Title

The Infrastructure Cost for Depot Charging of Battery Electric Trucks

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Table of Contents

Abstract

Electric vehicle (EV) depot charging increases the feasibility for fleet operators to convert fleets from internal combustion engine vehicles to zero-emission vehicles (ZEVs). This study considers two example cases: a fleet of medium-duty delivery trucks and a fleet of heavy-duty short-haul trucks. In both cases, trucks are charged at a depot by direct current (DC) fast chargers (50 kW, 150 kW, or 350 kW), and we estimate charging infrastructure cost as a function of the EV fleet size. Results indicate that per-vehicle infrastructure cost will decrease substantially as the fleet size increases, though infrastructure cost is very sensitive to charger utilization rates. The higher the charger utilization, the lower the infrastructure cost will be, as the depot will need fewer chargers installed given a certain number of vehicles being charged. Therefore, one cost reduction strategy is to improve daily utilization rates to reduce the charger count demand and eventually reduce the infrastructure cost (the capital cost). Finally, results show that the annualized infrastructure cost is dwarfed by the annual cost of the electricity dispensed to the EV fleet.

Keywords: electric vehicle; fleet charging; infrastructure cost; direct current fast charger; delivery truck; heavy-duty truck

Acronyms

DC	direct current
DCFC	direct current fast charger
EV	electric vehicle
HD	heavy-duty
ICCT	International Council on Clean Transportation
MD	medium-duty
ZEV	zero-emission vehicle

1. Introduction

Fleet operators could use electric trucks to deliver goods and haul freight with zero tailpipe emissions. Electric vehicle (EV) depot charging “at base” increases the feasibility for fleet operators to convert their conventional fleet to a zero-emission vehicle (ZEV) fleet, which will need access to charging infrastructure such as direct current fast chargers (DCFCs). However, the cost of purchasing, installing, and operating the charging infrastructure to serve the EV fleet could be a limiting factor. Focusing on depot charging infrastructure for battery electric trucks, this study explores the cost of charging infrastructure for EV fleets as a function of the number of EVs, power of chargers, and how charging patterns occur. We address the following question: how do the economics change, from the system infrastructure and cost perspective, as a fleet operator adds vehicles to a fleet and adds chargers to serve these vehicles?

The capital cost for charging infrastructure generally includes charger equipment cost, installation cost, and local grid upgrade costs for utility service extension or transformers. We develop a model to estimate cost for each of those components and then sum them to estimate the infrastructure cost (capital cost). The cost data from existing literature, as input to our model, generally does not come from very large charging sites, so infrastructure cost results for a very large depot (over 3 MW of peak power) could be unreliable and, thus, are not estimated in this study. We also do not attempt to project costs into the future, and some costs may change significantly, for example, with scaled production over time.

In addition, we estimate the maintenance cost of the chargers and the cost for dispensed energy (electricity) from the depot. Consequently, the annualized cost can be estimated to reflect the overall cost including infrastructure cost, maintenance cost, and dispensed electricity cost.

Considering two common and important truck categories, this study builds a variety of charging scenarios, and presents cost results for a depot charging infrastructure which vary with the EV fleet size. For simplicity, each fleet is composed of only a single truck category, either medium-duty (MD) delivery trucks or heavy-duty (HD) short-haul trucks. In both cases, these trucks are assumed to charge only at the depot. The charging situation could be quite different if vehicles also charge at public charging stations, which is not considered here.

2. Overview of the Methodology

This study develops an approach to estimating the depot charging infrastructure costs for battery electric trucks. The approach breaks down the total infrastructure cost into major components and estimates these component costs individually, as shown in Figure 1. The figure also shows the complete calculation flow from the EV fleet size to charger count demand and eventually to the total infrastructure cost by adding up all the cost components. The major steps are described in detail in subsequent sections.

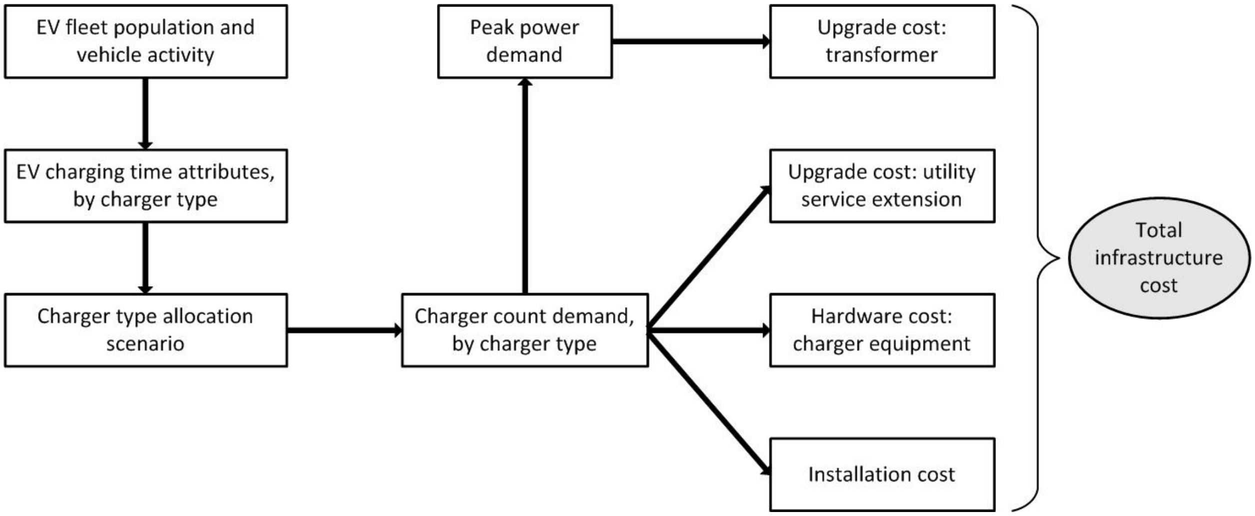

Figure 1. EV charging infrastructure cost (capital cost) calculation flow

3. Electric Vehicle Attributes

Electric trucks are equipped with batteries sized to provide a certain driving range; this EV battery size (or capacity) is also critical to estimating the daily electricity consumption and required charging per vehicle. For a particular truck type (MD delivery trucks or HD short-haul trucks), the more daily mileage driven on battery, the more electricity consumption and, possibly, the larger battery capacity needed.

Table 1 presents EV attributes affecting electricity consumption in the depot. Note that, in this study, the all electric range (AER) of a truck corresponds to the usable battery size. We assume one (and only one) full recharge per day per vehicle. In other words, we assume that one-time daily charging is sufficient to power the EV to run as far as its all electric range. We then assume the fleet safely designs the infrastructure system and capacity to meet the daily total energy requirements and the highest charging demand.

Table 1. EV attributes affecting electricity consumption

Vehicle attribute	MD delivery truck	HD short-haul truck
EV battery size (kWh)	187	500
Battery usable fraction	0.8	0.8
EV battery size usable (kWh)	150	400
EV energy consumption rate (kWh/mi)	0.85	2.35
EV all electric range (mi)	176	170

The EV attributes in Table 1 are generally consistent with the literature. A recent UC Davis study reported on modeling of MD delivery trucks with a battery of 199 kWh at 0.83 kWh/mi and HD short-haul trucks with a 564 kWh battery at 2.35 kWh/mi; based on an oversize factor of 1.6 to account for battery degradation and on-road fuel economy adjustments, the range is 150 miles for both electric truck types (Burke et al., 2022). An ICF report indicates that Class 6 urban delivery trucks correspond to 0.85 kWh/mi, at a battery size of 150 kWh (ICF, 2019). A report from the International Council on Clean Transportation (ICCT) indicates that a Class 8 drayage truck has a 500 kWh battery size, assuming 80% available for use, and drives a 175 miles range at full load (Dale and Lutsey, 2019). A study from the National Renewable Energy Laboratory indicates that the electricity consumption is 2.35 kWh/mi for Class 8 short-haul trucks (Hunter et al., 2021); this electricity consumption rate is also close to the number for Class 8 drayage trucks reported in a UCLA study (Filippo et al., 2019).

4. Charger Type and EV Charging Time Assumptions

This study is intended for medium- and heavy-duty trucks, rather than cars, so we do not use level 2 chargers (too slow to charge trucks) and, from a practical perspective, we consider only the following three types of direct-current (DC) fast chargers: DC Fast – 50 kW, DC Fast – 150 kW, and DC Fast – 350 kW. For a fleet designing its depot charging system, choosing between these options is a tradeoff between charging time, number of chargers needed, and possibly overall peak power and resulting demand charges from the electric utility.

Consistent with the ICCT report (Nicholas, 2019), chargers are defined by the listed power levels rather than the number of outlets. For example, a pedestal with two outlets, each providing 175 kW when two vehicles are connected to the pedestal, are counted as one 350 kW DC fast charger.

Charging time is critical in estimating the charge count demand. Table 2 summarizes the needed time to fully charge the battery of a truck so that the charged electricity is sufficient to cover the truck’s all electric range. We assume 50 kW or 150 kW DCFCs are stand-alone chargers than can provide the power to only one plugged-in vehicle at a time; in contrast, 350 kW DCFCs can be stand-alone chargers or split chargers that can distribute the power to two vehicles simultaneously. In principle, a high-power charger can charge a truck faster than a low-power charger, but this is not always true because the on-board battery attributes may be a limiting factor in some situations. With current technology, the acceptance power of the battery could be a bottleneck. In such cases, a large charger (say, a 350 kW DCFC) may not have an advantage, in terms of charging time, over lower power chargers (say, a 150 kW DCFC). This understanding is reflected in the assumption that both 150 kW and 350 kW DCFCs will need the same amount of time (2 hours) to fully charge an MD delivery truck. Additionally, for present technology batteries, we do not think one can fully charge the truck battery in less than 2 hours without significantly reducing the cycle life of the battery, so we assume a minimum charging time of 2 hours, as shown in Table 2.

Table 2. EV charging time needed across different charger power ratings

Charger type	DC Fast 50 kW	DC Fast 150 kW	DC Fast 350 kW	DC Fast 350 kW
Charger power rating (kW)	50	150	350	350
EVs charged at once (vehs)	1	1	2	1
MD Delivery Truck (hrs)	3.5	2.0	2.0	2.0
HD Short-haul Truck (hrs)	8.5	3.2	2.8	2.0

5. Charger Count Demand Scenarios

We look into three charger allocation scenarios, each with a particular charger type, and estimate their corresponding charger count demand, individually. Put another way, a fleet with a certain number of EVs can be served by any of the three scenarios, but each scenario will need a different number of chargers as the charger types (sizes) vary with scenario. The three charger scenarios are as follows.

- Scenario 1 – "DC Fast - all 50 kW": In this scenario, all charging demand will be met by 50 kW DCFCs and there are no other charger types included. If the fleet size increases, the added chargers will be 50 kW DCFCs as well.
- Scenario 2 – "DC Fast - all 150 kW": Likewise, all charging demand will be met only by 150 kW DCFCs.
- Scenario 3 – "DC Fast - all 350 kW": Likewise, all charging demand will be met only by 350 kW DCFCs.

This simple scenario design facilitates straightforward cost comparisons of different levels of DC fast chargers, which may help fleet operators or policy makers in deciding upon charger adoption.

6. Infrastructure Cost Components

As shown in Figure 1, total infrastructure cost is calculated as the sum of the following cost components: charger hardware cost, installation cost, upgrade cost for utility service extension and service panel, and transformer upgrade cost. (Depending on the specific site, additional utility side upgrades could be necessary. If the loads from a given site plus other nearby sites are large enough, significant further upgrades, such as increases to utility service, may be required. In this study we only consider transformer upgrades.) We developed a model to come up with the cost estimates as a function of the EV fleet size for all those components, with original cost data primarily from the Harvard report (Lee and Clark, 2018), the Rocky Mountain Institute (RMI) report (Nelder and Rogers, 2019), and the ICCT report (Nicholas, 2019). Table 3 shows the EV charging infrastructure cost components, primary data sources, and cost estimation assumptions utilized in this study. Given the key literature on infrastructure costs has a vintage around 2018 or 2019, the cost results throughout this study can be loosely considered in 2018 dollars. The charger hardware and installation costs are also consistent with a recent study (Borlaug et al., 2021) which summarizes electricity distribution system costs for depot charging of heavy-duty trucks, in 2019 dollars.

Table 3. EV charging infrastructure cost components and cost estimation assumptions

Infrastructure Cost Components	Cost Values	Data Sources and Assumptions
Charger Hardware Cost	\$30,000 for a 50 kW DCFC	Take the average of the three cost reports (Lee and Clark, 2018; Nelder and Rogers, 2019; Nicholas, 2019).
	\$81,000 for a 150 kW DCFC	
	\$140,000 for a 350 kW DCFC	
Installation Cost	$y = 47145x^{-0.449}$ for 50 kW DCFCs	Assume per unit installation cost is a power function of the number of chargers per site. The function is specified using data from Nicholas (2019). x: number of chargers per site; and y: installation cost (\$/unit).
	$y = 49502x^{-0.449}$ for 150 kW DCFCs	
	$y = 68360x^{-0.449}$ for 350 kW DCFCs	
Upgrade Cost for Utility Service Extension	If $x \leq 5$, $y = 17500$; and if $x > 5$, $y = 17500 + 3500(x-5)$.	Upgrade cost for utility service is \$17,500 per station for DCFCs (Lee and Clark, 2018). Assume upgrade cost increases by \$3500 for each additional DCFC, when there are over 5 chargers per site. x: number of chargers per site; and y: upgrade cost (\$/site).
Upgrade Cost for Transformer	\$44,000/transformer for transformer (150-300 kVA)	Take the average of the highest and the lowest costs from Nelder and Rogers (2019).
	\$56,800/transformer for transformer (500-750 kVA)	
	\$119,500/transformer for transformer (1000+ kVA)	

6.1. Charger Hardware Cost

Charger hardware cost refers to the cost for charger equipment. Taking the average of the three cost reports (Lee and Clark, 2018; Nelder and Rogers, 2019; Nicholas, 2019), this study uses the following numbers to represent the typical charger hardware cost (on a per charger basis): $30,000 for 50 kW DCFCs, $81,000 for 150 kW DCFCs, and $140,000 for 350 kW DCFCs.

6.2. Installation Cost

Installation cost refers to the cost associated with installing chargers, such as costs for trenching to protect electrical conduit, etc. Assuming that per unit installation cost is a power function of the number of chargers per site, we specified the function relationship by using the DCFC installation cost data from the ICCT study (Nicholas, 2019), in which installation cost includes labor, materials, permit, and taxes. As indicated by the functions in Table 3, per unit installation cost declines when the number of chargers per site increases. However, this is simply an assumption used in the study, as there is uncertainty in the assumed cost reduction associated with more chargers. Note that the actual installation cost is project-specific and may depend on many factors.

6.3. Upgrade Cost for Utility Service Extension

For adding significant electrical load as a result of EV charging events, the depot will incur local grid upgrade cost, which generally accounts for 1) upgrade to utility service extension and panel upgrade, and 2) upgrade to the local electrical distribution grid, such as transformer upgrades.

Based on the Harvard report, upgrade cost for utility service is $17,500 per station for DCFCs, regardless of charger rating levels (Lee and Clark, 2018). We assume that the upgrade cost of $17,500 per station applies to a charging site with 5 or fewer chargers; in the case of more than 5 chargers, each additional charger will incur a utility upgrade cost of $3,500, as indicated in Table 3.

6.4. Transformer Upgrade Cost

Transformer upgrade cost depends on the size of the transformer (Nelder and Rogers, 2019), while the needed transformer size is affected by peak power demand (in kilowatts). As shown in Figure 1, once the charger count demand is determined for a particular charger type (say, 150 kW DCFCs), the peak power demand can be calculated by simply adding up the power ratings (say, 150 kW) of all chargers included in the scenario. This simple method is discussed in the Harvard report (Lee and Clark, 2018).

Based on the RMI report (Nelder and Rogers, 2019), we use the average of the highest and the lowest costs to represent the typical transformer upgrade cost: $44,000 for a transformer of

150-300 kVA, $56,800 for a transformer of 500-750 kVA, and $119,500 for a transformer of 1000+ kVA.

7. Other Costs

In addition to estimating the charging infrastructure fixed cost using the method shown in Figure 1, we also estimated the cost for dispensed energy (electricity) from the depot and the maintenance cost of the chargers.

7.1. Energy Cost

Energy cost refers to the cost for electricity consumption (calculated on a $/kWh basis) plus the demand charge (calculated on a $/kW basis).

For depot charging, we use a California commercial electricity rate of $0.20/kWh. Based on the energy price forecast from the California Energy Commission (CEC), California statewide average commercial electricity prices are around $0.20/kWh from 2020 all the way to 2035 (CEC, 2022).

For a billing cycle which is typically on a monthly basis, peak power demand charges are calculated at a $17/kW rate. This is the statewide average rate for commercial demand charge rates in California, according to a cost survey study of the Utility Rate Database (NREL, 2017a).

7.2. Maintenance Cost

Annual maintenance cost, also known as operating and maintenance (O&M) cost, is assumed at $2,500/unit for DCFCs, the average number indicated in the Harvard report (Lee and Clark, 2018).

8. Results and Discussion: Reference Scenario

Based on the methodology, assumptions, and exogenous input discussed earlier, we used the model to estimate infrastructure costs for charging electric trucks, with a variety of scenarios. In this section we present our “reference scenario” results. This corresponds to a daily charger utilization rate of 50%; i.e., DCFCs are actually occupied 12 hours a day to charge EVs. This is based on the assumption that depot charging is available all day but since trucks are used fairly intensively, there are times when the charger cannot be used as there are no available trucks to charge. Note that this is a higher utilization rate than has been observed for public charging. In 2020, the average utilization in the U.S. was 1.8 hours per day, i.e., a 7.5% utilization rate (Bauer et al., 2021). Since fleets control depot chargers, a 50% utilization rate should be possible, and using available equipment as much as possible is desirable. Section 8.3 provides a sensitivity analysis to examine the cost impact of the daily utilizations.

Further, our reference scenario considers a truck depot with an EV fleet that can be fully served with the resulting peak power demand up to approximately 3 megawatts (MW). The cost data from existing literature generally does not come from very large charging sites, so infrastructure cost estimates for a very large depot (over 3 MW of peak power) could be unreliable and, thus, are not presented here.

8.1. Infrastructure Cost and Fleet Size: MD Delivery Truck

EV charging infrastructure cost is a function of the fleet size. At different numbers of the EVs, the infrastructure costs will differ as well. Typically, the larger the fleet size, the higher the infrastructure cost will be.

For MD delivery trucks, the estimated infrastructure costs are shown in Figure 2. Clearly, the infrastructure cost for 50 kW chargers is overwhelmingly lower than for the other charger types, regardless of the fleet size. The 150 kW chargers will be cheaper than the 350 kW chargers when the fleet is very small (up to 6 trucks); the two curves cross over a few times for a fleet between 7-30 trucks, indicating their costs are generally comparable. If the fleet is over 30 trucks, using the 350 kW chargers will be cheaper than the 150 kW chargers and the pattern is more pronounced when the fleet is even larger. This is mainly due to the assumption that each of the 350 kW chargers can charge two vehicles at a time.

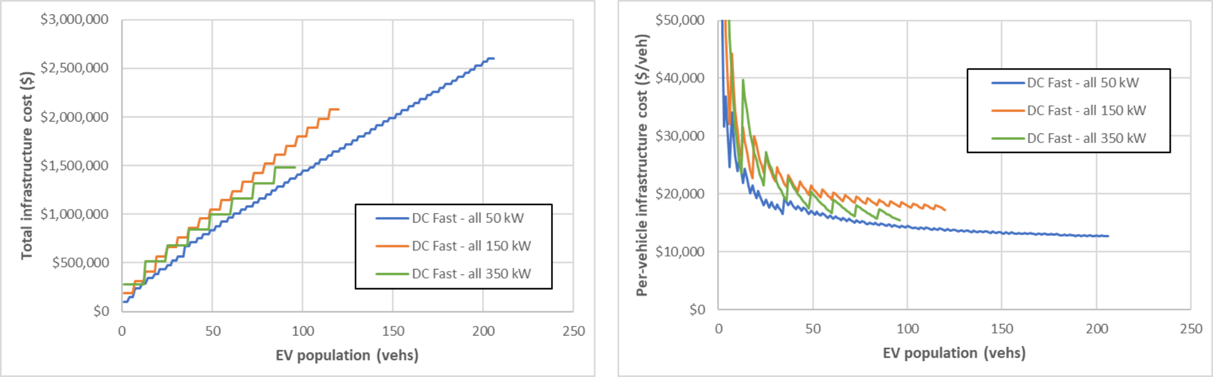

Figure 2. Infrastructure cost as a function of the fleet size: MD delivery truck

As we set the depot with a peak power limit around 3 MW, the 50 kW charger option seems capable of serving the largest fleet, just over 200 delivery trucks. However, the 150 kW option can only serve approximately 120 delivery trucks, and the 350 kW option serves the least, slightly less than 100 delivery trucks, as shown in Figure 2.

Regardless of the charger type (50 kW, 150 kW, or 350 kW), per-vehicle infrastructure costs decline dramatically as the fleet size increases; however, after the fleet size reaches approximately 50 MD delivery trucks, per-vehicle infrastructure cost reductions slow down significantly.

To sum up, from an infrastructure cost perspective, it is ideal for an EV fleet composed of MD delivery trucks to be served by 50 kW DCFCs, and it is not economical to deploy 150 kW or 350 kW DCFCs. That is also true from a peak power demand or fleet size perspective.

8.2. Infrastructure Cost and Fleet Size: HD Short-haul Truck

For HD short-haul trucks, as shown in Figure 3, the infrastructure cost curves are compared in three vehicle population groups. It is generally true that small chargers (say, 50 kW DCFCs) are cheaper than the other two options to introduce for the truck depot, especially for a very small fleet with only a few HD trucks (say, 1 to 5 trucks). Between 6 to 14 trucks, the three cost curves cross over a few times and present comparable cost values. If the fleet is made up of 15 trucks or more, the pattern is very clear that the 350 kW chargers are the cheapest, followed by the 150 kW chargers, and the 50 kW chargers are the most expensive option.

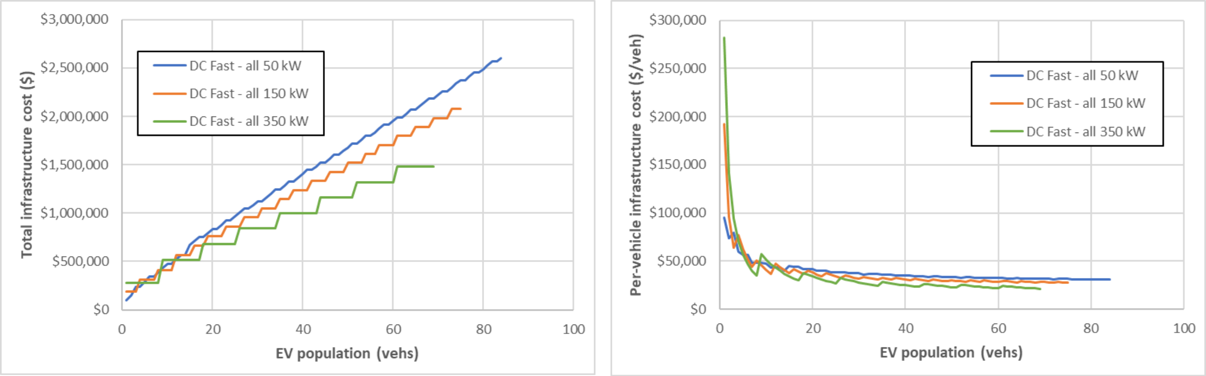

Figure 3. Infrastructure cost as a function of the fleet size: HD short-haul truck

Regardless of the charger type, per-vehicle infrastructure costs decline dramatically as the fleet size increases for the first few trucks; however, after approximately 10 HD short-haul trucks are added to the fleet, per-vehicle infrastructure costs decline only slowly.

From an infrastructure cost perspective, an EV fleet composed of HD short-haul trucks will be the best to be charged by 350 kW DCFCs, and it is not economical to deploy low-power chargers such as 50 kW DCFCs. Unless the fleet is only made up of a small number of HD trucks (say, 1-14 trucks), smaller chargers such as 50 kW or 150 kW chargers could play a cost-effective role.

8.3. Infrastructure Cost Sensitivity with respect to Charger Utilization Rates

The reference scenario of our model assumes a charger utilization rate of 50%, i.e., DCFCs are occupied 12 hours a day. However, the infrastructure cost is highly sensitive to the charge utilization, as the charger count estimates are directly proportional to the average number of hours per day each charger is actually in use (Bauer et al., 2021). Accordingly, a cost reduction strategy is to improve daily utilization to reduce the charger count demand and eventually reduce the infrastructure cost, though the ability of a fleet to do this will depend on its truck use timings and other requirements.

A charger utilization rate is calculated as the actual charging hours in a day divided by 24 hours. A recent ICCT study analyzed charger usage data and found that, in regions with higher EV penetration, chargers are likely to have higher levels of utilization (Bauer et al., 2021). The same ICCT study also indicates that the nationwide average utilization is expected to increase from 1.8 hours per day (a 7.5% utilization rate) in 2020 to over four hours a day by 2030.

We conducted a sensitivity analysis using the "DC Fast - all 150 kW" charger scenario for the MD delivery trucks as an example, looking at three different utilization rates:

- Utilization Rate = 10% (2.4 hours), close to the recent 7.5% public charging utilization;
- Utilization Rate = 25% (6 hours); and
- Utilization Rate = 50% (12 hours), the reference scenario in the study.

The results are shown in Figure 4, providing further evidence that infrastructure cost is very sensitive to charger utilization rates. Figure 4 also indicates that, to serve the same size fleet, charger utilization rates affect the infrastructure cost substantially. The higher the charger utilization, the lower the infrastructure cost will be. For example, when charging a fleet of 20 MD delivery trucks, per-vehicle infrastructure costs will decline from $90,000/vehicle (for a 10% utilization) to $43,000/vehicle (for a 25% utilization) and further to $28,000/vehicle (for a 50% utilization).

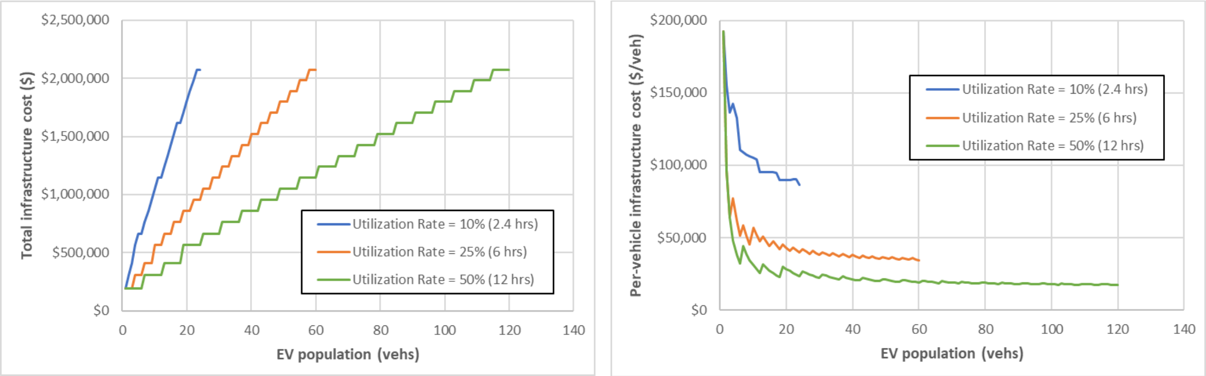

Figure 4. Infrastructure cost is very sensitive to charger utilization rates: the MD delivery truck example with 150 kW chargers

This analysis provides insight into how utilization affects infrastructure cost, which could be helpful as an input in larger investment decisions. However, decisions around how to deploy depot charging may require project-specific analysis of needs, vehicle flows, personnel availability, and timing of fleet electrification over time (to account for infrastructure changes), which is beyond the scope of this technical analysis.

8.4. Annualized Costs

Assuming the charging infrastructure has an economic lifetime of 15 years, at a 6% discount rate, the capital recovery factor (CRF) is approximately 0.10. By multiplying the CRF = 0.10, the total infrastructure cost estimated above can be annualized. Given annual maintenance costs and annual energy costs, the total annualized cost can be calculated using Equation 1, which is an overall consideration of all cost items estimated in this study.

$$\begin{aligned} &Total\ Annualized\ Cost\ (\$/yr) \\ &\quad = Infrastructure\ Cost\ \times CRF + Annual\ Maintenance\ Cost + Annual\ Energy\ Cost \end{aligned} \quad (1)$$

Moreover, by dividing the fleet size (i.e., vehicle population) or annual amount of electricity dispensed to vehicles, the total annualized cost can be further processed to be on a per-vehicle or per-kWh basis, as shown in Equations 2 and 3.

$$Per\ Vehicle\ Annualized\ Cost\ (\$/yr/veh) = \frac{Total\ Annualized\ Cost\ (\$/yr)}{Vehicle\ Population\ (veh)} \quad (2)$$

$$Per\ kWh\ Annualized\ Cost\ (\$/yr/kWh) = \frac{Total\ Annualized\ Cost\ (\$/yr)}{Annual\ Energy\ Dispensed\ (kWh)} \quad (3)$$

Again, we use the “DC Fast - all 150 kW” charger scenario for the MD delivery trucks as an example, looking at the annualized cost and its components all as a function of the fleet size, as shown in Figure 5. Note that the results correspond to the reference scenario with a 50% charger utilization for the depot. Although the charging infrastructure cost is generally huge as an investment, its annualized cost is dwarfed by the annual cost of the energy (electricity) dispensed to the fleet. This conclusion is even more pronounced in a sensitivity analysis using an electricity price higher than $0.20/kWh. Annual maintenance cost is minor, compared to the energy cost or even the annualized infrastructure cost. The per-vehicle annualized cost will be very high when the fleet only has a few trucks, but its declining trend is obvious as the fleet has more trucks in it. For example, the overall annualized cost goes down from $63,000/vehicle (when there is only one delivery truck in the depot) to $21,000/vehicle (when there are 10 delivery trucks).

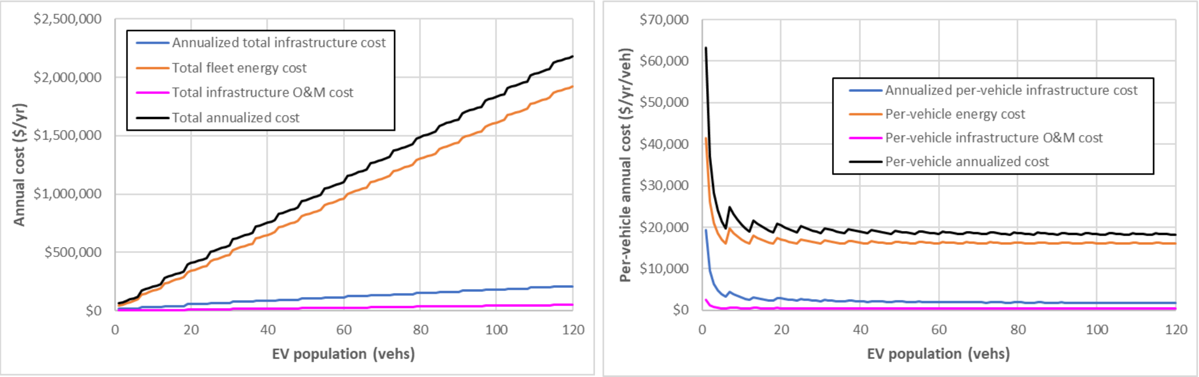

Figure 5. Annualized cost as a function of the fleet size: the MD delivery truck example with 150 kW chargers

Figure 6 shows the annualized cost per vehicle or per dispensed electricity. The per-kWh annualized cost demonstrates a similar declining pattern as the per-vehicle annualized cost. The more vehicles in the fleet, the lower the per-kWh annualized cost will be. For example, the per-kWh annualized cost goes down from $1.16/kWh (when there is only one delivery truck in the depot) to $0.38/kWh (when there are 10 delivery trucks), to $0.37/kWh (when there are 20 delivery trucks), and eventually to $0.34/kWh (when there are 100 delivery trucks).

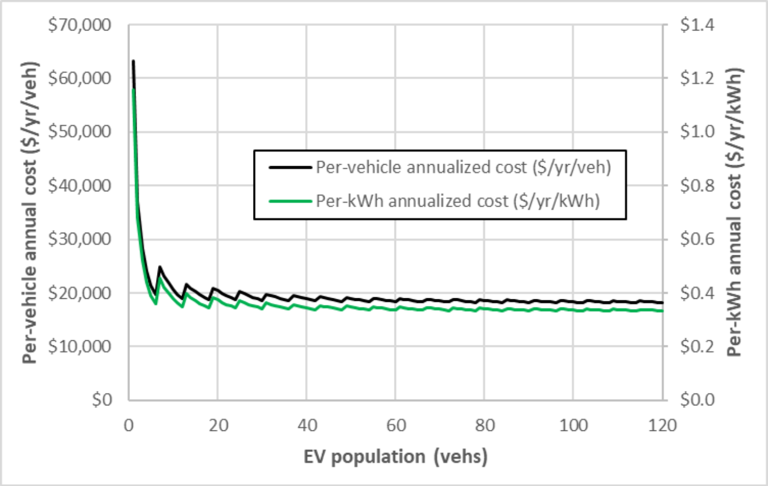

Figure 6. Annualized cost per vehicle or per dispensed electricity: the MD delivery truck example with 150 kW chargers

8.5. Demand Charge and Peak Power

As part of the energy cost, calculation of demand charges relies on the peak power demand, which is the highest power occurrence during any 15-minute interval over a billing cycle, typically on a monthly basis (NREL, 2017b; Lee and Clark, 2018). The peak of the incremental power due to the added chargers may or may not coincide with the peak when there are no chargers in the depot (Lee and Clark, 2018).

We assume that, during a billing cycle, the chargers' maximum power is higher than the depot's peak power (operating with no chargers being utilized). In a non-coincident peak situation (such as overnight charging of trucks in the depot), which is the reference scenario of this study, the demand charges are calculated based on adding up the power ratings of all chargers employed. In a coincident peak situation (such as daytime charging), we simply assume 1.1 times the non-coincident peak power as the ultimate global peak power and, based on that, the demand charges will be calculated. This simple assumption is intended to examine the impact of the coincident peak on the electricity cost (and eventually on the annualized overall cost).

Using the "DC Fast - all 150 kW" charger scenario as an example, Figure 7shows per-kWh annualized costs with non-coincident or coincident power peaks. As expected, the coincident peak scenario will result in a higher demand charge as its global peak power is also higher than the reference scenario (with the non-coincident peak). It also shows that, once the fleet is over 3 delivery trucks, the difference in per-kWh annualized costs is approximately $0.01/kWh.

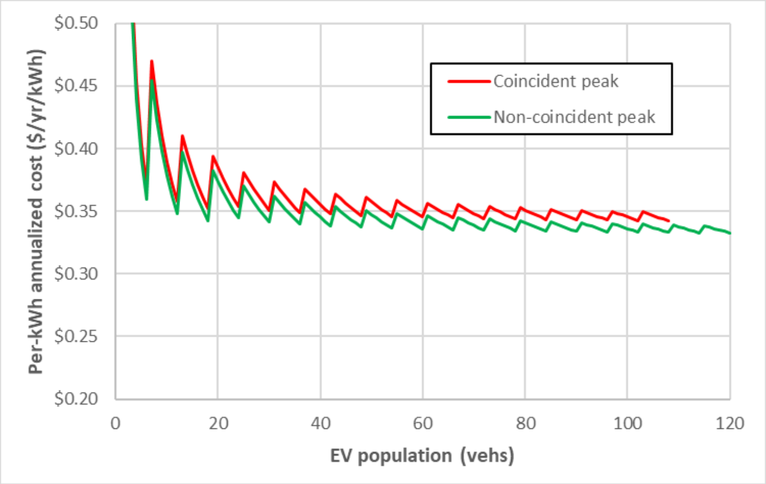

Figure 7. Per-kWh annualized costs with non-coincident or coincident power peaks: the MD delivery truck example

Note that adaptive charging (or charging management systems) can optimize the power output across a number of chargers in the same depot (SANDAG, 2022), which helps avoid overly building the EV infrastructure and reduces the peak-power demand charges for electricity use. In fact, new regulations have come up to promote managed charging to minimize the costs of vehicle-grid integration, e.g., using software platforms and aggregators to control charging (Nelder and Rogers, 2019). However, the benefits and costs of managed charging are beyond the scope of this study.

9. Summary and Conclusions

Depot charging increases the feasibility for fleet operators to convert their conventional fleet to a ZEV fleet. However, the cost of purchasing, installing, and operating the charging infrastructure to serve the EV fleet could be a limiting factor. In this study, we consider two common truck categories (MD delivery trucks and HD short-haul trucks), include three types of DC fast chargers (50 kW, 150 kW, and 350 kW), create a variety of charging scenarios, and estimate charging infrastructure cost as a function of the EV fleet size. Furthermore, dispensed electricity cost and charger maintenance cost are also accounted for, as part of the overall annualized cost.

Results indicate that the charging infrastructure cost is very expensive for a very small fleet such as only a handful of trucks. However, the per-vehicle infrastructure costs decrease dramatically when the fleet size increases within a small number of vehicles, and the size of these cost decreases shrinks after the fleet size reaches approximately 50 MD delivery trucks or approximately 10 HD short-haul trucks, assuming a 50% charger utilization rate is achieved (charging 12 of 24 hours on average). In addition, infrastructure cost (capital cost) is sensitive to charger utilization rates. The higher the charger utilization, the lower the infrastructure cost will be, as the depot will need fewer chargers installed given a certain number of vehicles being charged. Therefore, one of the cost reduction strategies is to improve daily utilization rates to reduce the charger count demand and eventually reduce the infrastructure cost (the capital cost). Finally, although the charging infrastructure cost is generally a huge investment, its annualized cost is much dwarfed by the annual cost of the electricity dispensed to the EV fleet.

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References

Burke, Andrew, Marshall Miller, Anish Kumar Sinha, Lewis Fulton, 2022. Evaluation of the Economics of Battery-Electric and Fuel Cell Trucks and Buses: Methods, Issues, and Results. Institute of Transportation Studies, University of California, Davis, Research Report UCD-ITS-RR-22-88. https://itspubs.ucdavis.edu/publication_detail.php?id=3768

ICF, 2019. Comparison of Medium- and Heavy-Duty Technologies in California. December 2019. https://caletc.com/assets/files/ICF-Truck-Report_Final_December-2019.pdf

Hall, Dale, Nic Lutsey, 2019. Estimating the infrastructure needs and costs for the launch of zero-emission trucks. International Council on Clean Transportation (ICCT). August 2019. https://theicct.org/sites/default/files/publications/ICCT_EV_HDVs_Infrastructure_20190809.pdf

Hunter, Chad, Michael Penev, Evan Reznicek, Jason Lustbader, Alicia Birky, and Chen Zhang, 2021. Spatial and Temporal Analysis of the Total Cost of Ownership for Class 8 Tractors and Class 4 Parcel Delivery Trucks. National Renewable Energy Laboratory (NREL). Technical Report. NREL/TP-5400-71796. September 2021. https://www.nrel.gov/docs/fy21osti/71796.pdf

Filippo, James Di, Colleen Callahan, Naseem Golestani, 2019. Zero-Emission Drayage Trucks: Challenges and Opportunities for the San Pedro Bay Ports. UCLA Luskin Center for Innovation. https://innovation.luskin.ucla.edu/wp-content/uploads/2019/10/Zero_Emission_Drayage_Trucks.pdf

Nicholas, Michael, 2019. Estimating electric vehicle charging infrastructure costs across major U.S. metropolitan areas. International Council on Clean Transportation (ICCT). August 2019. https://theicct.org/wp-content/uploads/2021/06/ICCT_EV_Charging_Cost_20190813.pdf

Nelder, Chris, Emily Rogers, 2019. Reducing EV Charging Infrastructure Costs. Rocky Mountain Institute (RMI). 2019. https://rmi.org/insight/reducing-ev-charging-infrastructure-costs

Lee, Henry, Alex Clark, 2018. Charging the Future: Challenges and Opportunities for Electric Vehicle Adoption, Harvard Kennedy School, September 2018. https://projects.iq.harvard.edu/files/energyconsortium/files/rwp18-026_lee_1.pdf

Borlaug, Brennan, Matteo Muratori, Madeline Gilleran, David Woody, William Muston, Thomas Canada, Andrew Ingram, Hal Gresham, Charlie McQueen, 2021. Heavy-duty truck electrification and the impacts of depot charging on electricity distribution systems. Nature Energy, Vol 6, 673–682. June 2021.

CEC (California Energy Commission), 2022. Presentation - Transportation Energy Demand Forecast. 2022 Integrated Energy Policy Report (IEPR). December 7, 2022.

NREL (National Renewable Energy Laboratory), 2017a. Maximum Demand Charge Rates for Commercial and Industrial Electricity Tariffs in the United States. Golden, CO: National Renewable Energy Laboratory.

Bauer, Gordon, Chih-Wei Hsu, Mike Nicholas, and Nic Lutsey, 2021. Charging up America: Assessing the growing need for U.S. charging infrastructure through 2030. International Council on Clean Transportation (ICCT). July 2021. https://theicct.org/wp-content/uploads/2021/12/charging-up-america-jul2021.pdf

NREL (National Renewable Energy Laboratory), 2017b. Identifying Potential Markets for Behind-the-Meter Battery Energy Storage: A Survey of U.S. Demand Charges. Golden, CO: National Renewable Energy Laboratory. https://www.cleanegroup.org/wp-content/uploads/NREL_BatteryStorage_2017.pdf

SANDAG (San Diego Association of Governments), 2022. Fleets Electric Vehicle Charging. Center for Sustainable Energy. https://www.sandag.org/uploads/projectid/projectid_511_25856.pdf (accessed April 25, 2022)