SHARED EV CHARGING STATIONS FOR THE AUSTIN AREA: OPPORTUNITIES FOR PUBLIC-PRIVATE PARTNERSHIPS

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ABSTRACT

The global decarbonization and electrification has led to the shift towards sustainable transportation and increased adoption of electric vehicles (EVs). Developing sufficient EV charging stations (EVCS) is essential to alleviate range anxiety of EV users and prompt the widespread acceptance of EVs. Considering land use limitations and operational cost, co-locating private EVCS with/alongside public EVCS has emerged as a promising approach which leverages the collaboration between government entities and private charging station operators. This study explores potential sites and costs for co-locating public-private (PP) charging hubs across the City of Austin area, considering both demand and supply aspects. Existing EVCS resources are examined by charging level, including Level 2 (240 volt) and DC fast charging (DCFC). POLARIS, an agent-based model, is used to simulate EVs and agent's behavior. Additionally, the paper provides design draft and cost estimations for potential EVCS.

Key words: Electric vehicles, Charging infrastructure planning, Agent-based modelling, POLARIS

INTRODUCTION

Car-sharing and ride-hailing services have gained widespread popularity globally. They are regarded as measures to alleviate traffic congestion and coincide with the increasing adoption of electric vehicles (EVs), which are known for their environmental friendliness compared to internal combustion engine (ICE) vehicles *(1,2,3)*. The rise of EVs is swiftly transforming the urban mobility services landscape, with transportation network companies (TNCs) responding by ramping up the inclusion of EVs in their fleets. So far, many governments, including those in Europe and China, have proposed bans on the sale of new conventional petrol and diesel vehicles in the near future, fostering an environment that encourages the uptake of EVs *(4, 5)*. However, EV markets still face hurdles to large-scale deployment, including high upfront purchase prices, limited driving range, and long charging times *(6)*. EVs typically offer lower ranges compared to conventional ICE vehicles, triggering consumer 'anxiety', particularly exacerbated by a lack of recharging infrastructure *(7)*.

Researchers have pointed out a chicken-egg dilemma exists in the EV market *(8, 9)*: Consumers are reluctant to buy EVs when they feel a lack of efficient access to charging facilities, yet the low usage of EVs tends to discourage Charging station operators (CSOs) from investing in charging infrastructure.

Sufficient charging infrastructure plays an integral role in the development of EVs. CSOs, including EV manufactures such as Tesla and EV fleet operators like Cruise or DiDi, have been striving to install charging stations in dense areas to feed charging demand from their customers and EV/shared autonomous electric vehicle (SAEV) fleets. *(10)* suggested that funding and supporting EV charging infrastructure can be private and public. Private charging port sharing is a novel business model that addresses the shortage of well-developed publicly accessible charging infrastructures that has been observed in major cities *(11)*. Typically, private ports only serve for their owners and often remain unused for a long time compared to the public ones *(12)*. Fully using private ports by sharing access with the public optimizes resource utilization and alleviates the problem of insufficient public ports. From the private CSO side, given their charging infrastructure shares some good characteristics with public infrastructure, collaboration with public stakeholders could be beneficial in the early stages of charging infrastructure deployment. In the long run, with greater EV uptake, public investment is desirable and important, particularly in DC fast-charging (DCFC) infrastructure.

Private EV fleets may do well to share their charging port sites with public ports. Co-locating private EV charging stations (EVCS) with/alongside public EVCS could maximize utilization, share installation and operation costs, and offer convenience for EV drivers. In this study, the City of Austin is used as study area. This research explores current EVCS service and simulates EV/SAEV fleet charging behavior across Austin. This will help us explore the opportunities of co-locating public-private charging hubs. Findings will serve as a reference for future CSOs. The next sections detail the current state of EV charging infrastructure studies, and describe how POLARIS, an agent-based model (ABM), works in this study. Following those, the distribution of public EVCS by charging level across the City of Austin is summarized, presenting simulated EV charging behavior to suggest potential sites for co-locating public-private (PP) EVCS. Subsequent sections provide the cost estimations for those potential EVCS and draw conclusions.

LITERATURE REVIEW

The worldwide efforts to reduce carbon emissions and promote electrification have driven the transition toward sustainable transportation. In the North American market, EV chargers are categorized by power rate, into Levels 1, 2, and 3, as shown in Table 1. U.S. Level 2 are considered suitable and common for home and workplace charging *(13)*, if those with low-charge batteries can leave their vehicles parked for 5+ hours (or simply “top off” or add electrified miles with lower durations of parked time – like while shopping at a grocery store). In contrast, DC fast charging (DCFC) replenishes an EV battery to at least 80% state of charge (SOC) in just 30 minutes, enabling drivers to ‘grab and go’ *(14)*. They are becoming prominent in EV supply equipment (EVSE) configurations due to their advantaged efficiency of recharging and enabling long-distance travel *(15)*.

Table 1. Charging Details (with Hours and Distances for Passenger Vehicles)

Charging Level	Voltage (V) & Current Type	Power Rate (kW)	EV Range per Charging Hour (miles/hr)	Avg. Charging Time (Empty Battery)	Location
Level 1 (US wall outlets)	120 V AC	1.3 to 2.4 kW	3 to 5 miles per hour of charging time	40 to 50 hrs (BEV) & 5 to 6 hrs (PHEV)	Primarily home
Level 2 (standard in EU & China)	208 to 240 V AC	7.4 to 22	12 to 30 miles per hour of charging time	4 to 10 hrs (BEV) & 1 to 2 hrs (PHEV)	Home, work, & public stations
Level 3 (DCFC)	480 to 1000 V DC	50+	180 to 240 miles per hour of charging time	0.5 to 1 hr (BEV)	Public

EVSE is commonly regarded as essential public service for supporting transportation electrification strategies. However, lack of easy access to charging stations is the third biggest barrier to promoting EV purchase and use, after price and driving range *(16)*. Constructing large-scale EVSE is not practical, especially in densely populated cities. As an emerging solution, private charging sharing has gained attention due to its complementary service performance alongside public EVSE *(12, 17, 18)*. Owners of parking spaces and private charging access tend to charge their EVs overnight, leaving their private charging ports idle during the daytime *(19)*. This tendency results in a low utilization rate, with private chargers remaining idle for up to 75% time of the day *(11)*. EV/SAEV fleet operators also continuously deploy their privately owned EVCS to meet fleet's charging demand. However, they face challenges related to higher cost, longer idle time, and limited depots when fleet-owned EVCS are not available for public use, as many incentives are towards public infrastructure. Many studies advocated making private EVSE open to the public to increase usage rate and co-locate new chargers with existing electric utilities to share total cost and sites *(12, 20)*. In Los Angeles, 550 Level 2 charging ports have been installed alongside city streetlights, achieving faster installation through strong coordination across public agencies *(21)*. However, few studies explored the prospect of public-private (PP) EVCS formed by co-locating fleet-owned ports alongside existing public EVCS and opening their access to household EVs (HHEV). Under this novel collaboration pattern, the PP EVCS placement should consider both fleet demands (in high-trip-density settings) and private HHEV charging patterns.

More realistic modeling of the charging pattern and demand helps better locate EVSE to provide recharging service. ABM stand out by their ability to simulate realistic charging strategies, vary home charger availability across populations spatially, and integrate charging decisions from HHEV users' standpoint *(22)*. Furthermore, simulation-based approaches with optimization-based control strategies are widely used in EV fleet operation *(23)*. POLARIS, an advanced ABM transportation simulation tool developed in C++ *(24, 25)*, is suitable for this study for its underlying mechanisms of individual travel behaviors, as well as their interactions with environments. This work synthesizes the PP EVCS location problem with HHEV charging pattern simulated by POLARIS to improve fleet operator guidance on deploying charging ports while considering HHEV charging behavior. PP EVCS opportunities will be explored by comparing current public charging resources distribution with simulated HHEV charging patterns. Further, this research provides insights into current charging resource distribution, along with suggestions for potential sites to deploy PP EVCS. Cost estimations are also detailed to illustrate potential savings under the PP novel mode, thereby enhancing understanding and providing an extension beyond the scope of most EVCS research in these aspects.

METHODOLOGY

The agent-based framework of POLARIS integrates activity-based model to simulate travel planning behavior *(24)*. This model consists of three main parts. First, it simulates multi-agent travel demand by modeling agents' 24-hour behaviors and actions *(26)*. Then, it assigns travel demand and simulates traffic by a network simulation model. Finally, the traffic management component monitors traffic details like accidents and congestions, providing feedback to the other two components. This study uses the POLARIS model to simulate EV charging demand and behavior, as described in Kavianipour et al. *(27)* which includes a detailed flowchart.

POLARIS relies on travel demand and supply models to synthesize and simulate agent travel and EV trips across large regions *(26)*. As supply inputs, POLARIS takes in details on charging station and plug information, including the coordinates of each current public EVCS and the plug types and counts it carries. Regarding the demand inputs, POLARIS synthesizes a representative population of the given region with socio-economic information provided by the region's metropolitan planning organization and the United States Census Bureau *(24)*. Charging behavior simulation involves decisions such as the need for charging at the end of a trip, the amount, timing, and charging location. A detailed explanation of charging decisions made throughout EV trip chains can be found in Verbas et al. *(28)*. EV users' charging behavior varies based on trip types: Intercity trips are typically planned ahead, and users fully charge their EVs before departure. In contrast, urban trips are daily outings where users may or may not prepare in advance, depending on the availability of home chargers. EV owners with home chargers typically charge EVs overnight to prepare for upcoming trips and rely less on public DCFC. However, those without home chargers will fully charge EVs whenever they need to, similar to conventional vehicle owners.

SUPPLIED PUBLIC EVCS ACROSS AUSTIN

Level 2 Public Charging Stations

The spatial distribution of public charging stations across Austin is shown in Figure 1. The majority of the Level 2 chargers are concentrated in workplaces and parking spaces adjacent to transportation hubs and commercial areas.

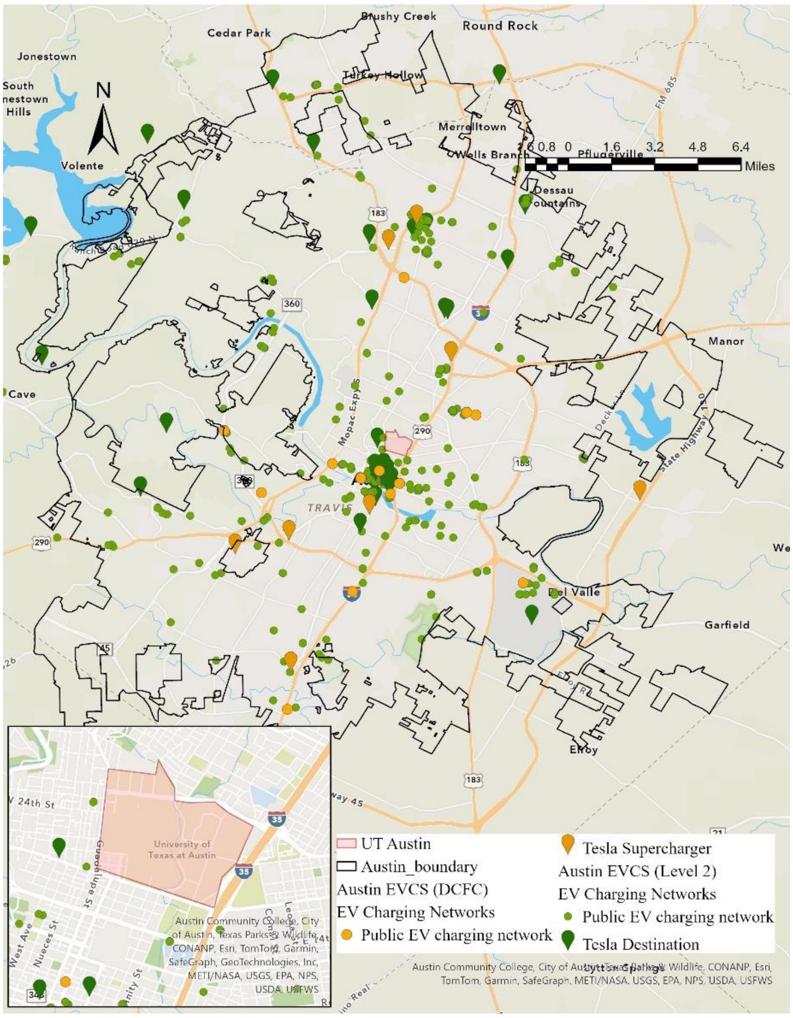


Figure 1. Charging Stations Distribution Within Austin *(Source:29)*

Table 2 summarizes the number of charging stations and ports in Austin area, based on data from AFDC of the U.S. DOE (2023). Public charging stations in Austin are predominantly Level 2 and DCFC stations, with more Level 2 stations in service. Assuming all public charging stations in Austin are occupied, a total of 979 EVs can be charged simultaneously at Level 2, 125 of which are at Tesla Destination Chargers. Given there are nearly 17,000 registered EVs in the city *(30)* and 404,121 households *(31)*, each Level 2 charging port serves roughly 17 EVs and 413 households across the City of Austin. Destination charging stations operated by Tesla often provide more charging ports with higher power compared to other EV charging networks. On average, Tesla Destination charging stations can charge more EVs at once than non-Tesla EVCSs (3.47 vs 2). These charging stations are located in places where drivers may stop for reasons other than charging, such as hotels, restaurants, shopping malls, and other commercial areas.

Table 2. Descriptive Statistics for Public Charging Stations *(Source: 29)*

	EVCS Type	# Stations	# Ports[a]	Average # Ports	Power Rate (kW)
Level 2	Non-Tesla Public charging	426 stations	854 ports	2 ports	6.48 to 21.6 kW
	Tesla Destination Charging	36	125	3.47	8 to 16
	Total	**462**	**979**	-	-
DCFC	Non-Tesla Public charging	29	29	1	50 to 125
	Tesla Superchargers	8	94	11.75	72 to 250
	Total	**37**	**123**	-	-

a. A single charging pedestal can accommodate one or more EVSE ports (or socket outlets) which provide power to charge EVs. Each port charges only one vehicle at a time *(29)*. The majority of charging networks now report the number of ports that can charge simultaneously *(32)*.

Austin Energy provides a more detailed description of the location categories for non-Tesla Level 2 public EVCS. Their Plug-In EVerywhere program network contains 439 charging stations and over 800 Level 2 charging ports in the City of Austin. Table 3 summarizes the charging stations and charging ports by location type. Level 2 charging stations in workplaces account for 36.9% of all service stations, ranking top among all location types, with an average of 1.88 charging ports. Charging stations in general workplaces provide the most ports (229) for charging, with parking lots in commercial areas (187) and residential apartment complexes (166) following behind. This is consistent with many studies that suggested charging stations could be co-located with parking lots and gas stations *(33, 34)*. Some of the charging pedestals built in these location types have only one charging port per pedestal, so these locations' average number of ports per pedestal is less than 2 (while the average number of ports for all other types is 2). There are relatively few charging resources near retail, education, and health areas. Limited resources are available within the 424-acre UT Austin campus and nearby north campus residential area, both of which hold potential for generating high-density trip and charging demand.

Table 3. Non-Tesla Public-Access Level 2 Stations by Location Type *(Source: 35)*

Category	Sub-category	# Level 2 Charging Stations	% of Stations	# Ports	% of Ports	Average # Ports
Education	University / College	4 stations	0.91%	8 ports	0.94%	2 ports
	High School / Other	10	2.28%	20	2.36%	2
Healthcare	Hospital / Treatment Center	10	2.28%	20	2.36%	2
Hospitality	Hotel / Resort	5	1.14%	10	1.18%	2
Multi-family Commercial	Condominium	2	0.46%	4	0.47%	2
	Apartment	88	20.0%	166	19.5%	1.89
Municipal	Library	8	1.82%	16	1.88%	2
	Municipal Workplace	7	1.59%	14	1.65%	2
	Parks and Recreation (Public)	1	0.23%	2	0.24%	2
	Municipal Parking	3	0.68%	6	0.71%	2
	Municipal Fleet	21	4.78%	42	4.95%	2
Parking	Airport	10	2.28%	20	2.36%	2
	Commercial	95	21.6%	187	22.0%	1.97
Parks and Recreation	Parks and Recreation	7	1.59%	14	1.65%	2
Retail	Shopping Center	3	0.68%	5	0.59%	1.67
	Strip Mall	1	0.23%	2	0.24%	2
	Car Rental / Car Share	2	0.46%	4	0.47%	2
Workplace	General Employers	122	27.8%	229	27.0%	1.88
	"High-Tech" Employers	40	9.11%	80	9.42%	2
	Total	439	100%	849	100%	1.95

Level 3 (DCFC) Public Charging Stations

Level 3 charging stations are not as common as Level 2 (Fig. 1). There are about 37 DCFC stations in Austin with power ranging from 50-250 kW. Tesla Superchargers make up 76% of the 123 DCFC charging ports in the Austin area (Table 2). 17% of non-Tesla DCFCs are co-located with public Level 2 charging stations, and each pedestal only houses one charging port. In contrast, Tesla Superchargers can simultaneously charge an average of 11.75 EVs at each site. Many public DCFC stations are within Downtown Austin, located in parking lots near restaurants and shopping malls. DCFC charging stations are also scattered along the I-35 freeway.

POTENTIAL SITES FOR FURURE PP EVCS

Simulated EVCS Service Usage Across Austin

This study uses POLARIS to generate a synthetic population using demographic data from the US Census for the 6-county Austin region, covering 5,300 square miles and 3,032,990 residents (in 1,207,496 households). During a typical tour, EV drivers move through the coded network, and batteries' SoC are updated at the link level based using a large-scale learning and prediction process via machine-learning approaches, as detailed by Moawad et al. *(28, 36)*. For within-day tours facing insufficient SoC, energy demand at a nearby (and not too busy) EVCS (up to 80% SOC) is estimated as a function of that driver's home charger availability, current SoC, tour distance, distance to EVCS, and other variables. To protect batteries from over-charging, charging ends at (or below) 80% SoC.

Taking the EV trip records derived from the charging demand simulation, POLARIS outputs contain comprehensive information such as location, timing, charging level, and duration of EV charging. Within the City of Austin, 88% of HHEV owners choose to charge EVs at home, while the remaining 12% use public EVCS. EVs charged at home are predominantly relying on Level 1 charging. For HHEV that get charged at public EVCS, 66% are using Level 2 chargers while 34% choose DCFC. The peak charging hours lie between 16:00 and 19:00, as shown in Figure 2. Specifically, the majority of charging activities occur at the 17:00 and 18:00 time slot, which accounts for 20% of total charging trips. A likely explanation for this trend could be that commuters heading home, particularly those without home chargers, may pass by places like shopping centers or restaurants where they can briefly stop and charge their EVs.

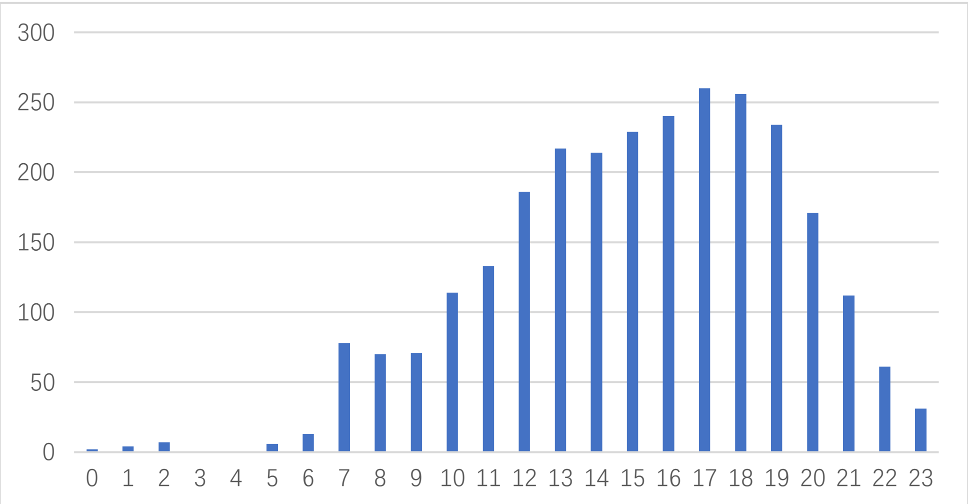


Figure 2. Charging Trip Counts by Hour

Daily charging service usage distribution is shown in Figure 3, with charging trips counts as weight for the heatmap. Downtown Austin, EVCS along highways such as I-35 and US-290, and Plaza surroundings demonstrate notable concentration of charging trips. These areas align with previous studies, which recommend placing EVCS along major highways where charging demand tends to be high to maximize profitability *(2)*. In addition, parking lots attached to Austin-Bergstrom International Airport (ABIA) in the southeastern area of Austin exhibit relatively dense charging trips.

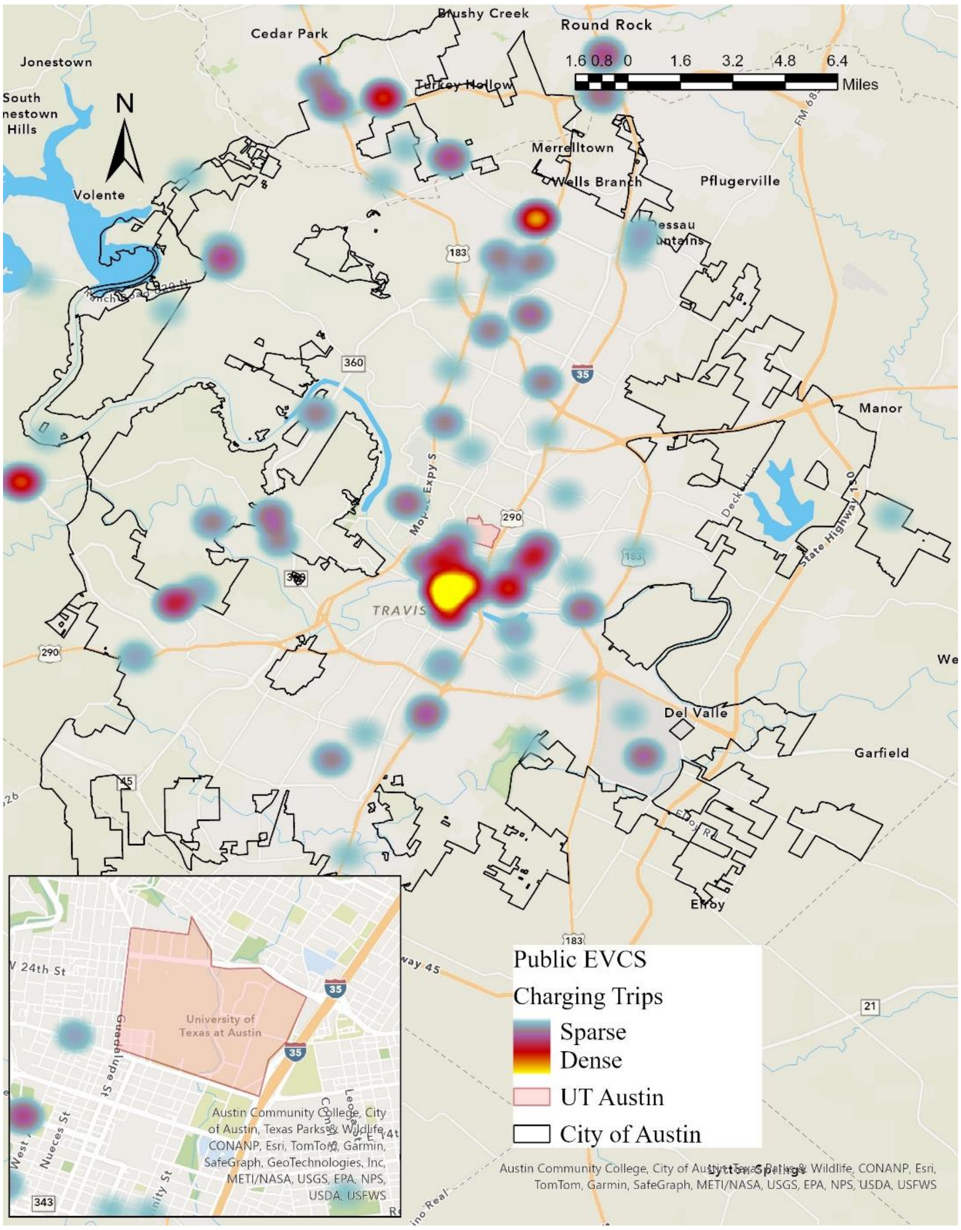


Figure 3. EVCS Usage Across Austin Area

Total energy consumption serves as another important metric to reflect charging demand. Figure 4 presents energy consumed at each public EVCS within Austin city, revealing a consistent demand pattern with Figure 3. EVCS located Downtown and along main routes deliver more energy to meet HHEV charging demand. Moreover, EVCS near schools/university, hospitals, and shopping centers in Central Austin also experience relatively higher energy consumption due to potential en route charging.

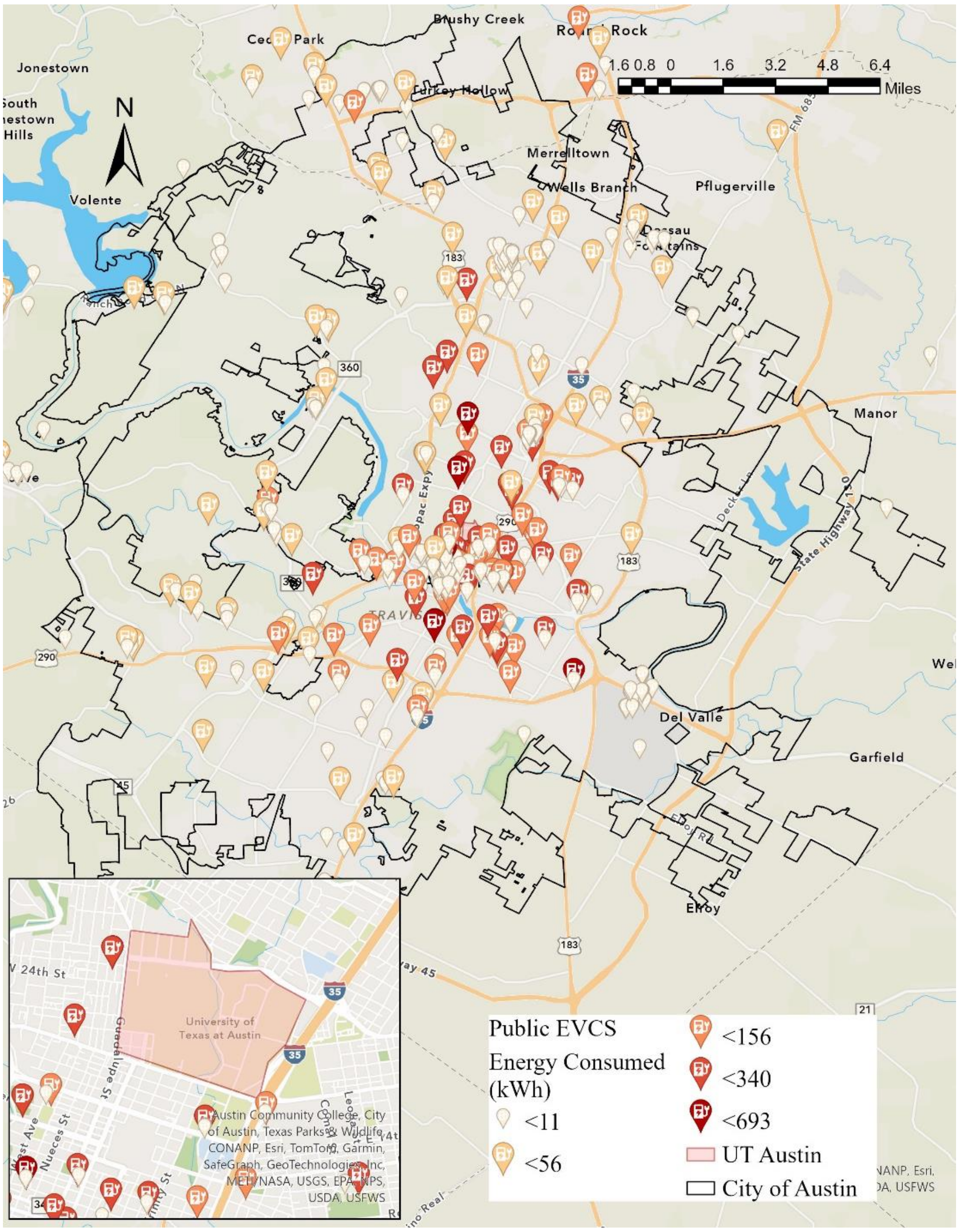


Figure 4. Energy Consumption (kWh) across Public EVCS

To further identify the potential market and sites for PP EVCS, Figure 5 shows the average charging wait time at public EVCS during peak hours. While most existing public EVCS serve HHEVs with minimal wait time, 20-min (average) wait times are common Downtown, along I-35, and near the ABIA airport, and 10-min waits are found in some northern residential locations – despite having many under-used (public) EVCS nearby, as highlighted in Figure 1.

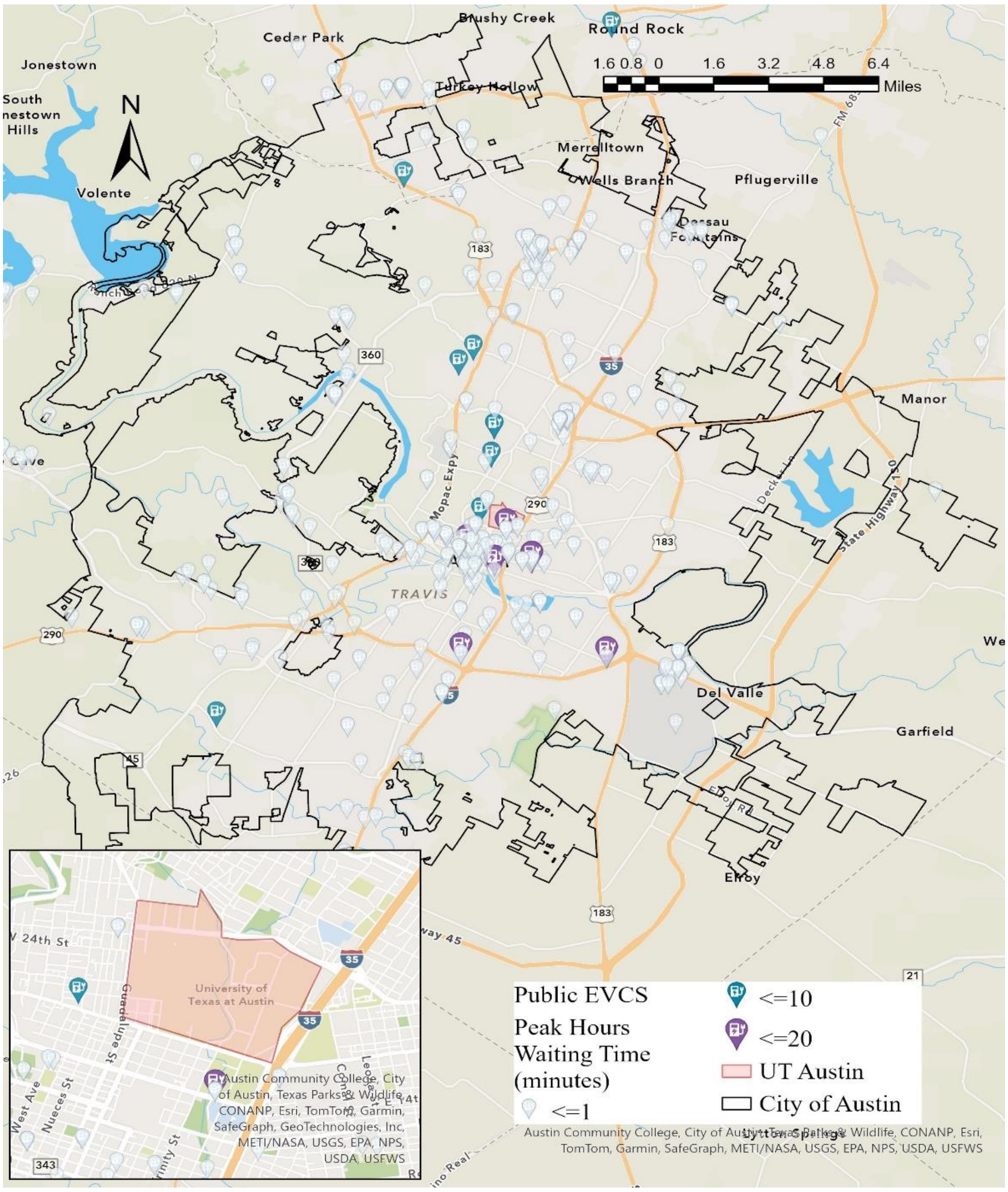


Figure 5. Average Waiting Time at Public EVCS During Peak Hours

Opportunities for PP EVCS

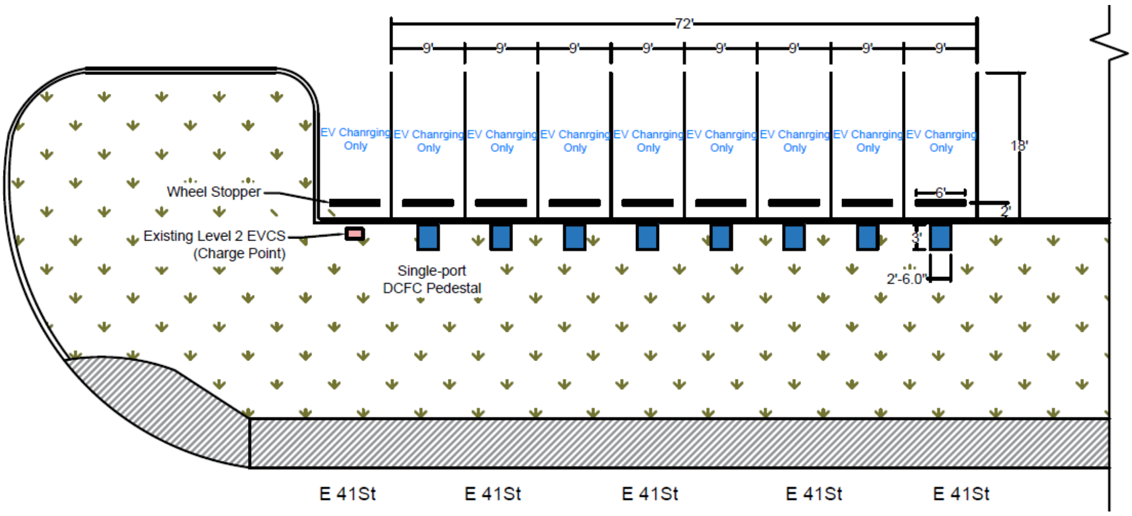
Downtown and Central Austin witness relatively more charging trips and longer charging delay (Fig. 3 and Fig. 4), particularly around the UT Austin campus, where limited charging resources are available to alleviate charging congestions. The campus has heavy daily traffic from students, faculty, staff and visitors, and there is a residential area just north of the campus, which could contribute to charging demand and offer potential sites for new EVCS. One potential site option includes UT garages, such as San Jacinto or San Antonio, as they can alleviate charging resources constraints and provide walkable distances to most of UT buildings and bus stops, effectively addressing last/first-mile concerns for travelers.

In Central Austin, where charging delay is relatively high, numerous parking lots are connected to commercial zones. Some parking lots have already installed charging stations, but the scale is not large, with Level 2 chargers being predominant type. As shown in Figure 1, DCFC stations are scattered throughout Austin, but fewer stations are available in Central areas with higher charging congestion compared to surrounding neighborhoods. The commercial areas in Central Austin, such as HEB, attract a large volume of daily travel and possess sufficient parking bays suitable for deploying new EVCS. When considering the co-location of PP charging infrastructure, parking lots adjacent to commercial areas or residential areas present promising potential sites. EVCS operators can explore opportunities for co-locating or upgrading existing charging power grid.

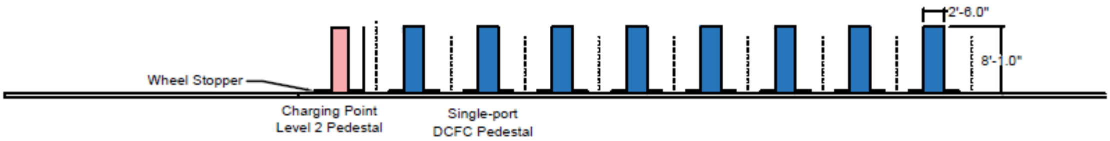
EVCS Sites Design Examples

Taking the parking lot attached to HEB in Central Austin as a case, Figure 6 presents a sample design of arranging charging pedestals here. The design features 8 new DCFC pedestals alongside an existing public Level 2 charging station. It is worth noting that these new DCFC pedestals are not solely invested and installed by private fleets, such as Tesla, which only charge their own EVs. Rather, they are established through collaborations with public CS operators or public entities. This kind of public-private charging station hub enables the charging infrastructures to be accessible by not only specific private EV fleets, but also private EV drivers, providing them certain public access to take advantage of these EVCS.

Given that parking bays are arranged parallelly on one side of the lawn, each bay can accommodate only one EV to get charged in real time. However, it becomes possible for a single pedestal to serve two parked EVs in parking lots with parking bays on both sides. This arrangement maximizes the utilization of charging infrastructure and optimizes the efficiency of available parking spaces.



(a) Plan View



(b) Profile View

Figure 6. EVCS Design at HEB Parking Lots

EVCS COST: MARKET AND ESTIMATION

The planning problem faced by many charging station investors is how to provide charging services to customers with random behavior and charging demand at a lower economic cost of charging facilities and practical operation *(33)*. Costs of owning and operating EVSE mainly include: EVSE hardware costs, installation fees, operation and maintenance expenses, additional capital costs (such as land and parking space acquisition), and incentive credits (to lower equipment or installation costs) *(37, 38)*. Studies have shown that coordinated charging can change the plug-in EV charging load and reduce the number of charging points by encouraging customers to charge their EVs during off-peak hours, resulting in corresponding investment cost savings *(39)*. In order to increase charger utilization and reduce unnecessary idle time at charging stations, many connection patterns between chargers and parking bays are proposed to automatically switch cables for the next EV waiting to be charged, e.g., SOMC *(39)*, MCMP *(33)*.

For both Level 2 and DC fast chargers, equipment costs vary greatly with power rating. Generally, Level 2 home chargers are less expensive than nonresidential chargers since they are wall-mounted in weatherproof locations, like garages. Commercial Level 2 chargers and DC fast chargers for public access are usually installed on a pedestal and exposed to the elements, adding cost to the chargers. The Rocky Mountain Institute paper *(38)* reported the range of Level 2 and DC fast charger costs in Table 4. According to Future Energy, a public dual-port Level 2 EVSE unit costs around $5,500 and can charge two vehicles simultaneously. Moreover, optional protective bollards, which cost approximately $400 each, and parking blocks, priced at around $600 each, may also be desired by commercial enterprises *(40)*.

Table 4. Range of Level 2 and DC Fast Charger Costs *(Source: 38)*

Charger Type	Location	Power Rate	Cost Range
Level 2 Charger	Residential	2.9 kW-7.7 kW	$380 - $689
	Commercial	7.7 kW-16.8 kW	$2,500 - $4,900
DC Fast Charger	Public	50 kW	$20,000 - $35,800
		150 kW	$75,600 - $100,000
		350 kW	$128,000 - $150,000

In 2019, the ICCT working paper *(41)* provided equipment costs by charging level and number of chargers per pedestal. Costs are summarized in Table 5.

Table 5. Hardware Cost by Charging Type and Number of Chargers Per Pedestal *(Source: 41)*

Charging Level	Type	Chargers Per Pedestal	Per Charger Cost
Level 2	Non-networked	1	$1,182
Level 2	Non-networked	2	$938
Level 2	Networked	1	$3,127
Level 2	Networked	2	$2,793
DCFC	Networked 50 kW	1	$28,401
DCFC	Networked 150 kW	1	$75,000
DCFC	Networked 350 kW	1	$140,000

Besides the cost estimations presented in the above table for single-port DC fast chargers, *(42)* also estimated the cost of dual-port 50 kW DCFC, revealing a cost range of $25,000 to $35,000 per charger. To estimate the cost of Level 2 and DCFC charging stations under various charging time, *(43)* presented cost estimates for commercial Level 2 and DC fast chargers in Table 6.

Table 6. Cost Estimation of Charger under Different Charge Time *(Source: 43)*

Charge Time	Charger Type	Amperage (A)	Voltage (V)	Power (kW)	Estimated Charger Cost
4-8 hours	Level 2	48 A	200-240 V	9.6 to 11.5 kW	\$700 – \$2,000
2-5 hours	Level 2	80	200-240	16 to 19.2	\$1,800 – \$4,000
1-2 hours	DCFC	100	480	48	\$30,000 – \$40,000
30-60 min	DCFC	200	480	96	\$55,000 – \$65,000
15-30 min	DCFC	250	480	120	\$65,000 – \$75,000

Unlike equipment costs, which are relatively static and depend on the level of charger, installation costs fluctuate over time and can be subject to market conditions. Local labor rates significantly impact DCFC installation costs, increasing up to \$350 per dollar increase in the labor rate. Additionally, longer physical distance between power source to DCFC leads to higher costs for materials, labor, and hardscape, with approximately \$200 per foot *(44)*. The cost of installation also varies greatly by location, with an estimated range of \$600 to \$12,700 for Level 2 and \$4,000 to \$51,000 for DCFC *(37)*. Take Blink dual-port DCFC as an example. The median installation cost for such a pedestal was \$22,626 *(45)*. *(41)* also provided installation costs for EVSE by charging types and number of chargers per site, as shown in Table 7.

Table 7. Installation Costs Per Charger by Type and Number of Chargers Per Site *(Source: 41)*

Charger Type	# Chargers Per Site	Per Charger Cost
Level 2*	1	\$2,836
	2	\$3,020
	3 to 5	\$3,090
	>6	\$2,305
DCFC (50 kW)	1	\$45,506
	2	\$36,235
	3 to 5	\$26,964
	>6	\$17,692
DCFC (150 kW)	1	\$47,781
	2	\$38,047
	3 to 5	\$28,312
	>6	\$18,577
DCFC (350 kW)	1	\$65,984
	2	\$52,541
	3 to 5	\$39,097
	>6	\$25,654

* Public and workplace Level 2 chargers outside of California state.

In general, more EVSE units installed at once usually lowers the average cost per unit, especially in commercial installations *(44)*.

CONCLUSIONS

In conclusion, the electrification of transportation requires the development of charging infrastructure to support the widespread adoption of EVs. The City of Austin serves as a case study, highlighting the need for both public and private support to develop EVSE. Co-locating private EVCS with/alongside public EVCS can maximize utilization and achieve cost-sharing while offering convenience for EV drivers. The public charging stations here are primarily Level 2 and DCFC, with approximately 462 Level 2 charging stations (with 1+ cords per station) and 37 DCFC charging stations serving the Austin area. Together, the 462 Level 2 stations can charge approximately 979 EVs simultaneously. Each Level 2 charging port serves roughly 17 EVs and 413 households across the City of Austin. DCFC stations are much more expensive to deploy, and Tesla Superchargers dominate the City of Austin's options, with Tesla's 8 supercharging stations making up 94 of the city's 123 Level 3 charging ports. This research applies POLARIS, an ABM, to simulate both EV trips and charging behavior. Areas with more charging trips and higher charging waiting times but limited access to charging stations, particularly near existing public EVCS, parking lots, gas stations, and highways, are identified as potential sites for PP EVCS in this research. Given the high costs associated with preparing and installing EVCS, fleet CSOs may explore investing in upgrading existing public charging infrastructures in addition to co-locating with public EVCS. To evaluate the effectiveness of this PP deploying mode, future research could evaluate performance metrics, including greenhouse gas reduction, charging service usage, wait time, customer satisfaction, revenue generation, and environmental impacts.

REFERENCES

1. Anastasiadis, E., Angeloudis, P., Ainalis, D., Ye, Q., Hsu, P. Y., Karamanis, R., ... & Stettler, M. (2020). On the Selection of Charging Facility Locations for EV-Based Ride-Hailing Services: A Computational Case Study. *Sustainability*, 13(1), 168.

2. Huang, Y., & Kockelman, K. M. (2020). Electric vehicle charging station locations: Elastic demand, station congestion, and network equilibrium. *Transportation Research Part D: Transport and Environment*, 78, 102179.

3. Sun, Z., Gao, W., Li, B., & Wang, L. (2020). Locating charging stations for electric vehicles. *Transport Policy*, 98, 48-54.

4. Zhou, W., Cleaver, C. J., Dunant, C. F., Allwood, J. M., & Lin, J. (2023). Cost, range anxiety and future electricity supply: A review of how today's technology trends may influence the future uptake of BEVs. Renewable and Sustainable Energy Reviews, 173, 113074.

5. Fulton, L. M., Jaffe, A., & McDonald, Z. (2019). Internal combustion engine bans and global oil use. Available at: https://escholarship.org/content/qt52j400b1/qt52j400b1_noSplash_d4b4cbfa7d110107136710b53fb32bc3.pdf?t=q1y2hw#:~:text=We%20find%20that%20national%20level%20ICE%20car%20bans,several%20decades%20for%20its%20full%20impact%20is%20realized.

6. Xu, M., Yang, H., & Wang, S. (2020). Mitigate the range anxiety: Siting battery charging stations for electric vehicle drivers. *Transportation Research Part C: Emerging Technologies*, 114, 164-188.

7. Andwari, A. M., Pesiridis, A., Rajoo, S., Martinez-Botas, R., & Esfahanian, V. (2017). A review of Battery Electric Vehicle technology and readiness levels. *Renewable and Sustainable Energy Reviews*, 78, 414-430.

8. Shi, L., Hao, Y., Lv, S., Cipcigan, L., & Liang, J. (2021). A comprehensive charging network planning scheme for promoting EV charging infrastructure considering the Chicken-Eggs dilemma. *Research in Transportation Economics*, 88, 100837.

9. Pardo-Bosch, F., Pujadas, P., Morton, C., & Cervera, C. (2021). Sustainable deployment of an electric vehicle public charging infrastructure network from a city business model perspective. *Sustainable Cities and Society*, 71, 102957.

10. LaMonaca, S., & Ryan, L. (2022). The state of play in electric vehicle charging services– A review of infrastructure provision, players, and policies. *Renewable and Sustainable Energy Reviews*, 154, 111733.

11. Wang, Y., Zhao, Z., & Baležentis, T. (2023). Benefit distribution in shared private charging pile projects based on modified Shapley value. *Energy*, 263, 125720.
12. Hou, Y., Chen, Y., Jiao, Y., Zhao, J., Ouyang, H., Zhu, P., ... & Liu, Y. (2017). A resolution of sharing private charging piles based on smart contract. In *2017 13Th International Conference on Natural Computation, Fuzzy Systems and Knowledge Discovery (Icnc-Fskd)* (pp. 3004-3008). IEEE.
13. U.S. Department of Transportation (DOT) (2022). Electric vehicle charging speeds. Retrieved January 16, 2023, from https://www.transportation.gov/rural/ev/toolkit/ev-basics/charging-speeds
14. Shahriar, S., Al-Ali, A. R., Osman, A. H., Dhou, S., & Nijim, M. (2020). Machine learning approaches for EV charging behavior: A review. *IEEE* Access 8.
15. Muratori, M., Kontou, E., & Eichman, J. (2019). Electricity rates for electric vehicle direct current fast charging in the United States. *Renewable and Sustainable Energy Reviews*, 113, 109235.
16. Engel, H., Hensley, R., Knupfer, S., & Sahdev, S. (2018). Charging ahead: Electric-vehicle infrastructure demand. McKinsey Center for Future Mobility, 8. URL: https://www.mckinsey.com.br/~/media/McKinsey/Industries/Automotive%20and%20Assembly/Our%20Insights/Charging%20ahead%20Electric-vehicle%20infrastructure%20demand/Charging-ahead-electric-vehicle-infrastructure-demand-final.pdf
17. Yang, X., Liu, J., Zhuge, C., Wong, A. T. C., & Wang, P. (2024). Exploring the potential of sharing private charging posts: A data-driven micro-simulation approach. *Sustainable Cities and Society*, 100, 105053.
Wang, G., Li, W., Zhang, J., Ge, Y., Fu, Z., Zhang, F., ... & Zhang, D. (2019). sharedcharging:
18. Data-driven shared charging for large-scale heterogeneous electric vehicle fleets. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies*, 3(3), 1-25.
19. Patt, A., Aplyn, D., Weyrich, P., & van Vliet, O. (2019). Availability of private charging infrastructure influences readiness to buy electric cars. *Transportation Research Part A: Policy and Practice*, 125, 1-7.
20. Zhao, Z., Zhang, L., Yang, M., Chai, J., & Li, S. (2020). Pricing for private charging pile sharing considering EV consumers based on non-cooperative game model. *Journal of Cleaner Production*, 254, 120039.
21. Teebay, Rick. (2023). Multi-Unit Dwelling Plug-in EV Charging Innovation Pilots (Final Report). United States. https://doi.org/10.2172/1991542
22. Liao, Y., Tozluoğlu, Ç., Sprei, F., Yeh, S., & Dhamal, S. (2023). Impacts of charging behavior on bev charging infrastructure needs and energy use. *Transportation Research Part D: Transport and Environment*, 116, 103645.
23. Dean, M. D., Gurumurthy, K. M., de Souza, F., Auld, J., & Kockelman, K. M. (2022). Synergies between repositioning and charging strategies for shared autonomous electric vehicle fleets. *Transportation Research Part D: Transport and Environment*, 108, 103314.
24. Auld, J., Hope, M., Ley, H., Sokolov, V., Xu, B., & Zhang, K. (2016). POLARIS: Agent-based modeling framework development and implementation for integrated travel demand and network and operations simulations. *Transportation Research Part C: Emerging Technologies*, 64, 101-116.
25. Dean, M. D., Gurumurthy, K. M., de Souza, F., Auld, J., & Kockelman, K. M. (2022) Synergies between repositioning and charging strategies for shared autonomous electric vehicle fleets. *Transportation Research Part D: Transport and Environment*, 108: 103314.
26. Gurumurthy, K. M., & Kockelman, K. M. (2022). Dynamic ride-sharing impacts of greater trip demand and aggregation at stops in shared autonomous vehicle systems. *Transportation*

Research Part A: Policy and Practice, 160, 114-125.
27. Kavianipour, M., Verbas, O., Rostami, A., Soltanpour, A., Gurumurthy, K. M., Ghamami, M., & Zockaie, A. (2023). Deploying Fast Charging Infrastructure for Electric Vehicles in Urban Networks: An Activity-Based Approach. *Transportation Research Record*, 03611981231189742.
28. Verbas, Ö., Kavianipour, M., Gurumurthy, K. M., Ghamami, M., Moawad, A., Zockaie, A.& Auld, J. (2023). Modeling the Energy and Environmental Impact of Varying Electric Vehicle Adoption and Charging Station Deployment: A Behavioral Approach Using Agent-Based Modeling. Presented at the 102nd Annual Meeting of the Transportation Research Board held in Washington, DC.
29. U.S. Department of Energy (DOE) (2023). Alternative Fuels Data Center: Developing Infrastructure to Charge Electric Vehicles. Retrieved January 19, 2023, from https://afdc.energy.gov/fuels/electricity_infrastructure.html
30. Thompson, K. (2022). As Texans conserve energy, how much power do Electric Vehicle Chargers use? KXAN Austin. Retrieved January 31, 2023, from https://www.kxan.com/news/local/austin/as-texans-conserve-energy-how-much-power-do-electric-vehicle-chargers-use/
31. U.S. Census Bureau (2021). U.S. Census Bureau quickfacts: Austin City, Texas. Retrieved February 1, 2023, from https://www.census.gov/quickfacts/fact/table/austincitytexas/LND110210
32. EVAdoption (2022). US charging network rankings. Retrieved December 13, 2022, from https://evadoption.com/ev-charging-stations-statistics/us-charging-network-rankings/
33. Chen, H., Hu, Z., Luo, H., Qin, J., Rajagopal, R., & Zhang, H. (2017) Design and planning of a multiple-charger multiple-port charging system for PEV charging station. *IEEE Transactions on Smart Grid*, 10(1), 173-183.
34. Zhang, H., Hu, Z., Xu, Z., & Song, Y. (2016). Optimal planning of PEV charging station with single output multiple cables charging spots. *IEEE Transactions on Smart Grid*, 8(5), 2119-2128.
35. Austin Energy (2022). Charging station map. Retrieved January 25, 2023, from https://austinenergy.com/green-power/plug-in-austin/charging-station-map
36. Moawad, A., Gurumurthy, K. M., Verbas, O., Li, Z., Islam, E., Freyermuth, V., and Rousseau, A. (2021). A Deep Learning Approach for Macroscopic Energy Consumption Prediction with Microscopic Quality for Electric Vehicles. arXiv preprint arXiv:2111.12861.
37. Smith, M., & Castellano, J. (2015). Costs associated with non-residential electric vehicle supply equipment: Factors to consider in the implementation of electric vehicle charging stations (No. DOE/EE-1289).
38. Nelder, C., & Rogers, E. (2019). Reducing EV charging infrastructure costs. Rocky Mountain Institute. URL: https://rmi.org/wp-content/uploads/2020/01/RMI-EV-Charging-Infrastructure-Costs.pdf
39. Zhang, H., Hu, Z., Xu, Z., & Song, Y. (2016). Optimal planning of PEV charging station with single output multiple cables charging spots. *IEEE Transactions on Smart Grid*, 8(5), 2119-2128.
40. DiNello, S. (2022). How much do EV charging stations cost? Future Energy. Retrieved February 2, 2023, from https://futureenergy.com/how-much-do-ev-charging-stations-cost/
41. Nicholas, M. (2019). Estimating electric vehicle charging infrastructure costs across major US metropolitan areas. URL: https://theicct.org/wp-content/uploads/2021/06/ICCT_EV_Charging_Cost_20190813.pdf
42. Zehnder, K.O., Lowry, S., & Ramos, S. (2020). Electric Vehicle Charging Study. HNTB Corporation. Available at: https://drive.ohio.gov/wps/wcm/connect/gov/4a58a392-917f-4735-8438-bfdbb3f0b7bd/2020-06-

26_EV_Charging_Study.pdf?MOD=AJPERES&CONVERT_TO=url&CACHEID=ROOTWORKSPACE.Z18_M1HGGIK0N0JO00QO9DDDDM3000-4a58a392-917f-4735-8438-bfdbb3f0b7bd-nc08aJ2
43. Peng, V. (2022). How much does a commercial EV charging station cost? WattLogic. Retrieved February 2, 2023, from https://wattlogic.com/blog/commercial-ev-charging-stations-cost/
44. Chu, K. C., Smart, J. G., & Schey, S. (2022). Breakdown of Electric Vehicle Supply Equipment Installation Costs (No. INL/RPT-22-68598-Rev000). Idaho National Lab.(INL), Idaho Falls, ID (United States).
45. The EV Project (2015). What were the Cost Drivers for the Direct Current Fast Charging Installations? Available: https://avt.inl.gov/sites/default/files/pdf/EVProj/WhatWereTheCostDriversForDCFCinstallations.pdf
ric Vehicles. arXiv preprint arXiv:2111.12861.