



What is the business case for public electric vehicle chargers?

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Abstract

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.

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 standards¹ in the US and the EU CO₂ emission performance

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

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standards²) to mandating their sales (Zero Emissions Vehicle regulation in the US³, Canada⁴, and Korea⁵ as well as the New Energy Vehicle regulation in China⁶) and even as far as banning the sale of gasoline vehicles⁷⁸. Thanks to these policies, electric vehicle sales have grown exponentially—doubling and then tripling in volume in 2020 and 2021 respectively compared to 2019⁹.

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 Fig. 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 than 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).

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

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 Chap. 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.>

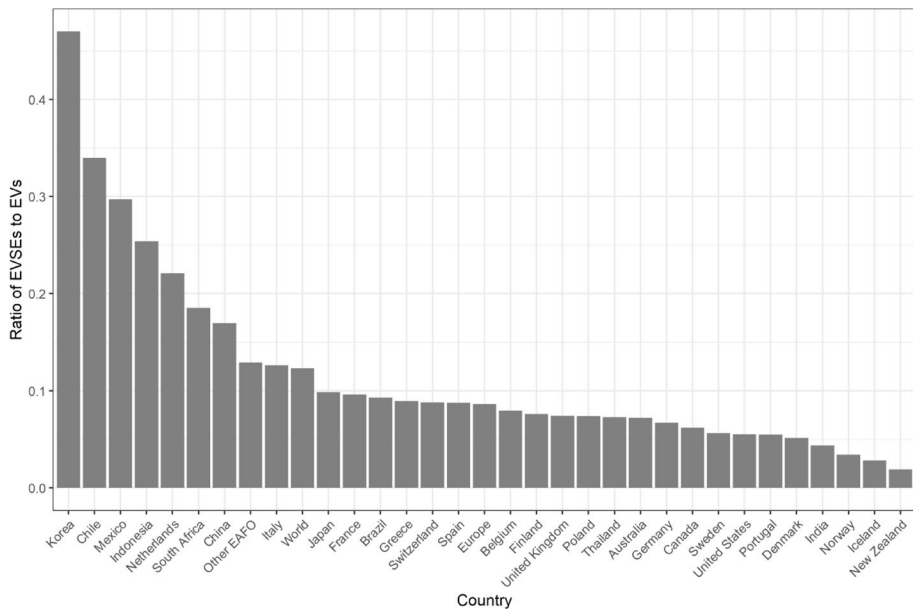


Fig. 1 Ratio of EVs to EV Chargers by country in 2020. Data from the Global EV Outlook (IEA (2021), *Global EV Outlook 2021*, IEA, Paris <https://www.iea.org/reports/global-ev-outlook-2021>, Licence: CC BY 4.0)

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. 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. While this has implications for vehicle manufacturing and access, the overall cost of infrastructure is unlikely to be substantially effected because the change in connector is a fairly 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.

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]. Borlaug et al. combines many of these factors to help elucidate a “levelized cost of charging” for drivers by integrating real-world charging patterns across the lifetime of an electric vehicle. They find that costs can vary tremendously and can lead to savings compared to traditional fuels of between \$3,000 to \$10,500 [19]. 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 [20, 21]. 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 [22]. The study unfortunately does not employ data to measure the factors identified in the study to estimate the economics of charger deployment. Two 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 [23] and Kim et al. which uses real utilization data but estimates feasible pricing schemes that allow for financial stability of charging services [24]. In Madina et al. the authors find that at between 4 and 5 vehicles visiting per day, with comparable fueling costs to gasoline vehicles (in other words, a fairly extreme profit margin on electricity), charging service operators can find a profitable business case—less with additional advertising to local businesses. In Kim et al., they find that the economic feasibility is barely viable under current observed prices in Korea of about \$0.23/kwh. When removing subsidies, the prices need to be increased by nearly 70% in order to achieve profitability. Lastly, in a study analyzing profitability of

chargers in Germany, Hecht et al. find that most charging providers are not profitable from selling energy, particularly for slower AC chargers [25]. DC fast chargers tend to do a little better, due to higher profit margins—though they also suffer from lower utilization, and the authors suggest that they should be combined with more profitable in-store sales and other secondary services. 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.

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 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

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 Fig. 2. The data in Fig. 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 [26].

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.

To provide some context on the range of costs that drivers observe, we provide distributions of costs extracted from the Plugshare data in Fig. 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

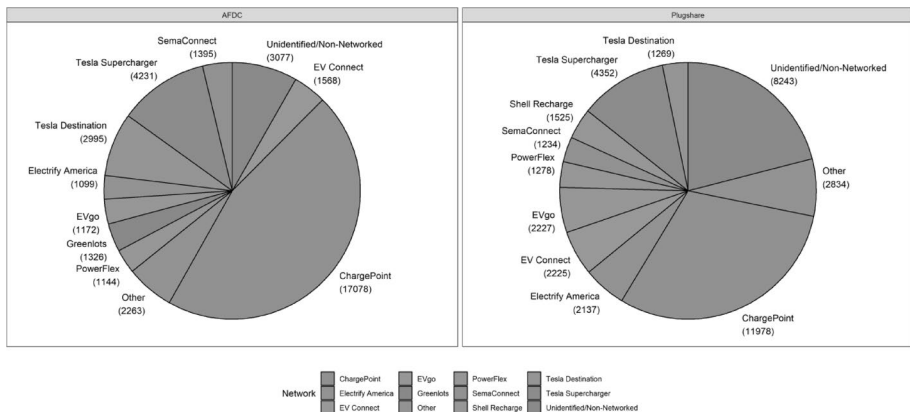


Fig. 2 Comparison of the number of charging plugs in California broken down by charging provider from the Alternative Fuels Data Center (Department of Energy) and Plugshare (a crowd-sourced charger location app)

Table 2 Counts of payment categories for California EV chargers for plugshare vs. AFDC

	Plugshare	AFDC
Flat connection fee only	50	—
\$/kWh only	7248	—
\$/hr flat	7824	—
\$/hr dynamic	276	1283
Combo \$/kWh and \$/hr	1420	107
Free	2930	4745
Unknown	19,554	31,213
Total	39,302	37,348

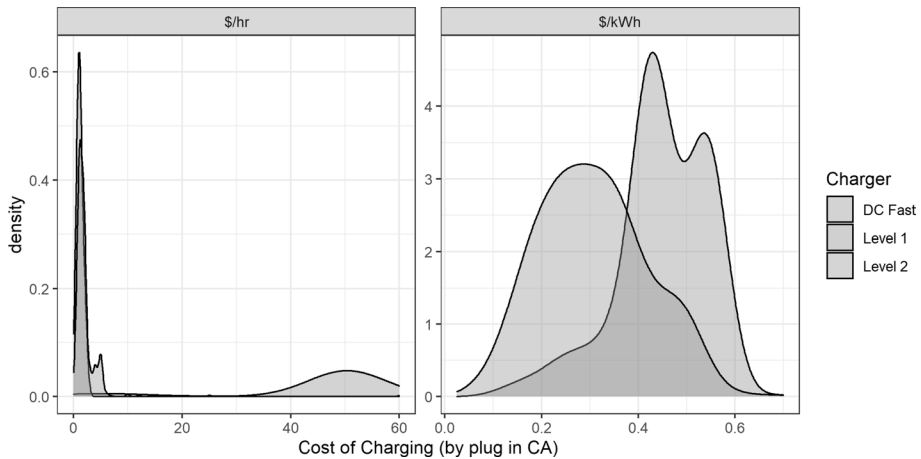


Fig. 3 Pricing rates for both hourly and energy pricing schemes for EV chargers in California

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.

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 to 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

Revenue per charging station is estimated using a two-stage bootstrap approach to account for variability both in user demand and pricing structures. The total monthly revenue, R , is calculated as:

$$R = \sum v_j r_{ij}$$

where:

- v_j represents the bootstrapped number of charging visits per month, drawn from the empirical distribution of observed station visit volumes,
- r_{ij} represents the bootstrapped per-event revenue, capturing variability in the pricing structure and session characteristics.

The per-event revenue, r_{ij} , is computed as:

$$\{\hat{r}\}_{ij} = c_i^{cnct.fee} + k_j c_i^{keh.rate} + \begin{cases} h_j c_i^{hr.rate}, & \text{if } i \in \{\text{hourly fee}\} \\ \max(h_j - c_i^{free.hr}, 0) \cdot c_i^{ree.hr}, & \text{if } i \in \{\text{dynamic hourly}\} \end{cases}$$

where:

- $c_i^{cnct.fee}$ is the connection fee associated with the selected pricing structure iii,
- $c_i^{kwh.rate}$ is the energy rate (cost per kilowatt-hour) associated with pricing structure iii,
- $c_i^{hr.rate}$ is the time-based charging rate (cost per hour),
- $c_i^{free.hr}$ is the number of free minutes or hours allowed before hourly charges begin (relevant for dynamic hourly pricing models),
- k_j is the bootstrapped energy consumption (in kWh) per session,
- h_j is the correlated bootstrapped session duration (in hours).

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 non-corresponding plans (e.g., for a “\$/kWh only” or energy only plan, both $cnctFee = \$0$ and $\$/hr = \0). This approach allows the model to flexibly capture both:

- heterogeneity in how chargers price access (connection fees, per-kWh rates, and/or

Table 3 Charger capital costs

Charger	Low	Mid	High
50 kW	\$40.5	\$61.3	\$82.6
150 kW	\$112.2	\$154.2	\$196.2
250 kW	\$30 ^a	\$146.1	\$240.8
350 kW	\$180.1	\$ 232.7	\$285.3

^aWe observed bids in the Texas Volkswagen Environmental Mitigation Program to subsidize chargers where Tesla implied costs of \$30,000 per charger (<https://www.tceq.texas.gov/downloads/air-quality/terp/txvemp/dcfch-22-applications-received.pdf>)

Table 4 Commercial averaged electricity prices by utility territory (2023)

Utility	Category (kW)	Avg weighted
PGE	< 100	\$ 0.245371
PGE	> 100	\$ 0.245044
SCE	20–500	\$ 0.218378
SCE	> 500	\$ 0.169490
SDGE	< 150	\$ 0.101955
SDGE	> 150	\$ 0.101955

time-based charges, including free-period structures),

- and variability in customer behavior (energy use and session lengths).

By summing over the bootstrapped number of visits per month, multiplied by the corresponding bootstrapped revenue per event, this method produces a distribution of expected station-level monthly revenues that reflects both types of uncertainty.

Cost data

The cost analysis for charging infrastructure in this study incorporates several key components. We focus on initial capital costs, electricity costs (both volumetric energy prices and demand charges), and maintenance expenses. These costs represent the primary operational and investment considerations from the perspective of the charging provider.

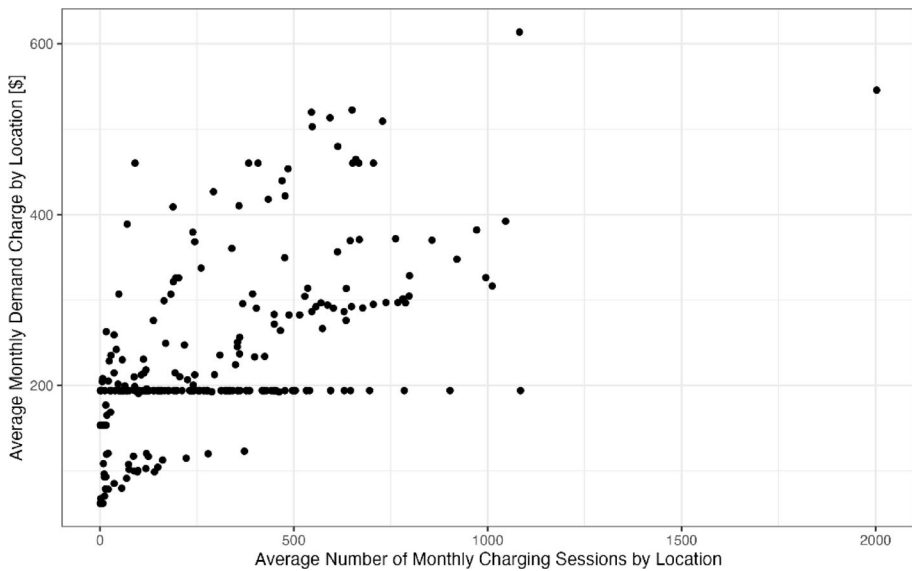
Table 3 presents the capital costs associated with various charger types. Costs are reported for low, mid, and high estimates to account for the variability observed in charger procurement and installation. The data reflect observed market bids, vendor pricing, and program documentation [27–32]. Notably, a very low cost for a 250 kW charger was observed through the Texas Volkswagen Environmental Mitigation Program, where Tesla indicated a \$30,000 per charger cost, substantially lower than typical market estimates.

Operating costs were assessed using publicly available utility tariff data for 2023. Table 4 summarizes the average commercial electricity prices for major investor-owned utilities (IOUs) in California. Average prices were weighted by territory and customer class. Similarly, Table 5 presents associated demand charges for each utility, which reflect an additional fixed cost based on maximum monthly peak demand.

Demand charges were estimated based on the maximum observed simultaneous charging activity at each site. Specifically, for each station and month, we identified the peak number of concurrent charging sessions by examining the overlap of individual charging events.

Table 5 Commercial demand charges by utility territory (2023)

Utility	Category (kW)	Charge
PGE	< 100	\$1.24/kW/month
PGE	> 100	\$1.91/kW/month
SCE	20–500	\$194.05/month
SCE	> 500	\$373.12/month
SDGE	< 150	\$30.68/10 kW/month
SDGE	> 150	\$76.71/25 kW/month

**Fig. 4** Average demand charge by charger location (calculated based on charger ratings and the maximum number of simultaneous charging events observed at each location), plotted against the average number of monthly charger sessions at each location

This peak concurrent load serves as a proxy for the site's contribution to maximum demand billing. To generalize demand charges across varying utilization levels, we correlated the maximum simultaneous sessions with the average number of monthly charging events at each location (Fig. 4). This relationship allows us to estimate the typical demand charge incurred as a function of monthly charging volume, enabling demand charges to be incorporated into the cost model as a utilization-dependent cost component.

In addition to capital and energy-related costs, we include an annual maintenance expense of \$400 per charger, consistent with estimates reported by the California Energy Commission¹⁰. Certain cost elements are explicitly omitted from this analysis. Electric hardware upgrades, such as transformer or service panel replacements, are typically funded by the utility and thus are not directly incurred by the charging provider. Land acquisition, leasing, or rent expenses are likewise excluded, as business models vary widely — with some providers owning their sites outright and others hosting chargers under third-party agreements — and because comprehensive and consistent data on site costs were unavailable.

¹⁰ California Energy Commission. "Electric Vehicle Charger Selection Guide". January 2018. https://afdc.energy.gov/files/u/publication/EV_Charger_Selection_Guide_2018-01-112.pdf.

The total cost of providing charging services, C , is calculated by summing the initial capital investment and the present value of annual operating expenses over the assumed project lifetime. The cost model captures both fixed and utilization-dependent components and incorporates a discounting process to account for the time value of money. The total cost is given by:

$$C = c^{cap.cost} + \sum_t \frac{12 (c^{elec.rate} \nu_j k_j + f^{demand.charge}(\nu_j)) + c^{annual.maint}}{(1+d)^t}$$

where:

- $c^{cap.cost}$ is the upfront capital cost associated with charger purchase and installation,
- $c^{elec.rate}$ is the volumetric electricity rate charged by the utility (in \$/kWh),
- ν_j is the bootstrapped number of monthly charging visits (indexed by j),
- k_j is the bootstrapped average energy consumption per charging event (in kWh),
- $f^{Demand.Charge}(\nu_j)$ is a function that maps the number of monthly visits to an estimated monthly demand charge, based on the correlation between station utilization and maximum observed concurrent sessions,
- $c^{annual.maint}$ is the assumed fixed annual maintenance cost (set at \$400 per charger),
- d is the discount rate (set at 10%),
- t is the analysis period (in years).

Energy charges are modeled as a function of session volume and session-specific energy consumption. Both energy and demand charges are originally monthly costs and are thus multiplied by 12 to represent an annualized value before discounting. Annual maintenance costs are assumed to be constant across years and independent of utilization.

The structure of $f^{Demand.Charge}(\nu_j)$ reflects the empirical relationship observed between average monthly station usage and maximum monthly simultaneous charging load, which in turn determines the applicable demand charge for each site under the relevant utility rate schedule. All operational costs are discounted back to present value using the assumed discount rate. The capital cost is assumed to be paid entirely upfront and is therefore not discounted.

Ultimately, we calculate payback of the infrastructure, t^* , as the minimum number of years required for the discounted sum of revenues to equal or exceed the present value of total costs:

$$t^* = \min \left\{ t : \sum_{\tau=1}^t \frac{R}{(1+d)^\tau} \geq C \right\}$$

where:

- C is the present value of total cost,
- R is the expected annual revenue (either a point estimate or bootstrapped),
- d is the discount rate.

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 Eq. (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 Fig. 5. 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

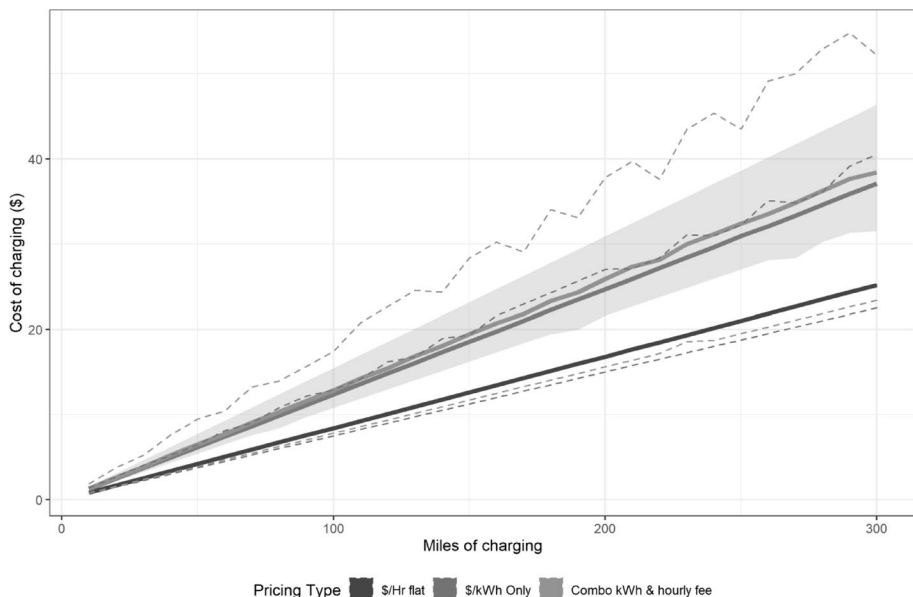


Fig. 5 Bootstrapped cost to customers to charge their vehicles across varying ranges of miles (assuming an EV efficiency of 0.3 kWh/mi). Solid line represents the mean cost to charge, shaded ribbon represents the 25th to 75th percentile of the costs, dotted lines represent the 5th to 95th percentile 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

of these rates, which average to about \$0.084/mi which is approximately one-third cheaper than the energy rates.

Taking a vertical slice at 100 miles along the x-axis in Fig. 5, 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 Fig. 6. 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 Fig. 6 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.

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 \$285,000 [27–32]. 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 Fig. 7, 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

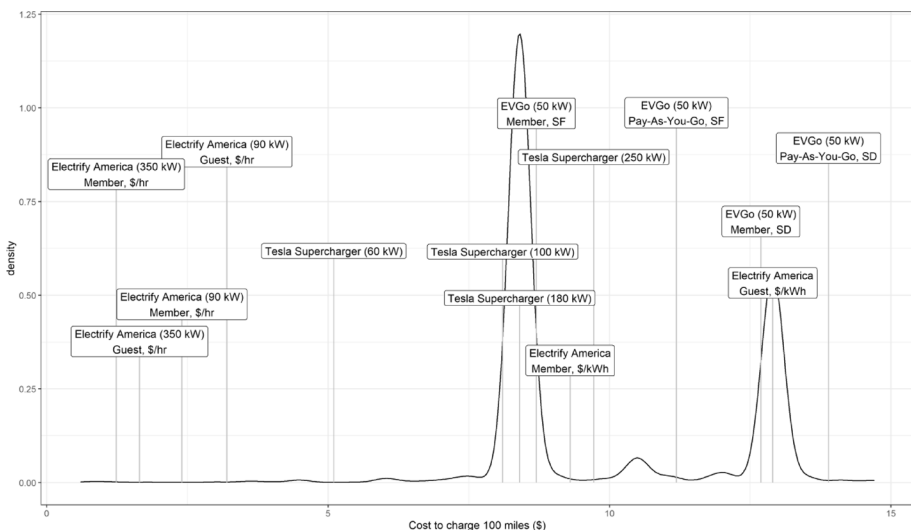


Fig. 6 Bootstrapped pricing from Plugshare data to charge 100 miles of range. Examples of major DCFC service providers are shown with corresponding prices based on advertised plans. Within the bootstrap, each service provider is only assumed to have one plan (we assume “pay-as-you-go” rather than member 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

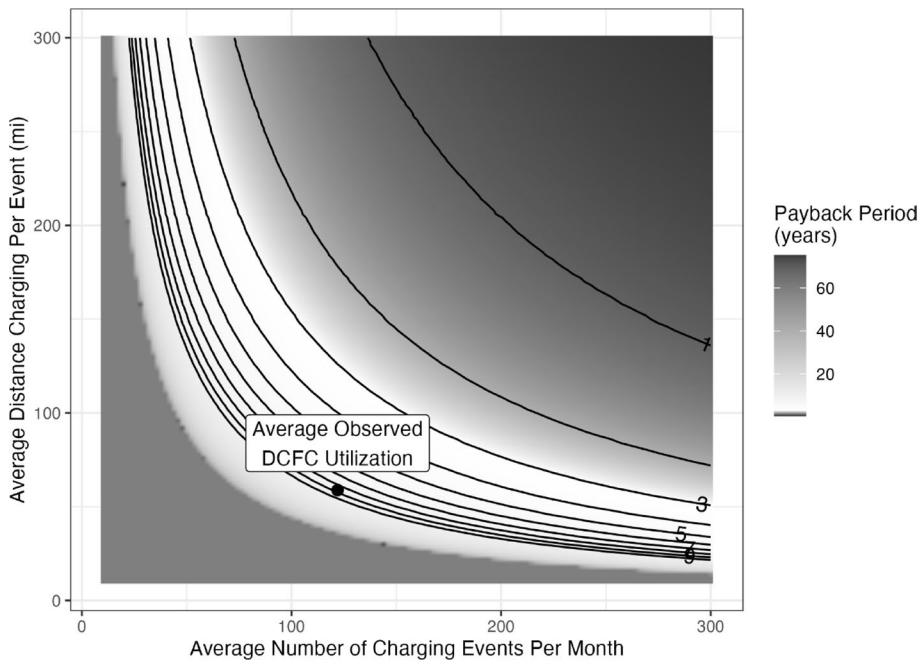


Fig. 7 Time to payback a 250 kW DC fast charger assuming a floor cost of \$30,000, and a \$0.1065/kWh electricity rate paid by the service provider, at a 10% discount rate. Even under favorable assumptions, the required utilization of the charger is fairly demanding—especially relative to the average 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

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. It should be noted that when we replicated this analysis in the presence of government subsidies (based on CalVIP bundled subsidy amounts¹¹), most DC fast chargers could easily achieve paybacks within 2–3 years.

In Fig. 8, we fix the payback period to 3 years to estimate the average kWh pricing needed for charging service providers to breakeven across the costs they observe deploying, operating, and maintaining the charger. The electricity price premium (on top of what they pay utilities, assumed to be a commercial rate) varies as a function of how often a charger is visited and how much charging happens at the charger per visit. For example, a relatively smaller \$0.1/kWh surcharge can achieve a 3-year payback if a charger receives 10 visitors per day that charge an average of 100 miles. However, at the current rate of utilization observed in the data, we estimate that more than a \$0.30/kWh surcharge would be required to breakeven within 3 years. This is the equivalent of adding about \$0.09/mi considering an average efficiency for the EV—which compares against about \$0.12/mi for fuel costs for the average gas car in the US.

¹¹ <https://www.energy.ca.gov/programs-and-topics/programs/clean-transportation-program/calevip-level-2-and-dc-fast-chargers#:~:text=For%20DC%20Fast%20Chargers%20C%20the,Chargers%20under%20a%20single%20rebate.>

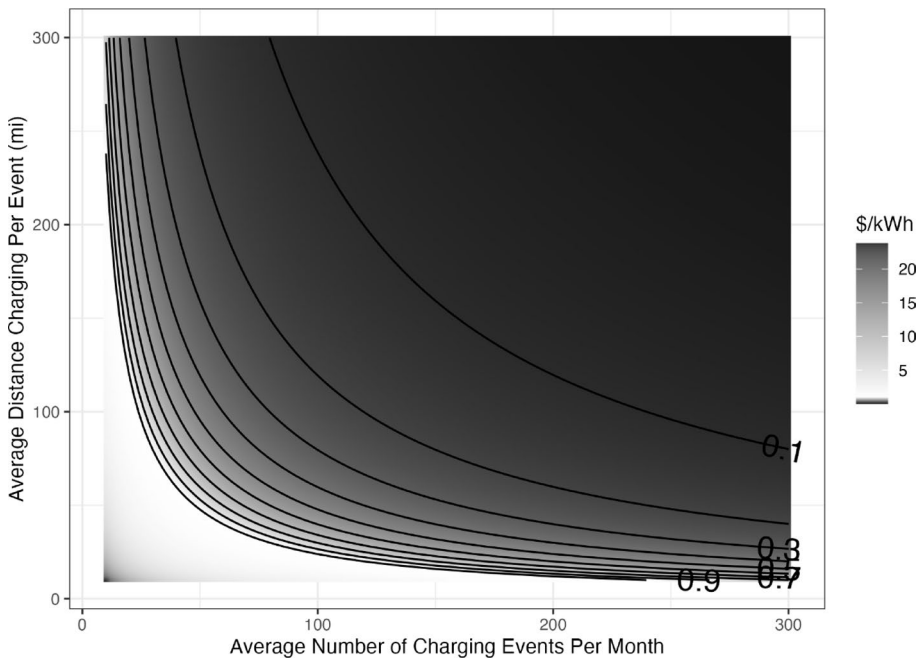


Fig. 8 Electricity price surcharge [\$/kWh] needed to obtain a breakeven 3-year payback time for DC fast chargers across a range of visits per month and kWh charged per visit. At the average observed utilization of about 120 visits per month charging 60 miles of range per visit, service providers would need to charge a little more than \$0.30/kWh on top of their existing electricity prices to breakeven within 3 years

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 low¹². 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 Fig. 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 chargers¹³, Whole Food's partnership with EVgo¹⁴, and Volta's

¹² Austin Chegini. "How Much Do Gas Station Owners Make?". *Eposnow*. April 29, 2021.

¹³ "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>.

¹⁴ "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/>.



Fig. 9 Local businesses to a DC fast charger located in Santa Monica, Los Angeles. This charger enjoys relatively high utilization with 1500 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 min walk (500 m)

unique offering of free charging to display ads in strip malls¹⁵). 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, in Fig. 9 we show an example of the plethora of services surrounding an EV DC fast charger in Santa Monica, California. Within 500 m of the charger, we observe 20 restaurants, 15 hotels, 5 grocery stores, 4 movie theaters, and 8 retail shopping businesses.

The density of services around the charger seen in Fig. 9 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 m) of 1,300 DC fast chargers around California with counts of each of the services. As can be seen in Fig. 10, almost all chargers have some services located near them, with the highest counts for dining, followed by shopping and hotels.

Across the 1300 chargers seen in Fig. 10, 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

¹⁵ 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>.

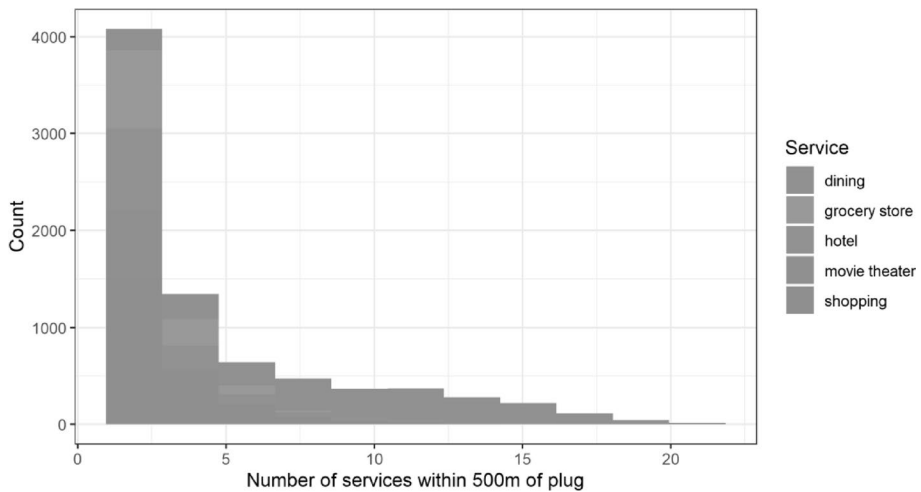


Fig. 10 Count of amenities located next to a sample of 1,300 DC fast chargers in California

Table 6 Linear regression results of average monthly counts of charging events per charger plug on number of services located within 500 m 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. R ² =0.0336, n=3,347	

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

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) (Table 6).

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. For example, the presence of chargers can increase the value of the property that it is operating on, adding a layer of complexity to the cost-benefit analysis. 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 evi-

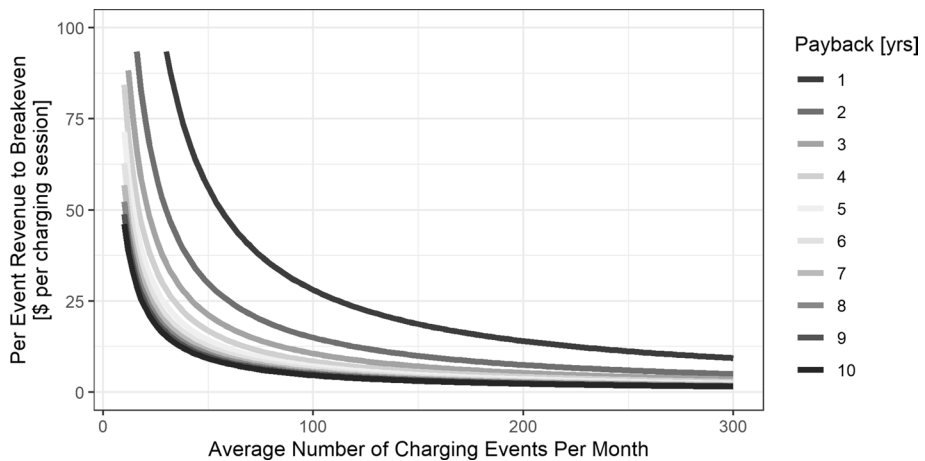


Fig. 11 Required revenue to breakeven across a range of payback periods at a 10% discount rate. The revenue is calculated on a per charging event basis, to achieve a three-year payback at the average observed station utilization rate of 120 visits per month, local businesses would need to extract an additional \$9 per event

dence that leveraging nearby businesses may be a viable source of alternative revenue to help breakeven on EV charger costs.

We conducted an additional payback analysis to investigate the required revenue to breakeven based on number of charging events per month. Figure 11 reveals the requirements across different payback assumptions, and at an average observed station utilization rate of 120 visits per month, businesses would need to extract slightly less than \$9 per visit to yield a 3 year payback—even with no revenue generated from the sale of electricity. This amount drops depending on the margin of profit that charging operators set based on the rates they charge their customers.

Policy options and recommendations

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.

Target subsidies toward flexible business models

Our results show that even with aggressive assumptions about doubling current utilization rates, most chargers still fail to recover costs within three years without subsidies. Subsidies should prioritize deployments in locations where demand is more robust or where partnerships with businesses offer opportunities for additional revenue streams. Rather than treating all deployments uniformly, incentives could be tiered based on projected utilization, existing site amenities, or demonstrated business partnerships.

Reform demand charge structures for public charging

Demand charges remain a significant fixed cost that scales poorly with low to moderate utilization. Our work shows that demand charges heavily penalize underused infrastructure, exacerbating financial difficulties. Policymakers should work with utilities and regulators to develop demand charge alternatives specific to EV charging infrastructure—such as rate-making reforms that reduce demand charges in favor of volumetric or time-of-use pricing structures for public DC fast charging stations.

Encourage co-location with commercial amenities

Our spatial analysis indicates a strong positive relationship between the density of nearby businesses (particularly restaurants and grocery stores) and charger utilization. Policies should encourage or incentivize charger deployment in commercially vibrant areas where drivers are likely to spend time and money while charging. Future grant programs could require or prioritize chargers co-located with key amenities to enhance both utilization and potential secondary revenue generation.

Support pricing innovation and transparency

Given the importance of pricing structures on revenues and customer behavior, policy should encourage experimentation with pricing models that better reflect charger use patterns and costs. Examples could include dynamic pricing to shift charging away from peak demand times, bundled charging and shopping discounts, or minimum session fees to help cover fixed costs. Transparency around pricing for consumers is also critical to build trust and avoid perceptions of unpredictable or excessive costs.

Broaden the business case beyond energy sales

The traditional model of selling electricity alone is insufficient for public charging profitability, as demonstrated in our revenue-cost gap findings. Policymakers should actively promote the integration of EV charging into broader commercial and retail ecosystems. This includes allowing advertising, loyalty programs, cross-promotions with nearby stores, and creating flexible zoning policies that encourage retail-hosted chargers.

Safeguard charger investment amid policy uncertainty

The potential rollback of federal incentives (e.g., IRA), GHG standards, and EV sales mandates creates additional risk for infrastructure investments. Policymakers should consider mechanisms such as “backstop” funding commitments, longer investment horizons for grants, or targeted supports that adjust automatically based on EV market conditions. Ensuring continuity of charger deployment through periods of federal or regulatory uncertainty will be critical to maintaining momentum.

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.

However, the future landscape remains highly uncertain. Potential rollbacks of key federal policies, including the Inflation Reduction Act (IRA) incentives, Corporate Average Fuel Economy (CAFE) standards, greenhouse gas (GHG) emission regulations, and the California waiver for Zero Emission Vehicle (ZEV) mandates, would fundamentally alter the projected trajectory of EV adoption. A slower uptake of EVs would, in turn, reduce the demand for charging infrastructure, directly impacting the financial viability of charger investments. These uncertainties introduce significant risk to both the scale and timing of infrastructure needs, reinforcing the importance of designing financially robust charging systems that can endure market and policy volatility.

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.

Author contributions Since there was a sole author on this manuscript, A.J. was responsible for all portions of this research.

Data availability Non-proprietary data can be accessed by reaching out to the author of this manuscript.

Declarations

Competing interests The authors declare no competing interests.

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