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What is the business case for public electric vehicle chargers?

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Executive Summary

Electric vehicle charging infrastructure is currently heavily subsidized in the United States at the local, state, and federal levels. However, the future success and growth of charging infrastructure to meet future EV demand will likely require chargers to become a sustainable business independent of government intervention. In this study, we examine the business case of electric vehicle chargers, focusing specifically on DC fast chargers. Our 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. We find 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) is substantially cheaper at $0.084/mi. However, when coupling these findings with utilization data and comparing it to costs associated with charger deployment, we find that the revenues are nowhere near being able to payback the capital and operating costs of the cheapest DC fast chargers observed in the literature in a three-year period—even when doubling the average number of events and amount of energy dispensed to charge vehicles. Despite these challenges, we also conduct a spatial analysis of local businesses and services co-located with EV chargers and identify this as a possible alternative revenue source for chargers in the future.

Keywords: electric vehicles, charging infrastructure

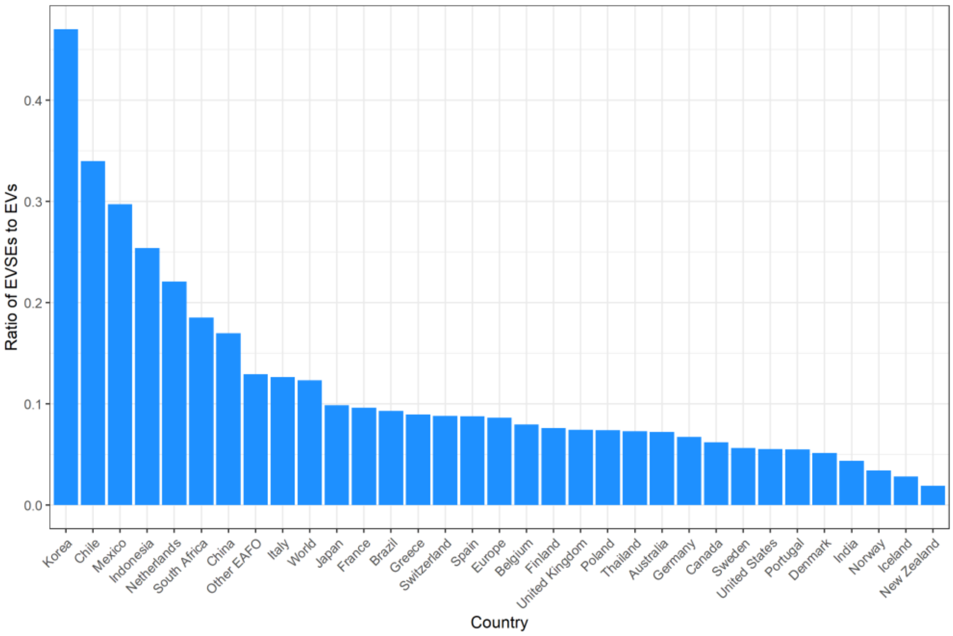
1 Introduction

Electric vehicles (EVs) have rapidly arisen in the last decade as part of the decarbonization solution for the transportation sector. As a result, governments around the world have passed policies supporting their growth from aggressive 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

[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.

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 to these policies, electric vehicle sales have grown exponentially—doubling and then tripling in volume in 2020 and 2021 respectively compared to 2019[9].

The advent of EV technology has simultaneously led to the deployment of electric vehicle supply equipment (EVSE) and associated infrastructure necessary to charge the vehicles. 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 has supported the diffusion of the technology into the mass market, though perception of density appears to be more important the actual number of stations (*1–4*). 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 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 of 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).



[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/

[9] Rives, Karin. "Global electric vehicle sales doubled; US made EV comeback in 2021". *S&P Global Market Intelligence*. May 24, 2022. https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/global-electric-vehicle-sales-doubled-us-made-ev-comeback-in-2021-70489884#:~:text=Worldwide%20EV%20sales%20doubled%20year,many%20as%20the%20year%20before.

Figure 1: Ratio of EVs to EV Chargers by country in 2020. Data from the Global EV Outlook.

Unlike traditional gasoline 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 (*5*), 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 to 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) which will provide $7.5 billion in funding for the deployment of charging stations.

The value of additional public infrastructure to support electric vehicle adoption has been demonstrated as a necessity to meet future charging demands (*6*, *7*). This need has been estimated to be at a minimum one DC fast charger for every 1,000 EVs on the road, a threshold that the US is currently meeting at about 2 DCFCs per 1,000 EVs (*8*). Several studies have also shown that populations of EV drivers place a high value on public fast chargers, particularly in cities and along highways (*9*) with willingness-to-pay values from drivers as high as $6,500 per driver (*10*). Javid et al. find that even from the perspective of economic impact from emissions reductions, the benefits from charging infrastructure deployment already offset the costs in the majority of counties in California (*11*). However, for the technology to be successful, the infrastructure must also ultimately become economically viable on its own 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 plans.

To properly understand the business model of electric vehicle charging infrastructure, we must understand 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 avoided to accurately simulate EV specific behavior (*12*). Other approaches have been taken to elicit behavior in stated preference surveys to understand how drivers currently charge their vehicles (*5*) or to understand how critical factors such as location, pricing, and demographics may affect behavior (*13*, *14*). However, the availability of empirical data has allowed for substantive revealed preference studies to determine real-world charging patterns (*15*, *16*) and even enabled detailed price responsiveness studies (*17*, *18*). 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 (*19*, *20*). 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. Zhang et al. 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 (*21*). The closest analogies to this study are works by Madina et al. which models potential business models to support the installation and deployment of charging stations (*22*) and Kim et al. which uses real utilization data but estimates feasible pricing schemes that allow for financial stability of charging services (*23*). 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.

The remainder of the paper is organized as follows: we provide an overview of the data and our analytical approach in the "Data and Methods" section. Following this, we present 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 we present alternative revenue sources to support charging as a sustainable business within the "Results" section. Lastly, we provide a discussion of the primary takeaways of our analysis alongside a discussion of the importance of this analysis in the context of future public charging infrastructure deployment.

2 Data and Methods

Pricing Rate Data

Our analysis focuses specifically on the state of California, which enjoys a relatively high volume of electric vehicles and a robust buildout of charging infrastructure across the state. For pricing, we first examine several major charging network provider plans, including Tesla Superchargers, EVGo, and Electrify America (Table 1).

Table 1: Pricing Plans in California of Major DC Fast Charging Networks

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 o Pay-as-you-go: \$0.34/kWh o EVgo Member: \$0.29/kWh + \$4.99 minimum monthly o EVgo Plus: \$0.25 + \$6.99 monthly fee • Los Angeles o Pay-as-you-go: \$0.32/kWh o EVgo Member: \$0.28/kWh + \$4.99 minimum monthly o EVgo Plus: \$0.29 + \$6.99 monthly fee • San Diego o Pay-as-you-go: \$0.43/kWh o EVgo Member: \$0.39/kWh + \$4.99 minimum monthly o EVgo Plus: \$0.29/kWh + \$6.99 monthly fee

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). The data sources are not entirely consistent though 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 a study by Xu et al. indicates that these counts may be an underestimate of the true number of public charging chargers (*24*).

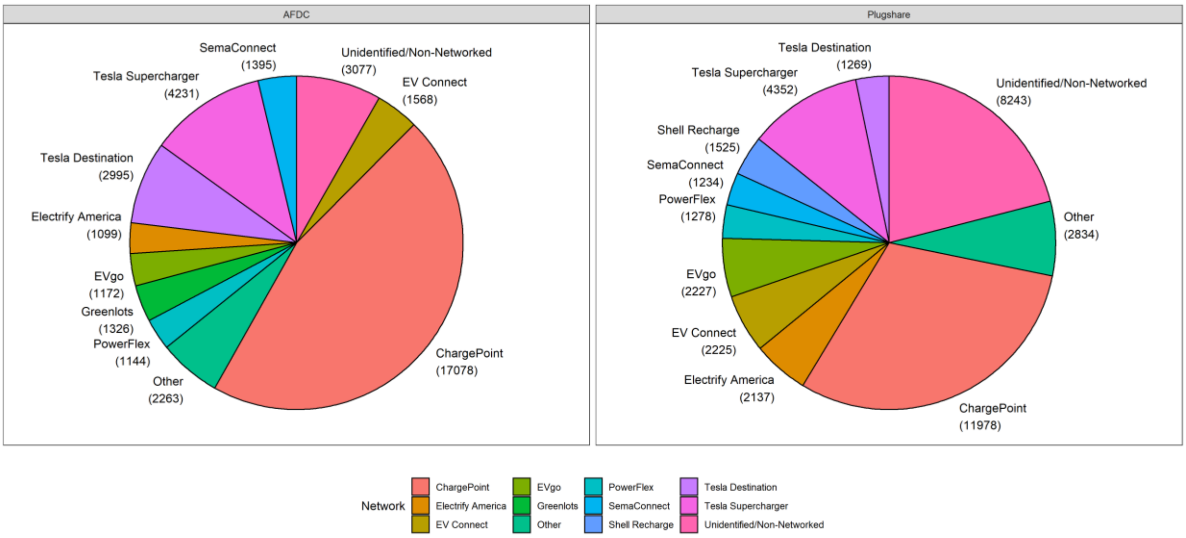


Figure 2: Comparison of the number of charging plugs in California broken down by charging provider from the Alternative Fuels Data Center (Department of Energy) and Plugshare (a crowd-sourced charger location app)

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% of their chargers containing pricing information. To further confound the issue, pricing rates and structures can also be fairly 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 of time before energy/hourly rates change, combinations of different rates, connections fees, and membership dues to name a few. With some simplifying assumptions, we generalize the categories of rate structures into those seen in Table 2.

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

To provide some context on the range of costs that drivers observe, we provide distributions of costs extracted from the Plugshare data in Figure 3. For hourly charging rates (left panel), we observe that 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, we do not observe this 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.

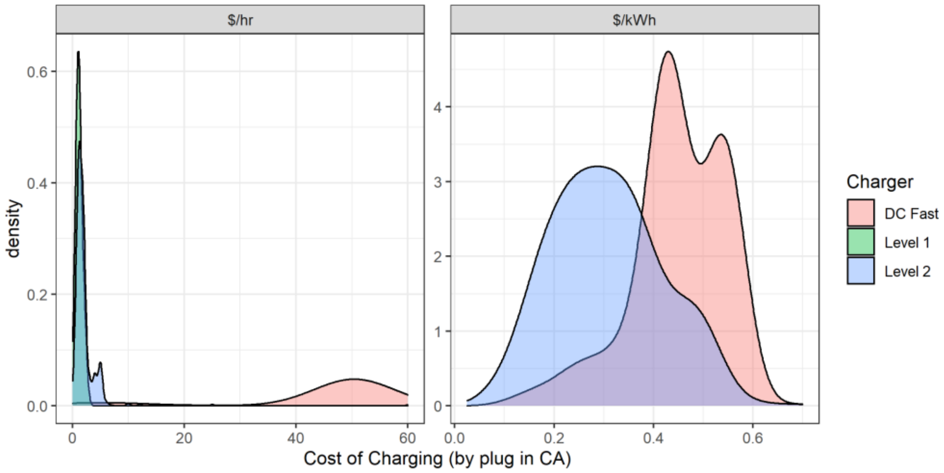


Figure 3: Pricing rates for both hourly and energy pricing schemes for EV chargers in California

Utilization Data

We employ 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 from 2014 through 2019. These chargers are located primarily in California. 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. Unfortunately, we do not have consistent data from Level 1 and Level 2 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, our 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 following equation:

$$totalCost_i = cnctFee_i + kWh_j \times \$/kWh_i + \begin{cases} hr_j \times \$/hr_i\,, \text{ if } i \in \{\text{hourly fee}\} \\ \max\left(hr_j - freeHr_i, 0\right) \times \$/hr_i\,, \text{ if } i \in \{\text{dynamic hourly}\} \end{cases} \quad (1)$$

Where *i* represents the bootstrapped draws from Plugshare 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 2 (excluding "Free" and "Unknown" categories. We allow rates within each draw to be $0 for noncorresponding plans (e.g., for a "$/kWh only" or energy only plan, both *cnctFee* = $0 and *$/hr* = $0). It should be noted that the hr_j is extracted from the *kWh* draw and calculated based on the charging speed corresponding to the bootstrapped *j* charging rate plan. This 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, our 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.

3 Results

In the results section, we focus on two pieces of analysis. 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.

Revenue Analysis

Based on our bootstrapped results from Equation (1), we convert kilowatt-hours of charging to miles of range based on an assumed EV efficiency of 0.3 kWh/mi. This allows us 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. We find that pricing rates based on energy ($/kWh) or rates based on a combination of energy and time ($/kWh and $/hr) tend to have 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 are able to take advantage of these rates, which average to about $0.084/mi which is approximately one-third cheaper than the energy rates.

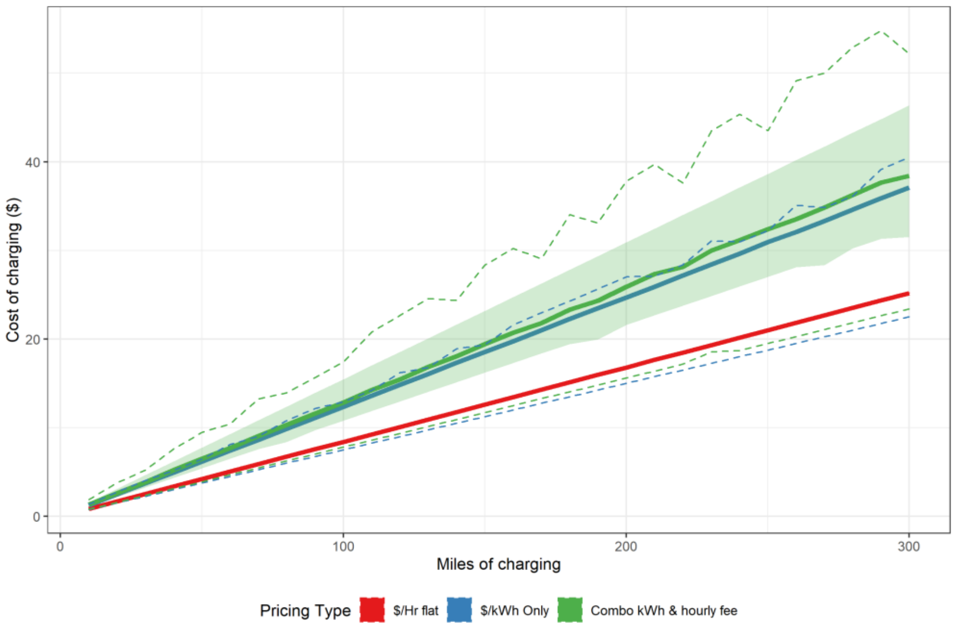


Figure 4: Bootstrapped cost to customers to charge their vehicles across varying ranges of miles (assuming an EV efficiency of 0.3 kWh/mi). Solid line represents the mean cost to charge, shaded ribbon represents the 25^{th} to 75^{th} percentile of the costs, dotted lines represent the 5^{th} to

95th percentile of the costs. We observe that 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.

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, and 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, our bootstrap on empirical 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 fairly similar range of prices to their customers for charging vehicles.

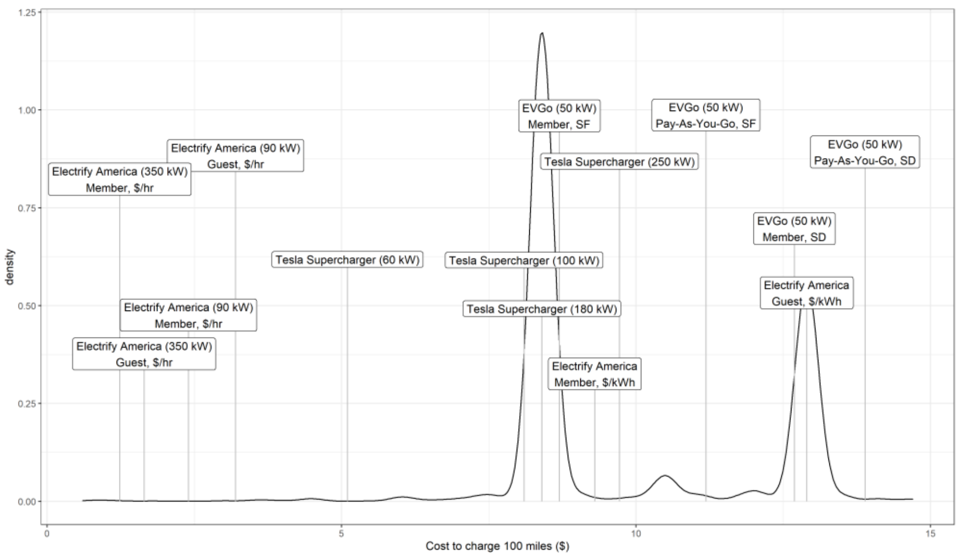


Figure 5: Bootstrapped pricing from Plugshare data to charge 100 miles of range. Examples of major DCFC service providers are shown with corresponding prices based on advertised plans. Within the bootstrap, each service provider is only assumed to have one plan (we assume "pay-as-you-go" rather than 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.

To assess the economic viability of charging stations, we also must also consider the cost of deploying DC fast charging infrastructure 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 (*25–29*). During our analysis, we found that even under the most optimistic scenario (lowest cost) 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 Figure 6, 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. 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.

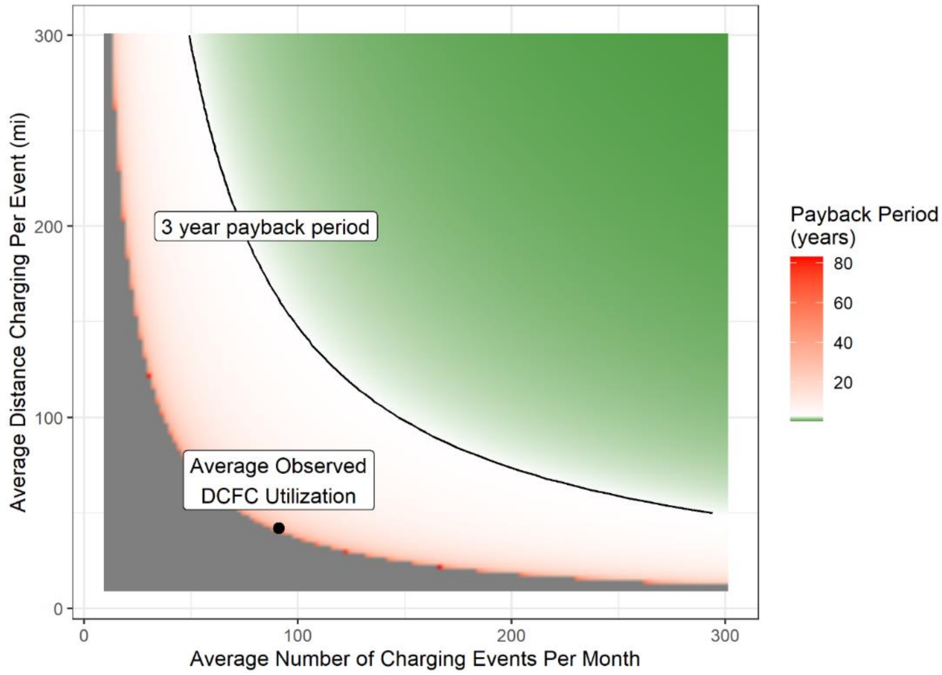


Figure 6: Time to payback a DC fast charger assuming a $30,000 capital cost, a $0.1065/kWh electricity rate paid by the service provider, and a 10% discount rate. Even under favorable assumptions, the required utilization of the charger is fairly demanding—especially relative to the average observed 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.

Alternative Sources of Revenue

One area of study that remains unaddressed by the literature at large are 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 is very low[10]. 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 (as we observe in Figure 3), 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 (Target's deployment of Tesla, Chargepoint, and Electrify America chargers[11], Whole Food's partnership with EVgo[12], and Volta's unique offering of free charging to display ads in strip malls[13]). 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.

The density of services around the charger seen in **Error! Reference source not found.** is not a unique occurrence either. We map 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

[10] Austin Chegini. "How Much Do Gas Station Owners Make?". *Eposnow*. April 29, 2021.
[11] "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
[12] "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/
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each of the services. As can be seen in Figure 7, almost all chargers have some services located near them, with the highest counts for dining, followed by shopping and hotels.

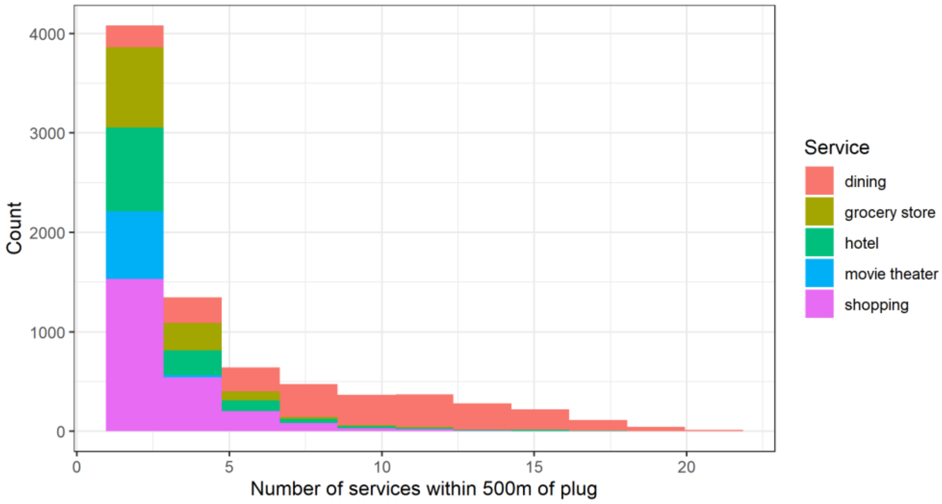

Figure 7: Count of amenities located next to a sample of 1,300 DC fast chargers in California

Across the 1,300 chargers seen in Figure 7, 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. We find 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 stores (with an average increase of 5.2 events per month per nearby grocery store).

4 Conclusions

Electric vehicle chargers are rapidly becoming a critical piece of transportation infrastructure as we transition towards electric vehicle technology. While current infrastructure enjoys subsidies at both the state (Low Carbon Fuel Standards, CALeVIP) and federal level (National Electric Vehicle Infrastructure program), these subsidies bring about questions of the financial sustainability and equity (taxpayers paying for services they do not use). 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.

Our study conducts an analysis of the business case for DC fast chargers throughout California employing a combination of empirical data using pricing rate structures at the plug-level from Plugshare and charger utilization data from several large-scale charging network providers. Our analysis indicates that even in the most optimistic scenario and 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, they would be unable to 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 in the near future unless prices as substantially increased or charging behavior drastically changes.

However, we also conduct a preliminary investigation of alternative revenue sources for charging infrastructure. Similar to 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. We find that not only are chargers in California already co-located with useful services, the use of chargers is heavily correlated with the density of these services in proximity to the chargers.

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