargers). This could be due to differences in travel patterns or attitudes of Tesla drivers, but this may also be indicative of Tesla owners having better experiences with Tesla-owned DC fast charging stations compared to owners of other BEVs. This could change when more BEVs have access to the Tesla supercharger network.

3.3.2. Public DC Fast Charging Choices

Figure 15 shows respondents' preferences for charging locations related to amenities and other frequent travel locations in the scenario that they do not have home charging. The highest percent of respondents indicated that would choose to charge at rest stops, which seems to indicate a preference for on-travel route charging. After rest stops, charging at malls, parking garages, and restaurants were the most commonly selected, indicating that drivers also prefer charging at destinations they frequently travel to or have opportunities to do other activities while they charge. Drivers were less likely to charge at locations such

FIG 13

Perceptions of Charging Options in the Event Respondents Did Not Have Home Charging Access

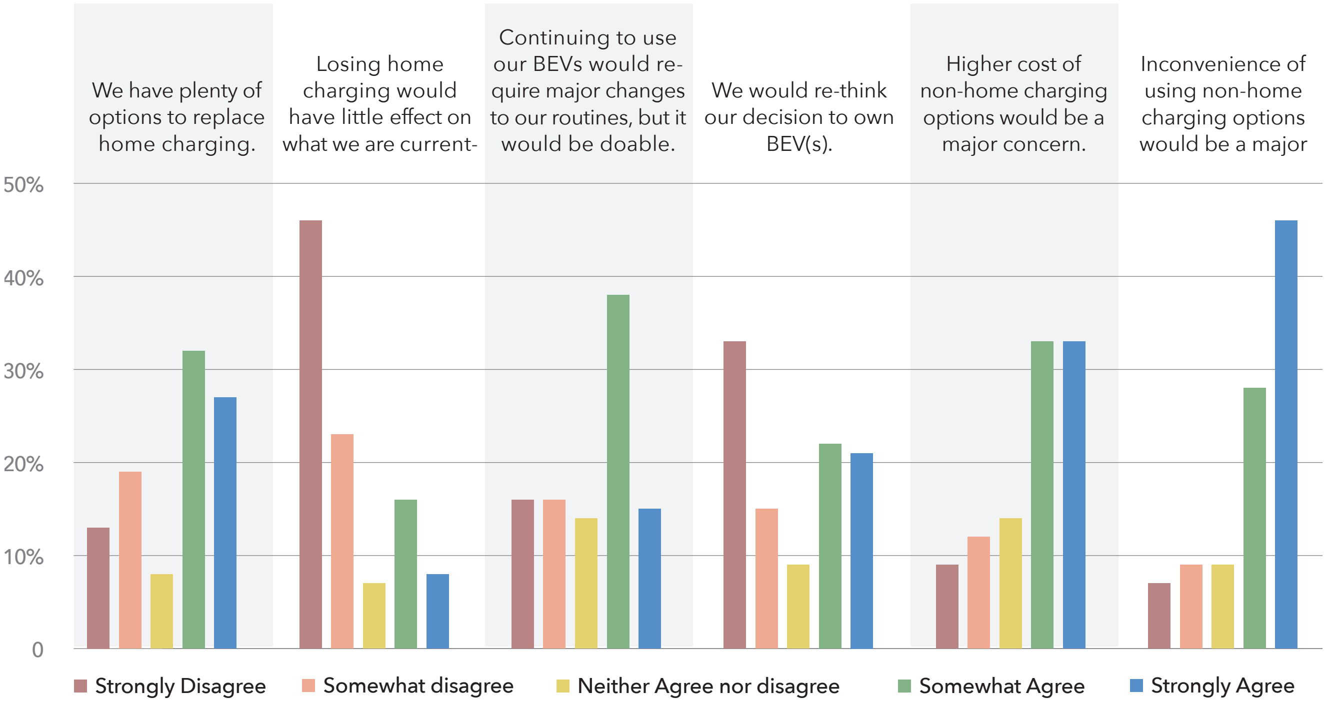
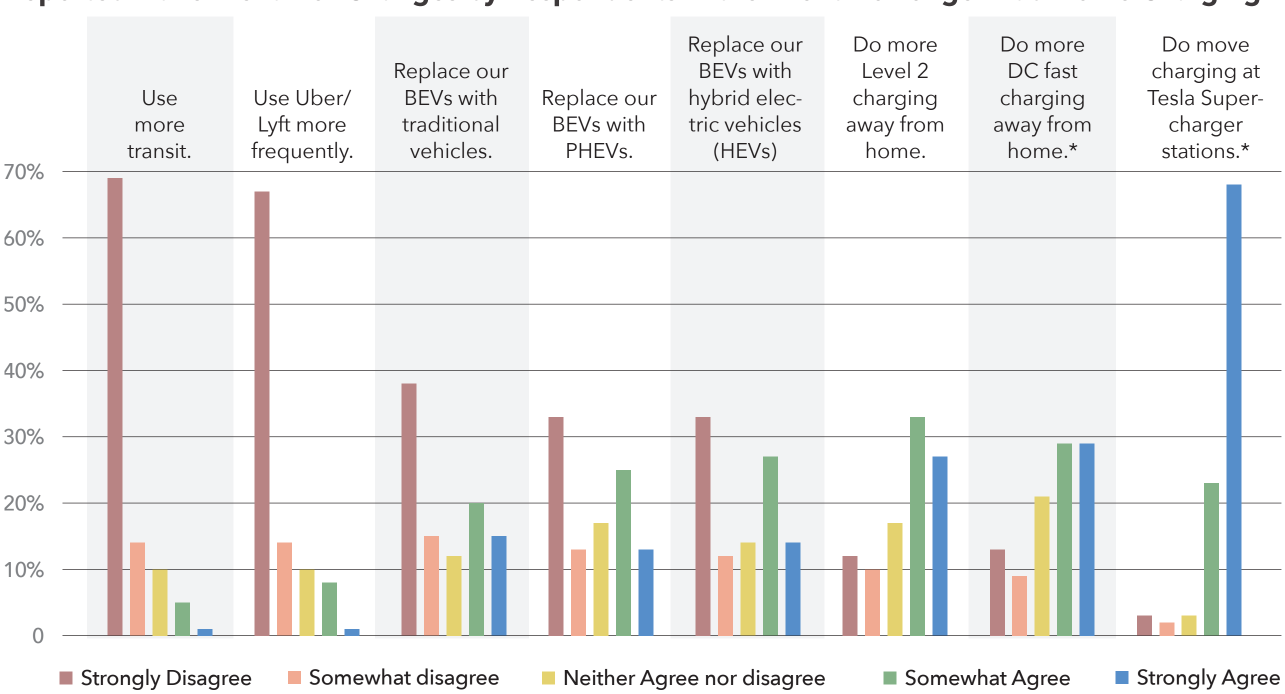


FIG 14

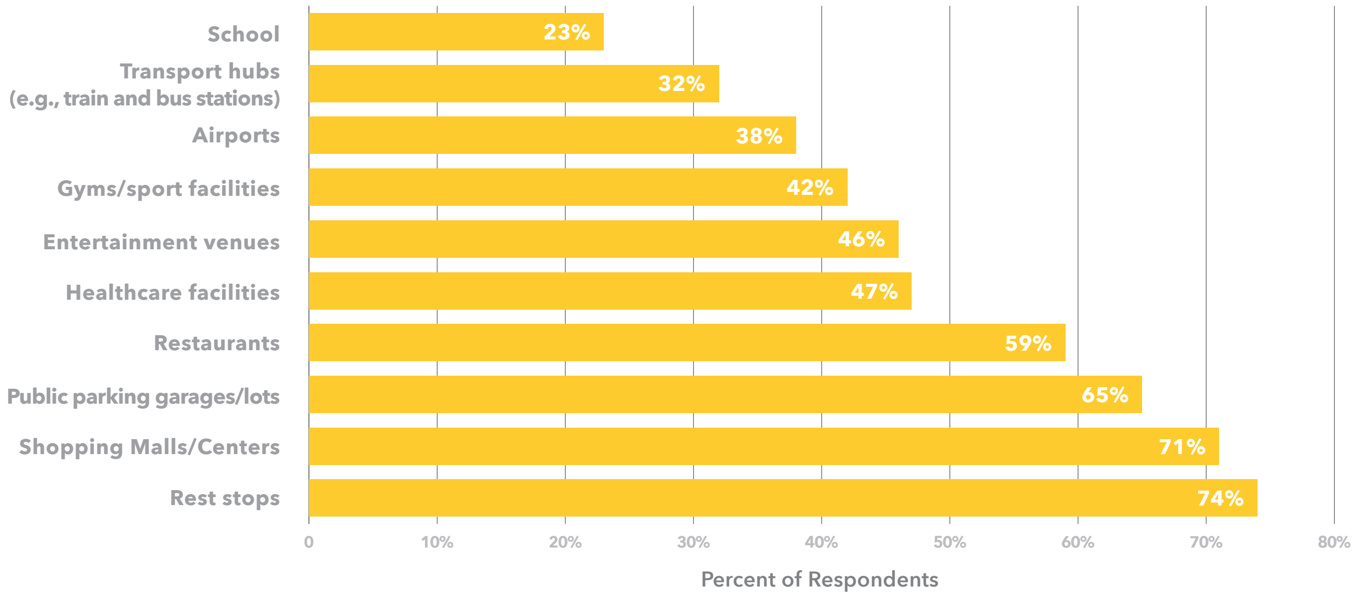
Reported Travel Behavior Changes by Respondents in the Event No Longer Had Home Charging



Note: Tesla buyers were asked about "Tesla Supercharger stations," owners of non-Tesla makes were asked about "DC fast charging"

FIG 15

Locations Respondents Would Use DCFC Charging at in the Scenario Respondents Cannot Charge from Home



as schools, airports, gyms, or healthcare facilities. This could be because these locations are visited less often. Overall, this indicates drivers prefer charging on travel routes and at locations they frequently visit.

Next, we explore results of the charging choice experiment (see Appendix Table A1 and Table A2 for full results). The results show the choice of DCFC locations is significantly influenced by charging cost, charging speed, detour time to the charger, the chance of waiting at charger, wait time at charger, and presence of amenities at the charging location.

For every $1 increase in the cost to add 100 miles of range (about 28 kWh on average) the odds of choosing that charging location fall by 14 percent (odds ratio 0.86). For every 1 additional minute of charging time for 100 miles of charging the odds of choosing that charger fall by 10 percent (odds ratio 0.9). For every 1 additional minute of detour to a charger the odds of choosing that charger decrease by 7 percent (odds ratio 0.93). If there is a chance of waiting to at a charger, the odds of choosing to charge there decrease by 13 percent (0.87). This further falls by 6 percent (odds ratio 0.94) for every additional minute of wait time. Finally, on the ordinal scale of available facilities at the charger, a unit increase (having restrooms and a convenience store, rather than only restrooms) corresponds to a 37 percent (odds ratio 1.37) increase in likelihood of choosing the charger.

TABLE 6

Estimates of Willingness to Pay for Reductions in Charging Time, Detour, Charge Wait, and Wait Time per 100 Miles of Charging

	Willingness to Pay ($/100 miles)
1 minute reduction in charging time	0.66
1 minute reduction in detour time to charger	0.48
No chance of waiting at charger	0.94
1 minute reduction in wait time at charger	0.39

Willingness to pay (WTP) measures give us an idea about how much consumers are willing to pay for a particular attribute or factor affecting their utility from an alternative. For example, a household's willingness to pay for charging time reductions is the increase in charging price that keeps the household's utility constant given a reduction in charging time. See Appendix for more information on WTP calculation.

Households will pay an additional $0.66 for a 1-minute reduction in charge time per 100 miles (or an additional $1.10 per session, where the average range added is 166 miles); $0.48 per 100 miles of charging for a 1-minute reduction in detour time (or about $0.80 additional per session); $0.94 per 100 miles of charging to reduce the chance of waiting (or about $1.57 per session); $0.39 per 100 miles of charging for a 1-minute reduction in wait time when there is a chance of waiting (or about $0.64 per session). Consumers therefore value reductions in charging time and detour time to a charger and prefer not having to wait for a charger.

Assuming the average charging session in the experiment added 46.5 kWh total or 28 kWh for each 100 miles of charging, we approximate willingness to pay on a kWh basis (like how DCFC is often billed). For charging speed, the willingness to pay of $0.66 per 1 minute reduction in charging time is equivalent to being willing to pay an additional $0.024 per kWh for an increase in charger power of 12.75kW, or for an increase in charger power of 100 kW an additional $0.184. The willingness to pay of $0.48 per 1 minute reduction in detour time per 100 miles of charging is about an additional $0.034 per kWh for a 1-minute reduction in detour time, or $0.17 for a 5-minute shorter detour. The willingness to pay for a 1-minute reduction in wait time is about an additional $0.014 per kWh, or about $0.07 per kWh for a 5-minute reduction in wait time.

3.4. Summary

First, this analysis shows high dependence on home charging among the sample, though most respondents have used public charging. Electric vehicle owners with home charging appear to perceive it as a lower cost and more convenient place to charge, and that without home charging access, their electric vehicle ownership would be a worse experience overall. 35 percent of buyers would switch to a conventional, hybrid, or plug-in hybrid vehicle. Respondents also report they would use more DCFC in the event they didn't have fast charging, though there are substantial differences in this between Tesla owners and owners of other BEVs. Far more Tesla owners report they would use Tesla DCFC Supercharger network compared to non-Tesla owners. This may be because electric vehicle owners have better experiences (including relating to reliability, payment, charging cost, etc.) with using Tesla charging stations compared to DCFC locations from other providers.

Overall, this analysis highlights the importance of home charging; however, a large proportion of future electric vehicle owners will depend on public charging and public charging is needed to support longer distance travel and occasional needs. In exploring preference for public charging locations, the report finds that most respondents would use public charging along existing travel routes (at rest stops) and at locations they travel to (e.g. malls, restaurants).

The survey also investigated preferences for DCFC on longer distance trips. This analysis finds the presence of additional amenities at a charge location is significantly correlated with charging choices, with a relatively high estimate. The presence of restrooms, convenience stores, coffee shop/restaurants, play areas/green outdoor spaces may induce BEV drivers to choose locations with these available, indicating substantial preferences for amenities at charging locations. These facilities could also provide additional revenue to charging infrastructure providers, potentially improving the business case of charging, and offsetting high charging installation and maintenance costs. We also find consumers prefer faster chargers, chargers with a shorter detour from their travel route, and chargers with a shorter time to wait to charge. BEV drivers are willing to pay a significant premium for reductions in charging time, reductions in the detour distance to a charger, and lower wait times. To increase utilization and to deploy infrastructure that drivers are willing to pay more for, providers should invest in faster charging, chargers that are shorter detour times, chargers that have additional capacity to reduce the change of waiting, and chargers with amenities for drivers to use while charging.

Conclusion and Discussion

Electric vehicle chargers are rapidly becoming a critical piece of transportation infrastructure as we transition to 100% zero emission vehicle sales. While current infrastructure enjoys subsidies at both the state (e.g. Low Carbon Fuel Standards, CALeVIP) and federal level (e.g. National Electric Vehicle Infrastructure program), these subsidies cannot continue indefinitely and bring about questions of the financial sustainability and equity (taxpayers paying for services they do not use).

Chargers also need to be profitable after installation so that providers businesses do not fail or charging equipment is abandoned or poorly maintained. Therefore, it is critical that EV chargers become financially sustainable on their own, with the ability to recover their capital costs from revenues generated via the sale of electricity to drivers charging their EVs.

This report highlights that one avenue of chargers being profitable could be through the colocation of charging with amenities. The presence of amenities will both increase the number of EV drivers using a station, increasing utilization which can contribute to profitability, and could provide an additional source of revenue. Charging infrastructure providers could develop charging locations with amenities (café, restaurants, stores, etc.), or existing establishments could install chargers to bring more customers to their business. Both of these models would be like the business model of gasoline fueling stations where, according to the National Association of Convenience Stores, 2/3 of station profits are from non-fuel sales.[48]

4.1. Policy Implications

While the development of public fast charging infrastructure is necessary to facilitate electric vehicle travel on long distance trips, for households without home charging access and other occasional charging needs,[49,50] stakeholders should also consider how to provide electric vehicle owners access to home charging. This should include providing funding for those that cannot afford a home charger, supporting charging installation in rented home, installing chargers in shared parking lots, and exploring ways to provide charging access for those that do not park on a driveway, parking lot, or garage (e.g. installing curb charging for street parking). It is clear from our survey that home charging access offers a better electric vehicle ownership experience compared to not having home charging access. Even among this sample of early adopters, a significant percentage of respondents indicated they would rethink EV ownership without home charging. There is currently substantial focus on the development of public DCFC, something that may help facilitate the transition to EVs, but there should also be a focus on ensuring drivers have access to home charging. Below is an exploration of policy recommendations for public fast charging, followed by policy implications related to increasing access to home charging.

4.1.1. Support for Public Fast Charging

Given the current limitations in achieving economic viability for DC fast-charging stations, a comprehensive policy framework is crucial for sustainable development and operation. This section outlines a range of policy options and recommendations aimed at mitigating financial risks, promoting utilization, reducing costs, and educating stakeholders.

Continued Subsidy Support for Infrastructure

- **Balancing subsidy dependence:** While continued support is essential, it is equally crucial to design subsidies in a manner that doesn't create an over-reliance on external funding. One approach could be identifying optimal price-matching mechanisms where infrastructure providers match federal subsidies to a greater extent, thereby sharing the financial burden and potentially avoiding business models that only work with subsidies.
- **Operational and maintenance costs:** Subsidies should not be limited to initial capital expenditures; they must also consider operational and maintenance costs, which are ongoing and can significantly affect long-term sustainability. Including these costs in subsidy programs could result in reduced total costs of ownership, thereby enhancing the likelihood of successful, sustained operations.
- **Rewarding and supporting sustainable business models:** Policymakers could explore supporting charging providers who identify and develop methods of profitably operating charging stations, potentially by incorporating profitability metrics in funding criteria. This could include co-locating chargers with additional revenue generating amenities.

48 NACS. Consumer Behavior at the Pump [Internet]. 2019. Available from: https://www.convenience.org/Topics/Fuels/Documents/How-Consumers-React-to-Gas-Prices.pdf

49 Davis A, Chakraborty D, Tal G. How many chargers must California install to complete the transition to electric vehicles? An analysis of electric vehicle adoption and potential charging infrastructure needs 2022-2045. Under Review. 2022.

50 Hardman S, Jenn A, Tal G, Axsen J, Beard G, Daina N, et al. A review of consumer preferences of and interactions with electric vehicle charging infrastructure. Transportation Research Part D: Transport and Environment. 2018 Jul; 62:508–23.

Increasing Utilization

- **Support for EV adoption:** The fundamental driver of charger utilization is the prevalence of electric vehicles on the road. Therefore, policies aimed at increasing EV adoption rates, such as incentives to encourage EV purchases such as emissions and sales regulations (like Advanced Clean Cars II and the US federal greenhouse gas emissions standards)[51,52] and marketing and engagement campaigns that increase EV sales will also increase charger utilization.
- **Strategic deployment:** A more nuanced approach to charger placement can optimize charging utilization. There are two key types of chargers in this context:
    - » Access-Based Chargers: These are strategically deployed to provide spatially robust support, often located along major transit corridors.
    - » High-Utilization Chargers: Once a network of access chargers is established, focus should shift towards these chargers, typically situated in urban areas or high-traffic zones where they are likely to be used more frequently.
- **Co-locating chargers with amenities:** To increase utilization of EV charging locations for long trip travel charging locations should be located close to travel corridors, be co-located with amenities, and have enough charging outlets per location to reduce wait times. These considerations will increase utilization of charging and better serve EV drivers with charging locations they prefer to use. The co-location of chargers with amenities could also help create more profitable business models of PEV charging. This could be either by charging providers investing in amenities (e.g. cafés, restaurants) that provide additional revenue and increase charging utilization. Alternatively, existing establishments could invest in charging stations to bring more customers to their place of business.
- **Faster chargers and more chargers per location:** Drivers are more likely to choose charging locations and willing to pay more for chargers that offer faster charging speeds and for charging locations where there is a shorter wait time to use a charger. The latter could also be solved via routing drivers to chargers with shorter wait times or providing information on wait time in charging apps. Prior research also shows more chargers in one location can reduce the average installation cost per charger.[53]

Decreasing Charging Installation Costs

- **Innovative construction methods:** Innovative construction methods can serve as pivotal strategies for reducing costs associated with the deployment of DC fast charging infrastructure. Employing cutting-edge techniques in construction management and engineering could yield both time and cost savings. For instance, modular construction or prefabricated foundations can expedite the installation process and lower labor costs. For example, Tesla has utilized prefabricated foundations in constructing some of their Supercharger stations and has far lower deployment costs that other providers. Exploring these innovative methods could diminish initial capital expenditure and streamline operations, reducing the total cost of ownership over time.
- **Universal charging standards:** Developing and adopting universal charging standards (including for equipment) can decrease manufacturing and maintenance costs. This will not only simplify the consumer experience but can also spur competitive pricing and innovation in the charging market. This could be through government introduced standards and consolidation of EV charging equipment providers. The U.S. currently does not have an agreed upon standard, with some public funds requiring CCS installation whereas most automakers have indicated a switch to NACS.

51 Hardman S. Understanding the impact of reoccurring and non-financial incentives on plug-in electric vehicle adoption – A review. Transportation Research Part A: Policy and Practice. 2019 Jan;119:1–14.

52 Hardman S, Chandan A, Tal G, Turrentine T. The effectiveness of financial purchase incentives for battery electric vehicles – A review of the evidence. Renewable and Sustainable Energy Reviews. 2017 Dec;80:1100–11.

53 Gamage T, Tal G, Jenn AT. The costs and challenges of installing corridor DC Fast Chargers in California. Case Studies on Transport Policy. 2023 Mar;11:100969.

Education on Charging Infrastructure Opportunities

- **Partnerships with educational institutions:** Policymakers could initiate partnerships with universities and research organizations to investigate the social and environmental impacts of DC fast charging. Findings from such research could be integrated into public awareness campaigns to emphasize the broader benefits of EVs and their charging infrastructure, thus garnering additional public support.
- **Local business engagement:** Policymakers should actively demonstrate the revenue-generating potential of hosting charging stations to local businesses. They could do this through identifying the benefit of EV charging on businesses and educating businesses about the potential for increased dwell times at charging stations leading to higher local retail sales, thereby presenting a win-win scenario for both EV drivers and businesses.
- **Consumer education and awareness:** Public outreach campaigns could be designed to educate potential and current EV users on the availability and ease of use of DC fast chargers. Misinformation or lack of understanding about the charging infrastructure could deter potential users. Policymakers should collaborate with industry stakeholders to develop clear, informative educational materials that demystify the charging process.

4.1.2. Support for Home Charging Access

Results from the survey analysis highlight the importance of home charging access. As this research shows, home charging is cheaper, more convenient, more influential in the decision to buy an EV, and important for EV ownership. Support for home charging could include the following measures:

Allocating a portion of public funding to support home charging efforts

- Many programs only allocate funding to public charging or allocate a smaller portion of funding to home charging compared to public charging. Given access to home charging is influential in the decision to purchase an EV, the most convenient and lowest cost place to charge, and is the most frequently used charging location, more emphasis may be needed on home charging access. This could focus primarily on households who cannot afford home charging installation or households with difficulties installing a home charger. These households could be through the introduction of funding requirements in programs that direct funding to lower income households, renters or those living in apartments, drivers or who park on street.

Providing incentives for charging equipment and installation costs

- Some programs already provide incentives for home charging installation, often targeting lower income households. Continuing and expanding these programs will help support households to obtain home charging access. Some programs only cover charging equipment costs and do not cover costs associated with home power upgrades which can be prohibitively expensive. Incentives should be applicable to all costs related to EV charger installation.

Requirements for installation at existing buildings

- Some state (including California) and local (city, country) governments have introduced requirements to install charging at new building or make ready new buildings for charging installation. However, most people live in existing buildings and there are no requirements that encourage the installation of chargers in existing buildings. Policymakers could explore these regulations, such as potentially requiring charging installation in multiunit buildings at a rate like the rate of EV adoption in the fleet (which is around 5% in California).

Appendix

TABLE A1

Conditional Logit Model Estimates for Public DC Fast Charging Choices

Dependent Variables	Coefficient	Std. err.	z	P>z	[95% conf.	interval]
Charging Cost	-0.1436876	0.0050328	-28.55	<0.001	-0.1535517	-0.1338235
Charging Time/Speed	-0.0948027	0.0054794	-17.3	<0.001	-0.1055422	-0.0840633
Detour time to charger	-0.0688868	0.0061328	-11.23	<0.001	-0.0809069	-0.0568666
Chance of waiting at charger	-0.1356135	0.0579245	-2.34	0.019	-0.2491435	-0.0220835
Wait time at charger	-0.0557181	0.006186	-9.01	<0.001	-0.0678424	-0.0435937
Presence of facilities at chargercharger	0.3155003	0.019067	16.55	<0.001	0.2781297	0.3528708

Note: Number of obs = 8,816, LR chi2(6) = 1775.91, Prob > chi2 = 0.0000, Log likelihood = -2167.4353, Pseudo R2 = 0.2906

TABLE A2

Conditional Logit Model Estimates for Public DC Fast Charging Choices with Odds Ratios

Dependent Variables	Odds ratio	Std. err.	z	P>z	[95% conf.	interval]
Charging Cost	0.8661583	0.0043592	-28.55	<0.001	0.8576564	0.8747445
Charging Time/Speed	0.9095524	0.0049838	-17.3	<0.001	0.8998365	0.9193731
Detour time to charger	0.9334323	0.0057246	-11.23	<0.001	0.9222795	0.94472
Chance of waiting at charger	0.87318	0.0505785	-2.34	0.019	0.7794681	0.9781585
Wait time at charger	0.9458058	0.0058508	-9.01	<0.001	0.9344077	0.9573428
Presence of facilities at chargercharger	1.370945	0.0261398	16.55	<0.001	1.320657	1.423147

5.2. Calculating Charging Revenues

Given the especially high costs of DC fast charging infrastructure relative to Level 1 and 2 chargers, this study of business plans focuses primarily on public DC fast chargers. We leverage the pricing rate data combined with public infrastructure utilization data to determine distributions of total prices paid by EV drivers when charging. We bootstrap utilization data to generate a representative correlated distributions of energy and time associated with individual charging events which are then coupled to draws of pricing rates which can be used to calculate total costs in the equation shown below.
Where *i* represents the bootstrapped draws from Plug-

$$totalCost_i = cnctFee_i + kWh_j \times \$/kWh_i + \begin{cases} hr_j + \$/\text{hr}_i, \text{ if } i \in \{\text{hourly fee}\} \\ max(hr_j - \$/\text{free}Hr_i, 0) \times \$/hr_i, \text{ if } i \in \{\text{dynamic hourly}\} \end{cases}$$

Share rate options and j represents the bootstrapped draws from our infrastructure utilization data. Each draw i has an affiliated "plan type" as observed in Table 3 (excluding "Free" and "Unknown" categories. We allow rates within each draw to be $0 for non-corresponding plans (e.g., for a "$/kWh only" or energy only plan, both *cnctFee* = $0 and *$/hr.* = $0). It should be noted that the hr. is extracted from the *kWh* draw and calculated based on the charging speed corresponding to the bootstrapped j charging rate plan.

5.3. Estimating Willingness to Pay

Willingness to pay (WTP) measures give us an idea about how much consumers are willing to pay for a particular attribute or factor affecting their utility from an alternative. For example, a household's willingness to pay for charging time reductions is the increase in charging price that keeps the household's utility constant given a reduction in charging time. See appendix for more information on WTP calculation. Assuming the model is linear in parameters, the willingness to pay for a vehicle attribute 'a' is given by

$$WTP = -\beta a / \beta(price)$$

The negative sign indicates that the two changes are in the opposite direction: to keep utility constant, the price rises when waiting time at a charging station decreases. Below (Table) are the estimates of WTP for the different attributes of charging infrastructure that consumers may like to use during long-distance trips.