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Financial Feasibility of High-Power Fast Charging Stations: Case Study in San Diego California

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ABSTRACT

High-power fast charging stations are important in enabling electric vehicle (EV) travel and accelerating the transition to clean vehicles. In this study, we evaluate the financial viability of high power (125 and 400 kW) direct current fast charging stations (DCFCs) and identify capital and operational cost mitigation actions. A charging site in San Diego is chosen as a case study where the local utility is expected to serve a growing EV fleet during toward 2025 and beyond. Data from existing literature on charging infrastructure capital costs, utility-based electric vehicle charging rates, and CA-specific land and other costs serve as financial analysis inputs. Several scenarios are developed with varying the number of charging ports per station, charging power, as well as collocation of different energy storage sizes and photovoltaic arrays on site. The fast charging site is selected based on several land use and electricity grid criteria. Demand for electric vehicle charging over the analysis period enables estimation of the levelized cost of electricity that a charging service provider incurs annually. The results from the Electric Infrastructure Financial Analysis Tool (E-FAST) show that the break-even recharging prices for financial viability of the proposed fast charging stations (at a 10% discount rate) in San Diego vary from 35 to 50 cents per kWh. The results also show that bundling energy storage and photovoltaics with DCFCs leads to a strong business case with higher profitability indices and internal rates of return (above 10 percent).

Keywords: Electric Vehicles, Fast Charging, Financial Analysis, Case Study, San Diego, California

1. INTRODUCTION

The passenger vehicle mix is gradually changing as technological advancements improve light-duty vehicles fuel economy, leading to a more efficient transportation system. The landscape of personal mobility is also shaped by consumers' interest in conducting their daily trips in a sustainable manner [1]. The innovativeness, engineering ingenuity, and operational cost-effectiveness of plug-in electric vehicles (PEVs) attract consumer attention [2]. By partially or solely operating on electricity, PEVs have less or zero tailpipe emissions compared to conventional gasoline-fueled vehicles [3]. Such vehicles are promoted by government agencies through incentive allocation like tax credits and charging infrastructure subsidies and support, specifically due to their potential to improve regional air quality and drive down drivers' capital and operational costs [4], enabling this vehicle technology to break into the mass market.

Realizing the electric vehicle charging infrastructure services necessary to support PEV operations, commercial electric vehicle charging network providers invest in placing publicly accessible fast charging infrastructure along the transportation network [5]. Fast chargers have the potential to recharge vehicles at a faster service rate (300 miles in 15 minutes at a 350-400 kW port) than the one that drivers can achieve at home (usually with Level 1 or 2 charging) [5]. Public charging infrastructure placement is beneficial for the drivers as well as those considering purchasing PEVs, since it enables them to electrify more miles and conduct longer trips breaking down range-anxiety barriers. In the United States as of July 2020 there are 3,831 direct current fast charging stations (DCFC) with 14,638 charging outlets (referred to as ports in this analysis) [6] publicly available. Those are operated by twelve network providers. However, providers of such services compete for a small market share of PEV drivers, approximately 2-3% of the light duty vehicle sales in North America [7] and install emerging, costly infrastructure that has not reached economies of scale yet, which may hinder the financial success of their venture.

The literature on estimating direct current fast charging infrastructure costs and exploring the economic viability of DCFC installation and operation ventures is thin. During the early years of the potential market transition to electrified mobility, when utilization of charging stations is low, DCFC network providers are found to experience high operational costs due to demand charges (costs proportional to the peak charging power consumption during a billing period in $/kW), even close to $2/kWh [8]. Modest utilization along with high fixed electricity costs pose financial burdens for DCFC network expansion. Better electricity rate design for DCFC applications can enable utility cost recovery without hurting the competitiveness of light-duty electric vehicle fast charging services [9]. What is more, dynamic electricity pricing schemes could assist DCFC providers to reach financial viability goals [10]. Research on high power charging complexes identifies opportunities to mitigate high electricity costs by locating energy storage and photovoltaic arrays on site for high-power DCFC stations to reduce dependence on the electricity grid and to curb operational costs [11]. PEV fast charging stations with these capabilities are already being tested in the field [12,13].

In this study, we explore the effect of factors such as charging utilization, port power level, station power sharing, and energy storage and renewables integration on the operational and capital cost expected to be experienced by a DCFC infrastructure network provider. Such financial analysis is crucial for understanding the difficulties of sustaining a dense DCFC network when utilization levels vary and, in the future, can help towards determining DCFC subsidies needed in the early stages of light-duty vehicle electrification to sustain their operation. This effort aims to evaluate the financial viability of high power DCFC stations and shed light into ways that high capital and electricity cost components can be mitigated. Given that Lieven's market simulation reveals that the charging infrastructure is essentially the "bottleneck for the universal adoption of electric vehicles" [14], DCFC networks' economic prosperity is important in order to sustain adequate infrastructure availability and coverage to support electric vehicle operations. To our knowledge, this is one of few works that aims to aggregate data, literature, and propose models to explore financial metrics for fast charging stations, addressing transportation and electric grid considerations.

This study evaluates the economic viability of DCFC station scenarios of different power levels (125 and 400kW), number of ports (12, 24, 48) assuming that ports can operate simultaneously but power-sharing is needed, and collocation of on-site energy storage (ES) and photovoltaic arrays (PV). The analysis focuses in San Diego, California since the city falls within one utility service territory (San Diego Gas and Electric) and has significant PEV adoption levels, where currently PEVs constitute more than 5% of the 2017 vehicle registrations [15]. To determine utilization patterns of a DCFC station over the years 2018-2025 for San Diego we leverage the Electric Vehicle Infrastructure Projection (EVI-Pro) tool, which was developed under a collaboration of the California Energy Commission with the National Renewable Energy Laboratory (NREL). We use geographic information systems and data analysis to locate the case study's station in San Diego, adhering to several criteria, such as proximity to the city's downtown, electricity substation proximity, land cost, parking availability, etc. To size the energy storage and photovoltaic arrays collocated at the DCFC station site we leverage NREL's REopt Lite [16]. NREL's Electric infrastructure Financial Analysis Scenario Tool – E-FAST, adapted from H2FAST for hydrogen stations' financial analysis [17], is the modeling framework that calculates break-even electricity prices, profitability indices, and internal rates of return (IRR) over the alternative scenarios of DCFC station sizes, utilization, and storage/PV placement.

The remainder of this paper is organized as follows. The second section presents an overview of the financial analysis methodology used in E-FAST and briefly reviews other tools used to meet the studies objectives, such as EVI-Pro and REopt Lite. The third section describes data inputs, assumptions, and scenario descriptions, followed by a section dedicated to financial indices and IRR results. The last section summarizes findings, points out limitations, and proposes future research directions.

2. METHODOLOGY

Data synthesis and analysis was used to feed necessary information as inputs to the financial analysis model, E-FAST. Figure 1 summarizes the process followed to estimate profitability indices, IRR, and break-even electricity prices under these several scenarios of DCFC configuration.

Several scenarios are examined, combinations of different DCFC port power levels, number of ports per station, and ES and PV on-site collocation. The financial analysis of these scenarios spans a period from year 2018 to 2025. Geographic information systems and data analysis were used to determine the exact location of the charging station accounting for the following: location of existing DCFC [6], land use [18], parking spots availability, distance from highway intersection, proximity to electrical substations [19], and property taxes [20].

Determination of DCFC percentage of utilization over the analysis years was achieved in this case through EVI-Pro [21]. Inputs include plug-in electric vehicle average battery sizes and power levels assumptions, percent of PEV penetration, and regional travel demand for a typical weekend and weekday. EVI-Pro modeling outputs used in this paper include the expected hourly utilization percentage of an average DCFC station over the analysis period.

Sizing the energy storage and the photovoltaic arrays was determined via REopt Lite [16] and PVWatts [22] models. The load profiles (charging demand results) for each of the DCFC scenarios were used as inputs and the sizes of the ES and the PV were determined by the optimization models, subject to constraints of limited space available for PV installation on the chosen DCFC site. Several resources [11,16,23] are consulted to determine average values for capital and installation costs of DCFC, ES, and PV infrastructure. The San Diego Gas and Electric public grid integration rate [24] is used to estimate the levelized electricity cost in $ per kWh for the DCFC utilization profiles specified.

Finally, E-FAST is deployed to calculate profitability indices and IRR for all DCFC scenarios, as well as estimate break-even electricity prices for the DCFC network providers. The internal rate of return denotes the discount rate where the net present value of the project equals to zero. The break-even price denotes the price that the network provider would need to sell fast charging service electricity to receive internal rate of return that is equal to the discount rate specified in the analysis. To showcase the potential financial viability of a DCFC station venture, the profitability index of the station is estimated, which is denoted as the ratio of present value of future cash flows to initial equity investment for the DCFC station project. When this fraction is greater than 1, the project may make a profit for an equity investor over the 15-year project's life.

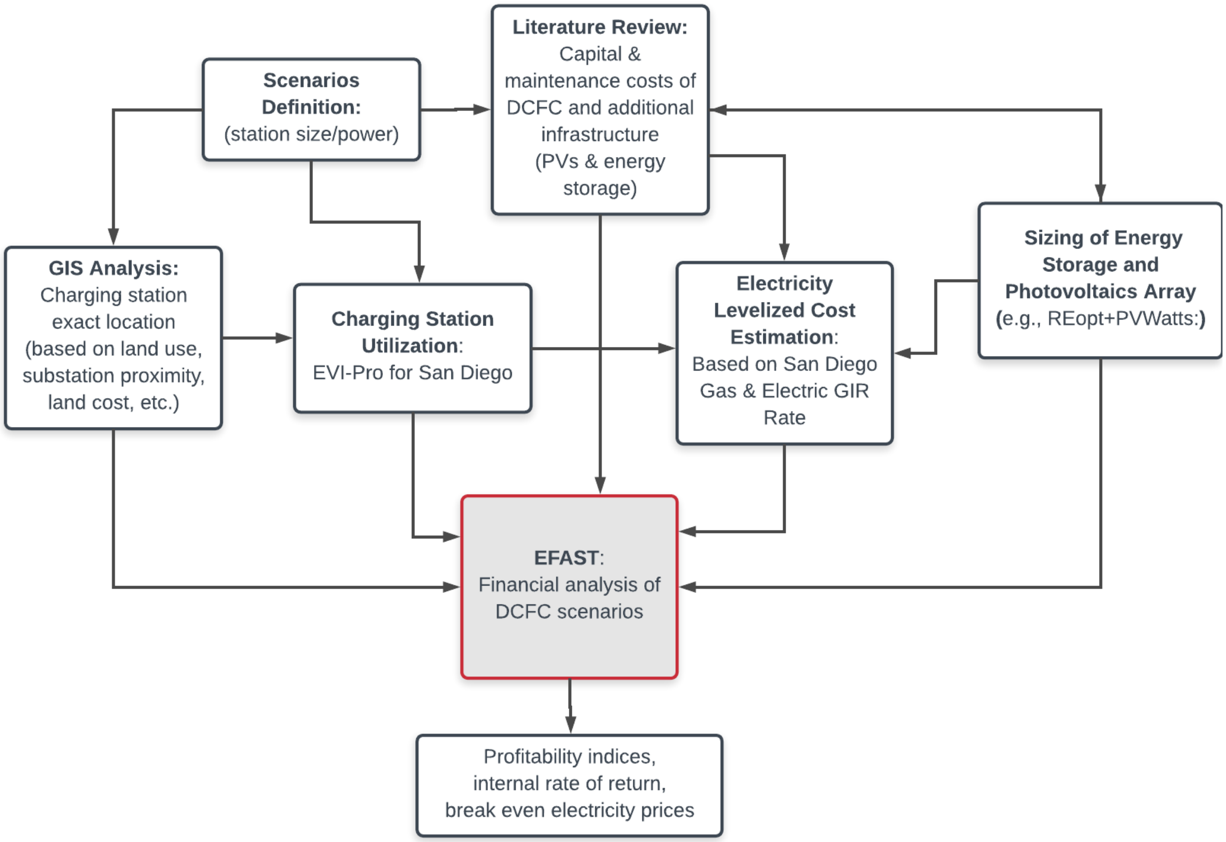


FIGURE 1 Processes and feedback loops used for achieving financial analysis of DCFC station scenarios.

E-FAST inputs include station utilization, applicable electricity prices, land costs, taxes (federal and capital gain) rates, infrastructure lifetime, and other parameters noted in TABLE 1.

TABLE 1: E-FAST General Financial Analysis Inputs

Parameters	Default Values	Notes
Years of the analysis	8	2018-2025
Equipment lifetime	20	
Discount rate for break-even price analysis	10%	
Escalation cost of electricity/year	0%	electricity tariff input as shown in FIGURES 8 & 9
Long term nominal charging station utilization per hour of day	max 95% weekends, 90% weekdays during busiest time of day	energy-based use (during busiest time of day utilization can reach x%)
Non-depreciable fixed assets costs	$30,000 per 12 parking spots	in accordance to Costar property data analysis [20]
End of project sale of non-depreciable assets	$36,000	assumption
Planned and unplanned maintenance [$/year]	$1,500/year	per port
Credit card fees Sales tax Federal rate California tax rate General inflation rate Leveraged after tax nominal discount rate	2.75% 7.75% 21% 7.75% 1.90% 10%	US- and CA-specific inputs assumptions

3. SCENARIO & DATA DESCRIPTION

This section presents data processing steps that were followed for this analysis, as well as scenario assumptions made, and other inputs. Specifically, in this section we are focusing on 1) the DCFC geographic information systems data analysis and the criteria based on which the DCFC was situated in San Diego, 2) the DCFC scenarios definition including ES and PV sizing, 3) the charging station utilization percentage, and 4) the capital and electricity tariff data used.

DCFC Site Location

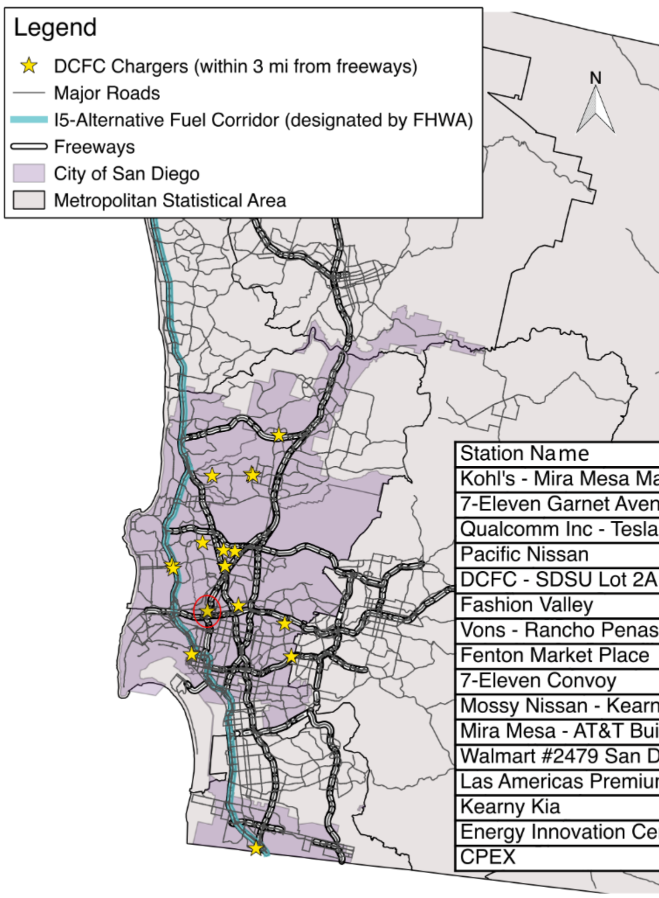
The DCFC site is in the city of San Diego CA, considering the following:

- Already existing DCFC site preferred [6].
- Proximity to major highway/freeway intersections (within 3 miles).
- Number of parking lot spots greater than the maximum number of ports - max 48 [20].
- Commercial land use preference(e.g., shopping centers, recreational facilities, etc.) [18].

- Proximity to existing substations [19].
- Land cost approximated by property tax information [20].
- Area availability for PV installation [22].

FIGURE 2 shows already existing, publicly available DCFC stations located within 3 miles from major intersections in the city of San Diego CA. The hypothetical station is located in Fashion Valley Shopping Center, where the number of parking spots exceeds 1,600, the land use constraints are satisfied, and the location is within a mile from an electrical substation (with total generation capacity of 9.61 MW). Fast charging locations should consider grid effects, such energy loss due to electric vehicle charging [25]. FIGURE 3 shows the distribution of the commercial property taxes values in the region; the chosen location's property tax at $1.5 per square feet is less than the median and the mean of the distribution in the region.

Given that some of our scenarios examine the potential of locating PV on-site, we account for limitations pertaining to area availability for their installation. In particular, 2,621 square meters are available for their potential installation on-site. It is assumed that there are no such limitations when it comes to ES collocation, though in practice associated electrical service and power conversion equipment would require area proximate to parking facilities.



Station Name	Street Address	EV DC Fast
Kohl's - Mira Mesa Mall	8110 Mira Mesa Blvd	4
7-Eleven Garnet Avenue	2805 Garnet Ave	1
Qualcomm Inc - Tesla	10155 Pacific Heights Blvd	12
Pacific Nissan	4433 Mission Bay Dr	1
DCFC - SDSU Lot 2A	5500 Campanile Dr	2
Fashion Valley	7007 Friars Rd	2
Vons - Rancho Penasquitos Towne Cntr	13289 Black Mountain Rd	4
Fenton Market Place	2149 Fenton Pkwy	2
7-Eleven Convoy	4080 Convoy St	1
Mossy Nissan - Kearny Mesa	8118 Clairemont Mesa Blvd	1
Mira Mesa - AT&T Building	8225 Mira Mesa Blvd	2
Walmart #2479 San Diego (College) Array	3412 College Ave	2
Las Americas Premium Outlets	4211 Camino De La Plz	4
Kearny Kia	7303 Clairemont Mesa Blvd	2
Energy Innovation Center - SDG&E	4760 Clairemont Mesa Blvd	4
CPEX	1600 Pacific Hwy	1

FIGURE 2: Existing DCFC stations in San Diego CA; chosen site within red circle.

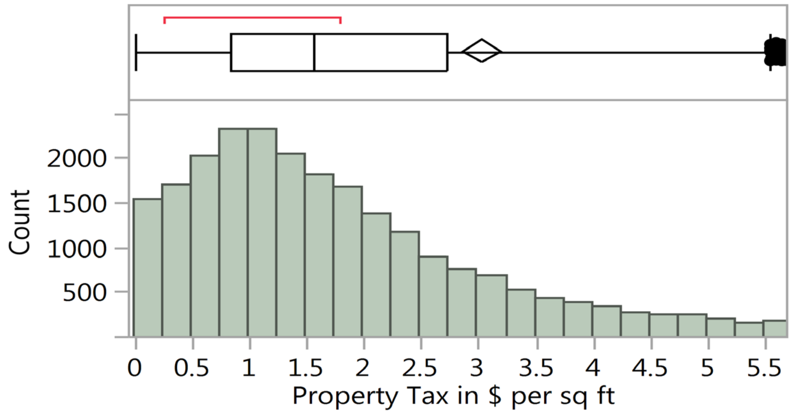


FIGURE 3: Commercial property tax distribution in San Diego, CA [20]**.**

DCFC Scenarios Definitions

After determining the station site location, scenarios which are combinations of the number of ports per station, power levels and collocation of ES or simultaneous ES and PV are defined. Those are presented in TABLE 2. Assumptions are made associated with peak power sharing, which are arbitrarily set to reduce potential electricity costs. The ES capacity is dictated by the size and the power level of the station. The bigger the station, the greater its usage, and the higher power level per port, the greater the optimized energy storage power and the battery capacity. The direct current PV system size is 393.1 kW in all scenario cases. That is also dictated by the limited area availability of the rooftop of the shopping mall that provides 2,621 square meters of area to install PV. The PV array's annual energy output is estimated at 671 MWh. The monthly variation of the PV energy output for San Diego is captured via PVWatts [22]. The DCFC station monthly power consumption in kW is expected to decrease due to the ES installation, and the PV collocation is expected to reduce energy consumed per month due to the ability of on-site electricity generation. ES may be key for the stable operation of the proposed system and reinforce integration of renewable energy use [26]. Note that PV do not only have the potential to reduce energy costs for fast charging providers but also increase the penetration of renewable sources for the transportation sector [27].

TABLE 2: Scenario Definition

Power Requirements & Performance Definitions	DCFC – 125 kW 12 / 24 / 48 ports	DCFC – 400 kW 12 / 24 / 48 ports
Peak plug power (KW)	125 kW	400 kW
Peak power-sharing (W/station)	500 kW / 1.5 MW / 4 MW	2 MW / 4.4 MW / 8 MW
Alternative scenario 1: Only ES Energy storage power (kW): Battery capacity (kWh):	46 kW / 139 kW / 367 kW 122 kWh / 366 kWh / 970 kWh	184 kW / 404 kW / 735 kW 485 kWh / 1,067 kWh / 1,939 kWh
Alternative scenario 2: Energy storage + PV size	ES: same as above PV: 393.1 kW (PVWatts)	ES: same as above PV: 393.1 kW (PVWatts)

Charging Utilization for San Diego DCFC Station

EVI-Pro modeling capabilities are leveraged for planning purposes in several cities and states in the U.S. *(e.g., 21)*. In this study, based on travel data pertaining to San Diego CA from the 2017 California Household Travel Survey [28], charging profiles of an average DCFC station in the region are generated, as shown in FIGURE 4. Even though we present annual utilization levels (serving as inputs to the financial analysis), differences among hour of day and typical weekday and weekend operations are captured. Note that by the end analysis year 2025, charging station usage is expected to reach 90%-95% during the peak hour of day of weekdays and weekends. Utilization percent during the early years is substantially lower, going from a load factor (i.e., average electrical load divided by peak load in a specified time period) of 5.08% in 2018 to 40.41% in 2025. The utilization rate increases quadratically with the number of charging ports in a station, even though power sharing among plugs might slow down recharging processes in this case.

There are differences in the average battery electric vehicle power levels assumed for DCFC 125kW and 400kW, as shown in FIGURE 5, since larger batteries warrant faster recharging. The average power of the y-axis is the weighted average of the different BEV range classes in the San Diego population that changes over time. Our hypothesis is that DCFC 400kW are more likely to be deployed to serve greater electric driving range vehicles.

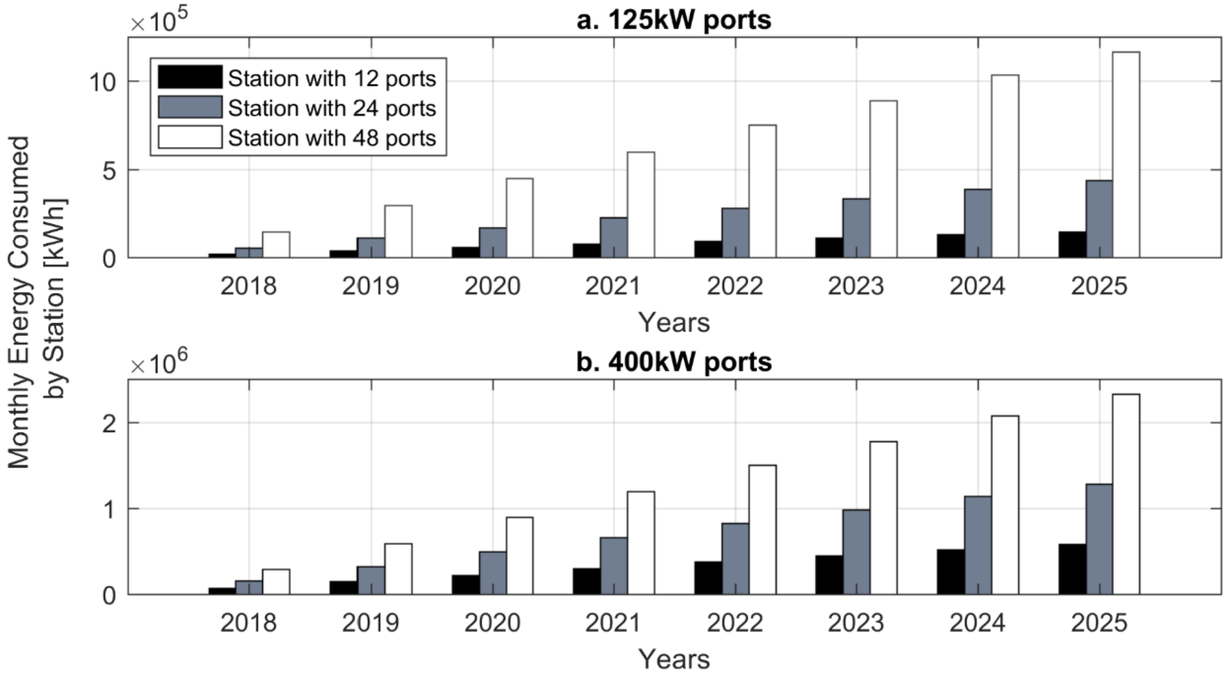


FIGURE 4: Monthly charging station energy use.

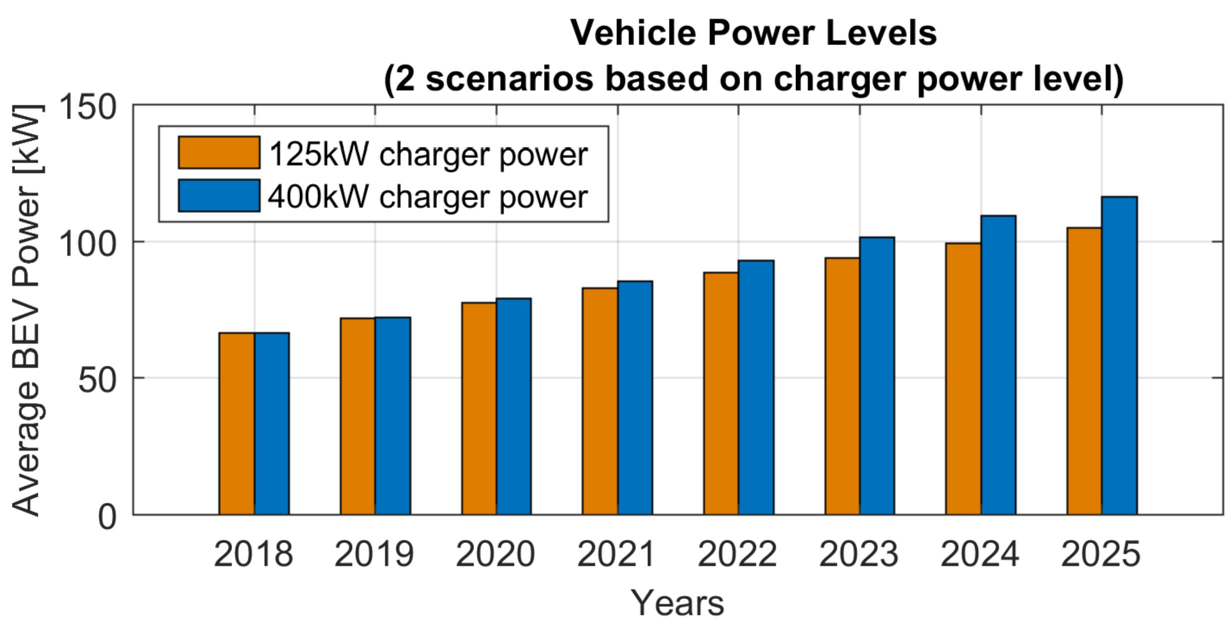


FIGURE 5: Average BEV battery power levels over the analysis years.

Capital and Electricity Tariff Datasets

Capital Costs

Literature review was conducted to attribute capital costs to various infrastructure components. The majority of those values stem from [11,16,23]. FIGURE 6 shows these costs that are estimated by breaking down cost components in a similar manner as those that appear in [11]. For example, the DCFC unit hardware cost assumption is 50 cents per Watt, the ES costs $500 for every kWh of energy capacity and $1000 per power level kW, and the PV infrastructure costs assumption is approximately $2000 per kWh. The investments required for transformer upgrades from 300kVA to 500, 1300 and 3900kVA for the 12/24/48 ports of 125kW-each scenarios and to 1300, 4400 and 9100 for the 12/24/48 ports of 400kW-each scenarios are accounted for. Those assumptions are presented in TABLE A1 of the Appendix section. Other costs taken into consideration include permit fees, conduit and cables ($2,333/unit), surface and underground work ($6,600/unit), equipment installation and management and design costs.

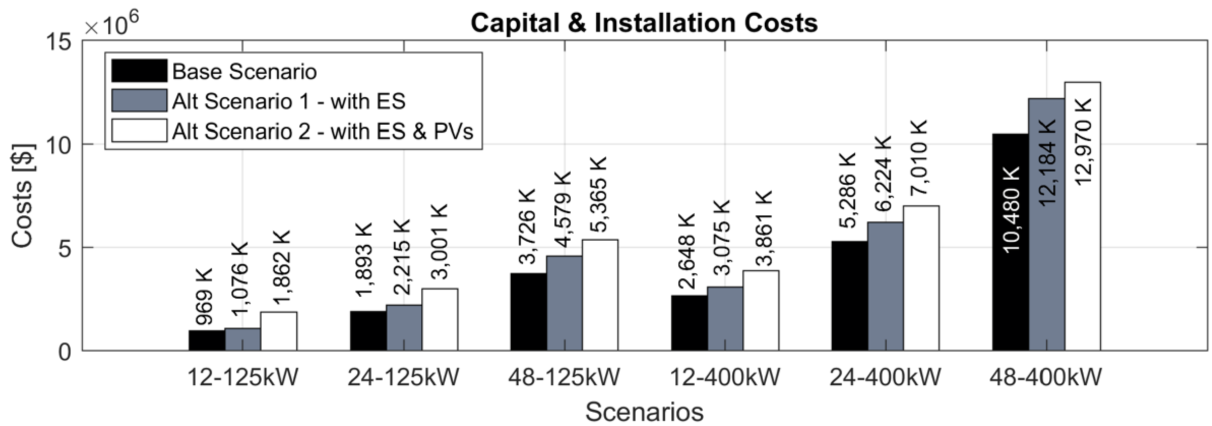


FIGURE 6: Capital and installation costs for scenarios considered.

As expected, the capital investment increases with the installation of ES (Alt Scenario 1) and ES and PV (Alt Scenario 2) compared to the base case scenario. Also, the capital cost increases as the number of charging ports and power level increase. For example, capital investment increase of approximately 173% is needed when considering 12 ports of 400kW power level compared to 12 ports of 125kW. An increase of capital cost by 11.05% is needed when considering placing ES in a 12-port station of 125kW power each compared to the base case and by 92.14% when considering collocating ES and PV at a 12-port station of similar power level ports.

Electricity Cost

An actual DCFC applicable electricity tariff offered currently for pilot projects by San Diego Gas and Electric utility company in the San Diego region is selected. More specifically, the public charging grid integration rate is applicable for "electrification of local highways & green taxi/shuttle/rideshare projects" [24]. The tariff is characterized as critical peak pricing. There are no grid integration or demand charges, only a base energy charge at 13.871 cents per kWh as well as California ISO day ahead hourly price component which varies by time of use. Historical data are used to capture that energy time-of-use component in $ per kWh, using data from March 2017-February 2018. Critical peak pricing hourly adders are used as a mechanism to recover portion of electricity generation and distribution costs incurred by the utility: for the system top demand 150 hours 50.535 cents per kWh and for the circuit top demand 200 hours a charge of 18.656 cents per kWh. To address the best- and worst-case scenarios, we examine the effects of these adders under the assumption that chargers are not utilized during these top system and circuit hours (best case) and when the chargers are utilized at the maximum rate during these top system demand hours (worst case). FIGURE 6 showcases the indicative differences between the best and worst-case scenario.

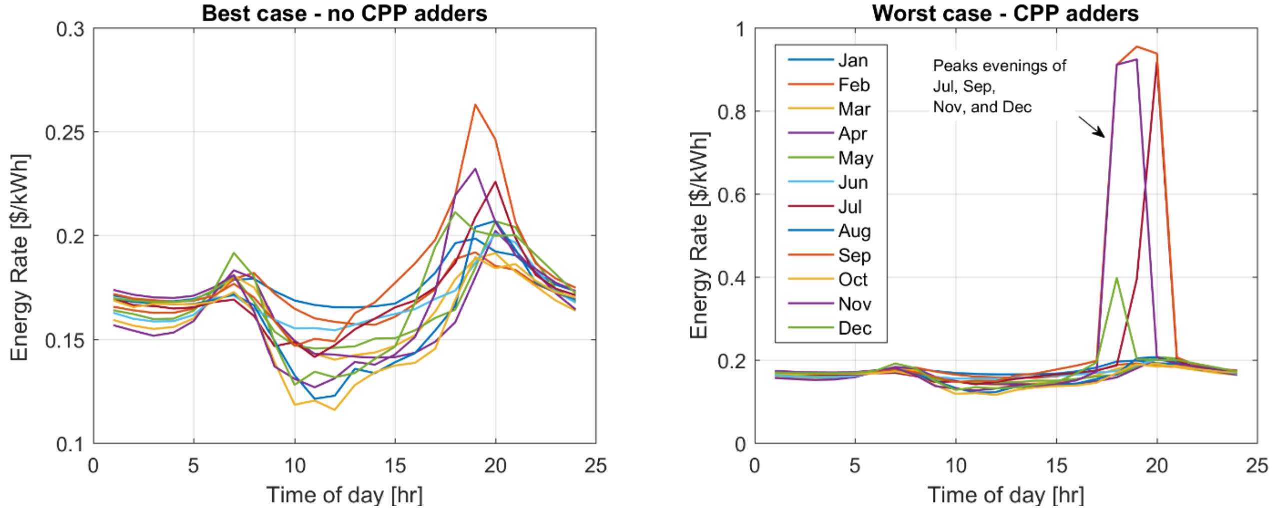


FIGURE 6: San Diego Gas and Electric electricity rate applicable to public DCFC.

Levelized costs of electricity are examined for the electricity rate, under the utilization profiles assumptions shown in FIGURE 7. In FIGURE 7, for a 12 plug and 125kW and 400 kW per port station, the electricity cost is expected to decrease over the years due to increased charging station utilization in the worst case were critical peak pricing adders occur at the worst possible hour of day (when maximum energy is consumed). As ports' power level and utilization increases (e.g., from graph a. to b.) the levelized cost is expected to decrease, partially because greater amount of energy is consumed. The levelized cost in $ per kWh further decreases with the collocation of ES and the PV, comparing a. to e. and b. to f. subgraphs. Note that for both ES and PV installation on the DCFC site shown in e. and f., in the early years due to limited amount of energy which can be generated by the PV, the cost is low; as the energy requirements increase over the years so does the average levelized cost of electricity.

FIGURE 8 presents similar results for the 24-port station. It is evident that the increased energy and utilization levels distribute the fixed electricity cost across a higher volume of kWh sold. For that reason, significant savings are observed, particularly in the early years: in year 2018 average levelized electricity costs drops from $0.4 per kWh to $0.25 per kWh comparing 12- to 24-ports station sizes. Greater energy use assumptions for larger station sizes result in lower electricity costs incurred by the DCFC provider. There are no significant differences between 400kW stations of 12 and 24 ports levelized costs, since both best and worst-case scenarios converge to around 16 cents per kWh after year 2020.

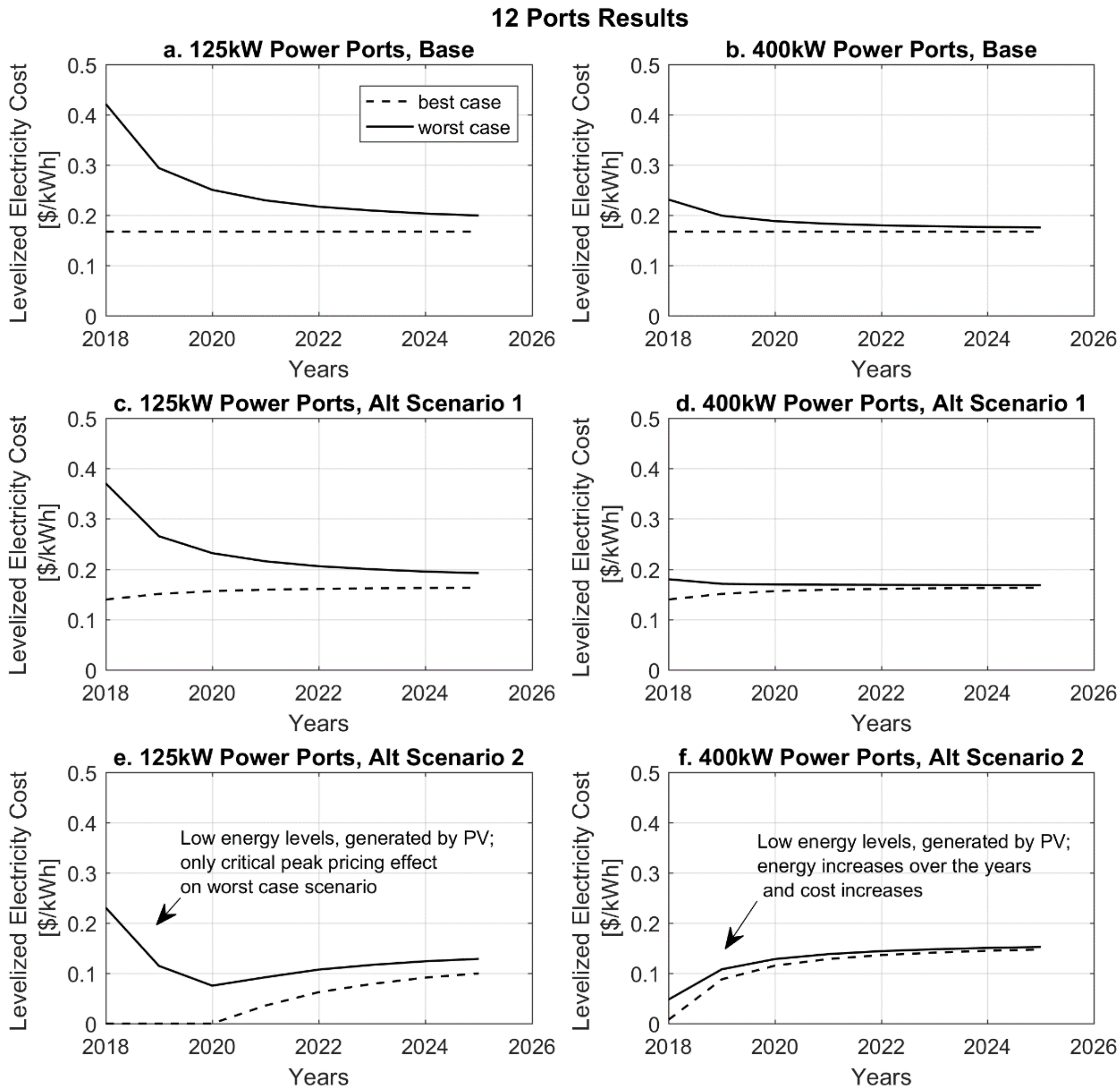


FIGURE 7: Levelized electricity costs for a 12-port DCFC station over the analysis years.

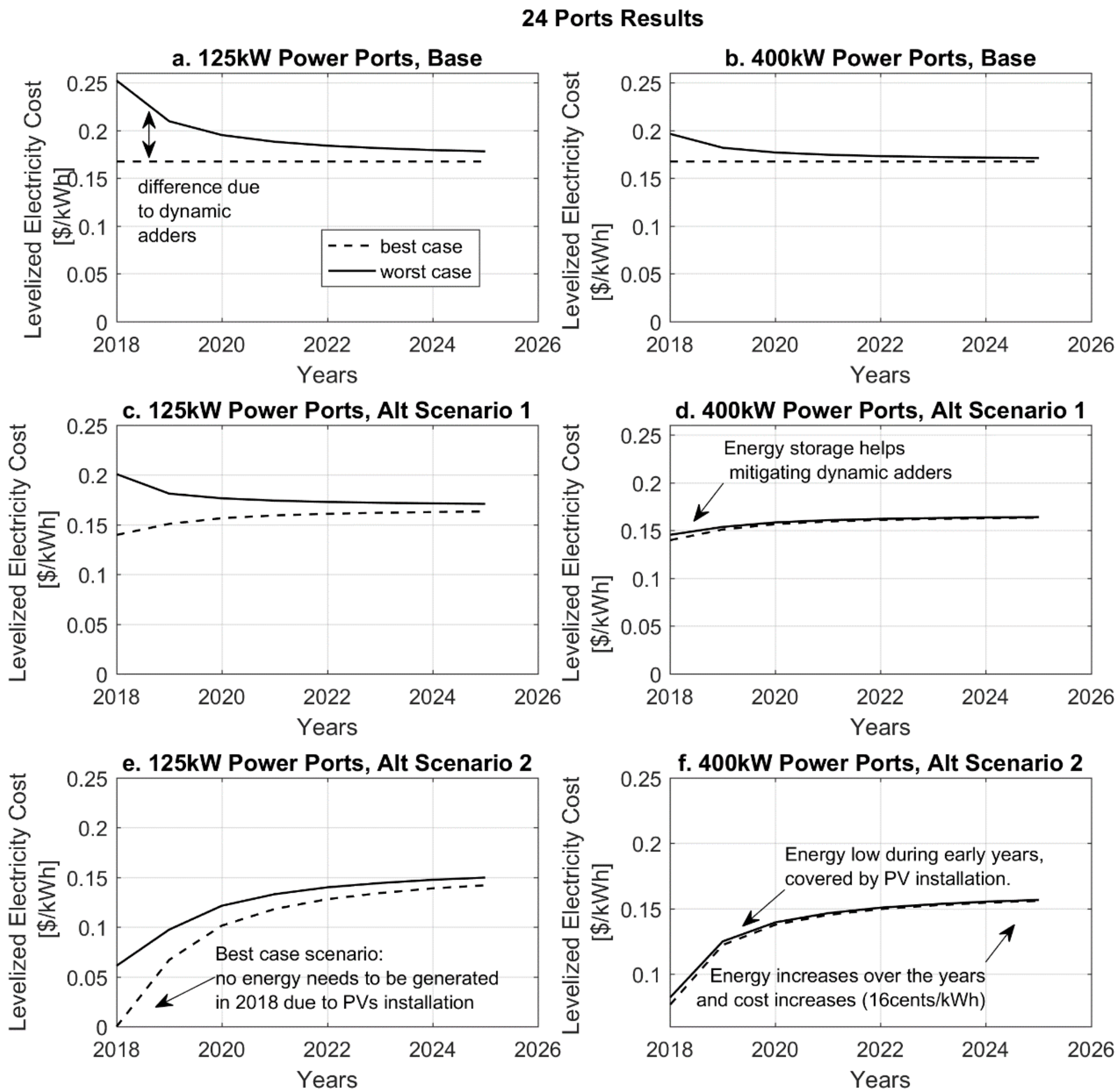


FIGURE 8: Levelized electricity costs for a 24-port DCFC station over the analysis years.

The financial analysis results discussed in the following section are generated under the assumption of the worst-case electricity cost for the scenarios explored. These costs vary from 15 cents per kWh to 40 cents per kWh, indicative of the results portrayed above.

4. RESULTS

The results in TABLE 3 shows that as DCFC load increases with increased number of plugs, the break-even price of electricity decreases. ES and PV operational savings (these reduce the amount of electricity drawn from the grid) justify their high capital and installation costs. For the base scenario, it is evident that ES collocation is beneficial since it reduces the impacts of critical peak pricing; this leads to the reduction of the break-even electricity price and the increase of the profitability index for the alternative Scenario-1 configuration. Increases in the number of charging ports result higher electricity load levels, which justify the investment in both energy storage and photovoltaics (approximately 10-12% break-even price reduction as shown in TABLE 3).

TABLE 4 shows similar results for extreme high power 400kW charging stations. Even though the percentage of DCFC station utilization here is similar to that of a DCFC station with 125kW ports, the average energy per charging event requested from the grid is higher, based on FIGURE 6 assumptions. This results in having alternative scenario 2 with ES and PV collocation as the best option for minimum break-even price and highest profitability index, no matter the number of plugs of the station. It suggests that the operational costs savings achieved warrant ES and PV collocation, despite the high capital and installation costs. Renewables integration can result in up to 15% break-even price reductions in this case.

When looking into the 12 plugs at 125kW scenario, it appears from FIGURE 8 that levelized cost of electricity approaches $0.20/kWh in later years of operation. In Table 3 the break-even price is estimated at $0.49/kWh. This suggests that about 40% of the break-even price covers cost of electricity with the remaining 60% covering capital and installation costs. Similar percentages can be observed for the rest of the scenarios when it comes to electricity cost and break-even prices comparisons.

TABLE 3: Break-even Electricity Prices (BEP), Profitability Indices (PI), and Internal Rate of Return (IRR) of DCFC Station with 125 kW Ports

	12 Plugs - DCFC 125kW			24 Plugs - DCFC 125kW			48 Plugs - DCFC 125kW		
Scenarios & Metrics	**BEP [$/ kWh]**	**PI**	**IRR**	**BEP [$/ kWh]**	**PI**	**IRR**	**BEP [$/ kWh]**	**PI**	**IRR**
Base Scenario	0.49	1.04	4.36%	0.48	1.08	8.52%	0.43	1.34	8.10%
Alt Scenario 1	***0.45***	***1.23***	***7.41%***	***0.42***	***1.38***	***8.45%***	0.42	1.40	8.52%
Alt Scenario 2	0.50	1.10	*2.22%*	***0.42***	***1.39***	***8.33%***	***0.38***	***1.64***	***11.48%***

TABLE 4: Break-even Electricity Prices (BEP), Profitability Indices (PI), and Internal Rate of Return (IRR) of DCFC Station with 400 kW Ports

	12 Plugs - DCFC 125kW			24 Plugs - DCFC 125kW			48 Plugs - DCFC 125kW		
Scenarios & Metrics	**BEP [$/ kWh]**	**PI**	**IRR**	**BEP [$/ kWh]**	**PI**	**IRR**	**BEP [$/ kWh]**	**PI**	**IRR**
Base Scenario	0.50	1.13	4.36%	0.46	1.17	5.83%	0.42	1.34	8.61%
Alt Scenario 1	0.49	1.19	3.72%	0.45	1.22	5.90%	0.40	1.43	9.84%
Alt Scenario 2	***0.43***	***1.30***	***7.09%***	***0.42***	***1.31***	***6.52%***	***0.36***	***1.66***	***12.94%***

Break-even electricity pricing results presented in this section are more affordable compared to Francfort et al. [11]. The authors there estimate break-even prices varying from $0.60/kWh to over a $1/kWh for different power levels and station configurations, under 30% load factor assumptions.

5. DISCUSSION

The analysis presented in this paper aims to shed light on the potential magnitude of capital investments and operational costs of fast charging station installation and utilization. To promote and sustain PEV operations, achieving good charging infrastructure coverage of the transportation network is critical and, thus, financial prosperity of DCFC ventures is important to be explored. This work not only investigates financial indices for different sizes and power levels of charging stations and their potential integration with renewables, but also presents tools that can assist with meeting such an objective. E-FAST is primarily used for determining financial metrics for a set of alternate DCFC configurations, but several other tools, such as EVI-Pro, REopt and GIS analytics, are combined to enable capturing the cost and utilization inputs.

Findings suggest that charging utilization and energy levels are the most significant factors for achieving satisfactorily annual financial performance. Growth in charger utilization leads to lower cost of electricity, which is critical particularly in earlier years of the EV market. Due to the operational savings that can be achieved with the collocation of energy storage and photovoltaics under optimistic growth of DCFC demand in the San Diego region, internal rate of return for such projects is increased. Break-even prices estimated vary from $ 0.36 to 0.50 per kWh, prices that are not so different from the ones offered currently by certain DCFC networks, such as EVgo's Pay As You Go or Membership plans in San Diego [29]. This result could still be considered expensive comparing to gas-fueling equivalent that could be less than $0.30/kWh and compared to much lower residential electricity rates (around $0.15/kWh or less) [11]. However, the higher value that BEV drivers place on fast charging to enable additional travel is the subject of ongoing study [31].

While this is one of the first attempts in understanding DCFC finances, the study has a few limitations. Firstly, the unavailability of detailed data in the field hinders the development of accurate financial viability metrics. The costs are based on several spatiotemporal components, such as land costs, utility rate structures, infrastructure costs learning curves, etc. and there is little to no actual open data that we can point to for more accurate outputs. In addition, non-energy fixed and variable operational and maintenance cost data specific to individual fast charging network operators is excluded from this analysis. Also, integrating transportation and grid operations involves combining tools whose input and outputs have very different dimensions. Even though, for example, we are capable of tracking hourly DCFC utilization levels from EVI-Pro, we convert these to monthly values to match E-FAST inputs dimensions. Last but not least, the variety of parameters that can vary in this analysis and potentially impact the results of our study warrants the need for establishing more realistic scenarios dependent on actual PEV penetration potentials. Future efforts will focus on addressing these limitations.

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APPENDIX

Table A1: Capital and Installation Cost Components and Sources

Cost Components	12 ports 125kW	24 ports 125kW	48 ports 125kW	12 ports 400kW	24 ports 400kW	48 ports 400kW	References
Engineering design ($)	2,500	2,500	2,500	2,500	2,500	2,500	PG&E data
Permit fees (3% of equipment installation)	1,450	1,975	2,500	1,600	2,050	2,500	PG&E data
kVA transformer update (from 300kVA)	500kVA	1,300kVA	3,900kVA	1,300kVA	4,400kVA	9,100kVA	[30]
Utility interconnection cost (update from 300kVA in $)	8,481	30,400	103,200	30,400	117,400	248,800	[11]
Load center and meter section ($916 per unit)	10,992	21,984	43,968	10,992	21,984	43,968	[11]
ES System Power Size (kW)	46	139	368	184	404	735	[16]
ES System Capacity (kWh)	122	366	970	485	1,067	1,939	[16]
ES System Cost ($500 per kWh + $1000 per kW)	107,000	322,000	853,000	426,500	937,500	1,704,500	[16].
PV Output (kWh)	393	393	393	393	393	393	[22]
PV System Cost ($2000 per kW)	786,000	786,000	786,000	786,000	786,000	786,000	[11]

DCFC Unit Hardware ($0.5/W)	750,000	1,500,000	3,000,000	2,400,000	4,800,000	9,600,000	[11]
Conduit & cables ($2,333/unit)	17,904	35,808	71,616	19,852	39,704	79,408	PG&E data
Concrete pads material & labor ($2,000/unit)	20,600	34,600	48,600	20,600	34,600	48,600	PG&E data
Site surface and underground work ($6,667/unit)	80,000	160,000	320,000	80,000	160,000	320,000	[11]
Fixed cite improvements (lighting, pavement striping etc.)	22,000	31,000	40,000	22,000	31,000	40,000	PG&E data[1]
Equipment installation costs	48,340	65,840	83,340	53,340	68,340	83,340	[23]
Project management cost (12% of labor/subcontract)	6,893	8,993	11,093	7,493	9,293	11,093	[11]
Total Capital w/o ES & PV ($)	**969,160**	**1,893,100**	**3,726,817**	**2,648,777**	**5,286,871**	**10,480,209**	
Total Capital Alt Scenario 1 ($)	**1,076,160**	**2,215,100**	**4,579,817**	**3,075,277**	**6,224,371**	**12,184,709**	
Total Capital Alt Scenario 2 ($)	**1,862,160**	**3,001,100**	**5,365,817**	**3,861,277**	**7,010,371**	**12,970,709**	

[1] Pacific Gas & Electric (PG&E) utility data shared via California Energy Commission.

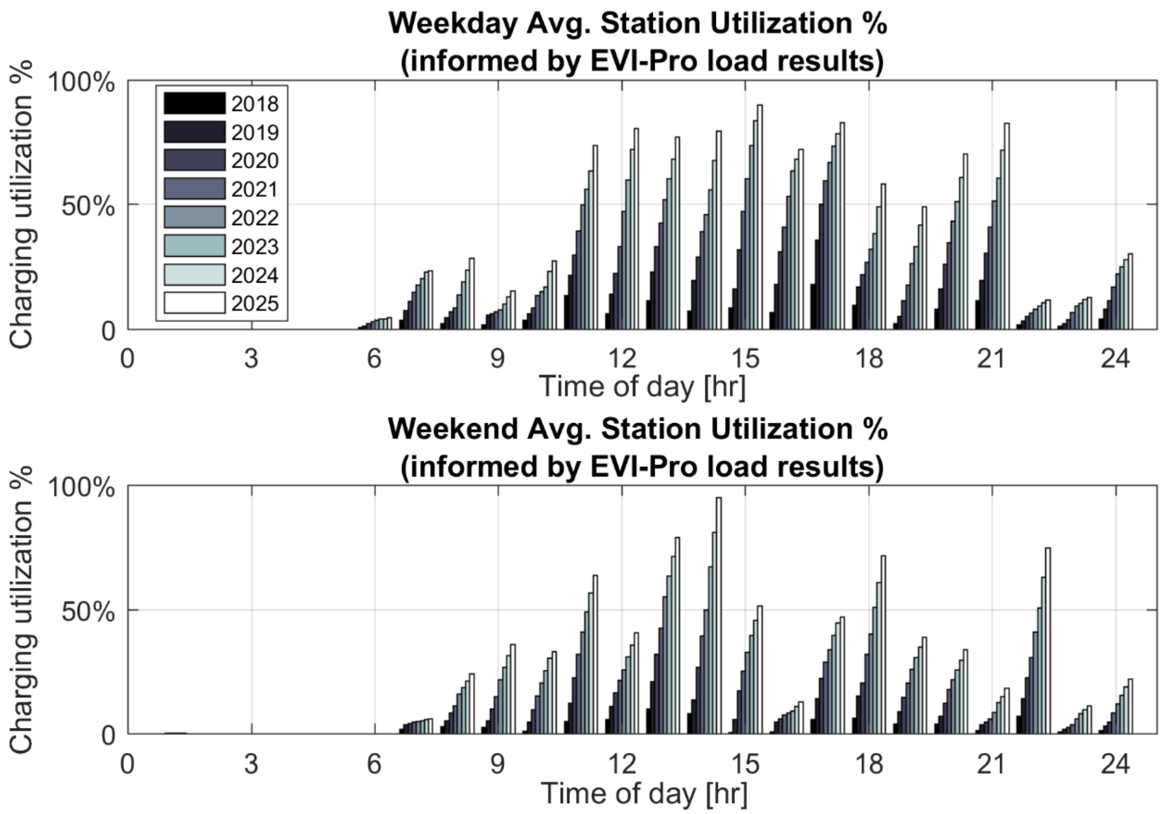

FIGURE A1: Time-of-day charging utilization level in San Diego CA (varying between weekday and weekend), based on EVI-Pro [21]**.**

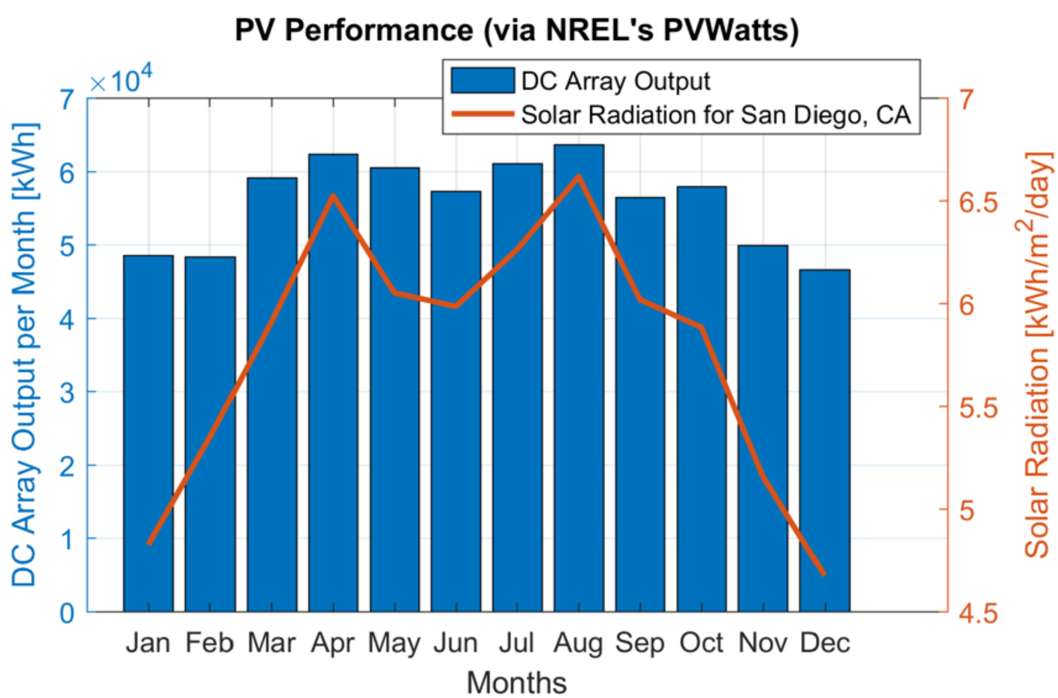

FIGURE A2: Performance of a 393.1 kW photovoltaic array (2621 sq. meters) in San Diego CA, based on PVWatts [22]**.**