LIVABLE CITY YEAR 2017–2018
IN PARTNERSHIP WITH
CITY OF TACOMA

CITY OF TACOMA

NEIGHBORHOOD AND WORKPLACE ELECTRIC VEHICLE CHARGING DEPLOYMENT

UNIVERSITY OF WASHINGTON
CIVIL AND ENVIRONMENTAL ENGINEERING

CET 583: TRANSPORTATION ENERGY AND SUSTAINABILITY

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SPRING 2018

LIVABLE CITY YEAR

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Electric cars lined up to charge in Toronto, Ontario. COVER PHOTO CREDIT: MARIORDO

ACKNOWLEDGMENTS

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ABOUT LIVABLE CITY YEAR

The University of Washington's Livable City Year (LCY) initiative enables local governments to engage UW faculty and students for one academic year to work on city-defined projects that promote local sustainability and livability goals. The program engages hundreds of students each year in high-priority projects, creating momentum on real-world challenges while enabling the students to serve and learn from communities. Partner cities benefit directly from bold and applied ideas that propel fresh thinking, improve livability for residents and invigorate city staff. Focus areas include environmental sustainability; economic viability; population health; and social equity, inclusion, and access. The program's 2017–2018 partner is the City of Tacoma; this follows a partnership with the City of Auburn in 2016–2017.

The LCY program is led by faculty directors Branden Born (Department of Urban Design and Planning), Jennifer Otten (School of Public Health) and Anne Taufen (Urban Studies Program, UW Tacoma), with support from Program Manager Teri Thomson Randall. The program was launched in 2016 in collaboration with UW Sustainability and Urban@UW, with foundational support from the Association of Washington Cities, the College of Built Environments, the Department of Urban Design and Planning, and Undergraduate Academic Affairs.

LCY is modeled after the University of Oregon's Sustainable City Year Program, and is a member of the Educational Partnerships for Innovation in Communities Network (EPIC-N), the collection of institutions that have successfully adopted this new model for community innovation and change.

For more information, contact the program at uwlcy@uw.edu.

LIVABLE
CITY YEAR

ABOUT TACOMA

The third largest city in the state of Washington, Tacoma is a diverse, progressive, international gateway to the Pacific Rim. The port city of nearly 210,000 people has evolved considerably over the last two decades, propelled by significant development including the University of Washington Tacoma, the Tacoma Link light rail system, the restored urban waterfront of the Thea Foss Waterway, the expansions of both the MultiCare and CHI Franciscan health systems, and a significant influx of foreign direct investment in its downtown core.

Washington State's highest density of art and history museums are found in Tacoma, which is home to a flourishing creative community of writers, artists, musicians, photographers, filmmakers, chefs, entrepreneurs, and business owners who each add their unique flair to the city's vibrant commercial landscape. The iconic Tacoma Dome has endured as a high-demand venue for some of the largest names in the entertainment industry.

A magnet for families looking for affordable single-family homes in the Puget Sound area, Tacoma also draws those seeking a more urban downtown setting with competitively priced condos and apartments that feature panoramic mountain and water views. The city's natural beauty and proximity to the Puget Sound and Mount Rainier draws hikers, runners, bicyclists, and maritime enthusiasts to the area, while its lively social scene is infused with energy by thousands of students attending the University of Washington Tacoma and other academic institutions.

The City of Tacoma's strategic plan, Tacoma 2025, was adopted in January 2015 following unprecedented public participation and contribution. The plan articulates the City's core values of opportunity, equity, partnerships, and accountability, and expresses the City's deep commitment to apply these values in all of its decisions and programming. Each Livable City Year project ties into the principles and focus areas of this strategic plan. The City of Tacoma is proud of its 2017–2018 Livable City Year partnership with the University of Washington and of the opportunity this brings to its residents.

Tacoma

TACOMA 2025 STRATEGIC PLAN

The *Neighborhood and Workplace Electric Vehicle Charging Deployment* project supports the Livability and Equity and Accessibility goals of the 2025 Strategic Plan and was sponsored by the City's Office of Environmental Policy and Sustainability.

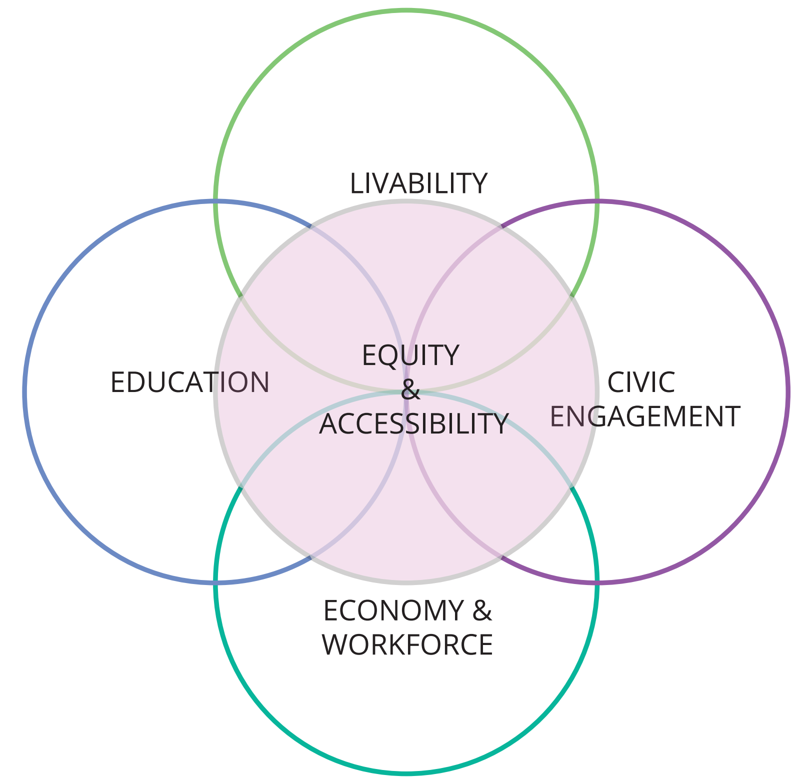
Goal #1 Livability
The City of Tacoma will be a city of choice in the region known for connected neighborhoods, accessible and efficient transportation transit options, and vibrant arts and culture. Residents will be healthy and have access to services and community amenities while maintaining affordability.

Goal #2 Economy and Workforce
By 2025, Tacoma will be a growing economy where Tacoma residents can find livable wage jobs in key industry areas. Tacoma will be a place of choice for employers, professionals, and new graduates.

Goal #3 Education
Tacoma will lead the region in educational attainment amongst youth and adults. In addition to producing more graduates from high school and college, more college graduates will find employment in the region. Lifelong learning and access to education will be prioritized and valued.

Goal #4 Civic Engagement
Tacoma residents will be engaged participants in making Tacoma a well-run city. The leadership of the city, both elected and volunteer, will reflect the diversity of the city and residents and will fully participate in community decision-making.

Goal #5 Equity and Accessibility
Tacoma will ensure that all residents are treated equitably and have access to services, facilities, and financial stability. Disaggregated data will be used to make decisions, direct funding, and develop strategies to address disparate outcomes.



RESOURCES

Tacoma 2025 Strategic Plan: https://www.cityoftacoma.org/tacoma_2025

Office of Environmental Policy and Sustainability
https://www.cityoftacoma.org/government/city_departments/environmentalservices/office_of_environmental_policy_and_sustainability

Livable City Year: https://www.washington.edu/livable-city-year/

Department of Civil and Environmental Engineering
https://www.ce.washington.edu/

EXECUTIVE SUMMARY

Tacoma, a port city in Washington State, has partnered with the University of Washington for Livable City Year (LCY) 2017-18, with the goal of working to improve the quality of life in Tacoma. One of the projects in the LCY partnership was to propose strategies to boost the electric vehicle (EV) infrastructure of the City of Tacoma. There are challenges to reaching the city's goal of 2,000 private EVs by 2020: high prices, range anxiety, lack of awareness about EVs, and lack of experience on the part of dealership in selling EVs. Associated with challenges are the barriers to installing the necessary infrastructure needed for EVs, i.e., the electric vehicle supply equipment (EVSE), colloquially referred to as chargers.

This document proposes how the City of Tacoma should go about increasing EV infrastructure at all levels of the charging system. These are grouped into three classes: 1) residential EV charging stations (single-family households and multi-unit dwellings), 2) public EV charging stations and 3) workplace EV charging stations.

RESIDENTIAL

Residential EV charging infrastructure is the most important to support; currently about 82% of total charging events occur at home. Residential charging is also a category offering significant opportunity for growth. In particular, multi-unit dwellings (MUD) are underserved with chargers. While the vast majority of residential chargers are installed in single-family houses, MUDs account for around 35% of housing units in Tacoma, and about 37% of EV owners live in MUDs statewide (2009 – 2013 ACS). Since MUDs are dense, utilization rates may increase even more if more chargers are installed. Promoting EV use in MUDs will also help Tacoma achieve its goal of expanding EV use equitably.

Based on our calculations, the total cost to equip MUDs with enough EVSE charging stations to support the 2,000 EVs targeted is roughly $1.7 million. In the world of transportation infrastructure, this is incredibly cheap. For individual property owners and landlords, however, the sticker price (about $2,000 for a domestic "Level 2" charger) can still be prohibitive. Existing polices to encourage the EV charger installation include tax credits, rebates, and waiving permit fees. But the owner-

Constructing public charging stations is important for overcoming range limitations and for promoting use of electric vehicles. さかおり

rental structure of residential units presents some challenges to the effectiveness of these tools. Owner-occupied households see direct benefits from investing in chargers, while rental-occupied households have different return structures and may therefore require different incentives. In order to assess this variability, we compared four scenarios (single family residences, MUD with an owner and 5 renters, MUD with 6 renters, and MUD with 6 renters sharing chargers), and analyzed the net present value (NPV) and discounted payback period (DPP). Sharing chargers and collecting commissions or user fees, rather than offering one-time rebates, seems to shorten DPP. That means the City of Tacoma may consider directing its budget more toward promoting user fee-based programs rather than one-time rebates.

Research suggests that EV adoption is correlated with household income and other socioeconomic as well as geographic factors. In order to explore the equity dimension of potential EV charging programs, we ran simulations based on a fairness model with an assumed budget of 100 chargers. We found out that an efficiency-oriented policy – i.e., a policy intended to stimulate EV adoption most quickly and cheaply – will incur higher return and shorter period of DPP if focused on a few higher-income neighborhoods, while an equity-oriented policy – one with chargers distributed evenly across all neighborhoods – has lower return and longer DPP. The City of Tacoma needs to consider these results when deciding how to balance its adoption goals with its equity goals.

An additional challenge with increased use of EVs is the demand on the power grid. Smart chargers could help by addressing peak demand for electricity. Smart chargers are especially applicable for residential settings, where a car owner may be able to leave the vehicle for extended periods. For example, setting the smart charger to charge overnight, when demand is lower and electricity price is cheaper, will distribute overall electricity demand more evenly throughout the day while benefiting EV owners in terms of total costs and utilities in terms of delivery logistics.

PUBLIC

While “public” charging (i.e., charging that takes place somewhere other than home or work) is estimated to make up only 10-20% of charging by 2020, it is of critical importance to overcoming range limitations and therefore EV adoption, so it should be a focus of the city’s promotion efforts. We conducted a site suitability analysis, drawing on factors like commercial density and proximity to major roadways, along with cost estimations in terms of charger acquisition, installation, operation, and maintenance. While public charging stations should be distributed across the city, our analysis shows that the central neighborhoods in ZIP codes 98409 and 98405 and, specifically, corridors like South Tacoma Way will support the most charging stations. It should be noted that while in residential situations, the most affordable “Level 1” chargers may be used (which draw roughly the power of a toaster and take up to 24 hours to charge a typical EV), public chargers will need to be the more powerful and expensive “Level 2” chargers (which draw the power of a clothes dryer and can supply a full charge in 8 hours) or DC Fast Chargers (DCFC, which can charge a Tesla in 30 minutes while drawing the power of a convenience store).

Because of the substantial capital investment involved with public charging facilities – a single DCFC charger can cost $10,000-$40,000 – innovative business models will be required. Since this is an emerging area, it is too early at this time to say which model would be best for Tacoma. It is likely several models will coexist; all should be explored. This models include dedicated regional fast charging stations, not unlike typical gas stations (e.g., companies like EVITA, Greenlots, and EV4); EV stations coupled with other commercial locations, like big box stores (e.g., IKEA, Walmart, grocery stores); private fleets operated by automakers (e.g., Volkswagen, BMW, Daimler or Tesla) or app based “sharing” services (e.g. Chargie); and stations operated by independent advocacy groups (e.g., EV100). In any case, there will likely be non-financial hurdles as well, including information gaps and potential conflicts relating to congestion and power grid burden.

WORKPLACE

Over 70% of the people who work in Tacoma live outside the city, and the vast majority of these commute to work in cars. While the expansion of mass transit like the Link light rail may reduce the number of car commuters, workplace charging will still present an important opportunity for growing Tacoma's EV infrastructure. We found that to support the targeted 2,000 EVs by 2020, about 45 workplace chargers will be necessary.

To determine the ideal locations for workplace chargers, we performed an analysis similar to the one performed for public chargers, factoring in population, employment, and road densities, as well as what we call "employer/employee readiness," which takes into account the business domain of the worksite, average income of employees, and internal demand for EV services. Again, because of the capital investment required for high-speed chargers and in order to assure maximum use for the chargers, we focused on major employers. The analysis concluded that Davita, the Emerald Queen Casino, the Puyallup Tribe, the University of Puget Sound, and Tacoma Community College would be the prime candidates for successful workplace charging programs. The City of Tacoma can use the workplace desirability index and conduct the bidding process to optimize the allocation of funds.

Beyond the direct benefit to employers and employees, there are other possible benefits with increased presence of workplace chargers. Workplace chargers can be used by the public during off hours, which would provide key charging options for garage orphans and EV owners living in MUDs. In situations where parking is access controlled, chargers could be used after-hours by fleet vehicles. Ultimately, we were able to demonstrate both financial advantages (through simulated NPV) and environmental benefits in terms of reduced greenhouse gas emissions with the mobilization of workplace chargers.

EV charging for employees outside San Francisco City Hall FELIX CRAMER

Introduction

Charging infrastructure has a significant effect on consumer adoption of electric vehicles (EVs). It is generally accepted that the relative attractiveness of EVs and other alternative fuel vehicles depends on several factors. These include up-front cost, operating costs that include fuel (electricity) and maintenance, range, refueling/recharging time, the availability of refueling infrastructure, environmental impacts, and government incentives. In the case of EVs, many of these factors are determined by the charging infrastructure: the number, type, locations, and pricing of charging stations. It is generally accepted that to make EVs more attractive to consumers, charging opportunities should be ubiquitous, fast, and inexpensive.

Our report draws on an extensive amount of literature pertaining to guiding communities and governments to developing electric vehicle infrastructure and EV support equipment (EVSE) to promote the adoption of EVs. In the appendix, we include an annotated list of the most relevant and useful prior reports and guidelines. It is neither an exhaustive nor all-inclusive list of EV community implementation guidance, but, rather, captures the essence of EV implementation at the local level from early 2010s. For further reading, please consult this appendix.

The best practices from the literature and other peer jurisdictions can be grouped into four categories, which we elaborate on below:

- Outreach, education, training, and marketing
- Facilitating stakeholder partnerships
- Charging stations deployment plan, siting, and design
- Incentives and grants for EVs and EVSE development

The overall goal is to provide Tacoma with predetermined candidate locations that the City and its partners can invest in when funding is made available.

OUTREACH, EDUCATION, TRAINING, AND MARKETING

The best first step for developing and implementing an EV and EVSE development strategy is to create outreach events, education opportunities, training sessions, and marketing campaigns to increase awareness and promote visibility of the strategy and initiative. Outreach, education, training, and marketing are ongoing efforts that span the life of the initiative. These components will require continual attention, care, and effort to keep the momentum of the initiative moving forward. Initial outreach and education efforts should be at the higher levels of local governments (city and county). Buy-in from the community and county policy-makers, decision-makers, and leaders affords much needed visibility and support in developing and eventually implementing a strategy. Simultaneous efforts of outreach, education, training, and marketing should target stakeholders and the public. Targeting stakeholders serves the end of establishing a partnership to foster support for the strategy[1]. Targeting the public serves the goal of increasing awareness and visibility of the plan, promoting adoption, educating, and demonstrating the technology. Some efforts to serve the goals of outreach, education, training, and marketing include:

- Local government fleet turnover and EV adoption
- Local government public EVSE development
- Ride-and-drive demonstration events
- Information sharing over different outlets to include social media blasts, municipal web pages, and/or tourism maps with locations of EVSE

FACILITATING STAKEHOLDER PARTNERSHIPS

A critical step for devising and implementing an EV and EVSE development plan is to get stakeholders on board early in the process. Early involvement allows the stakeholders the greatest amount of contribution, and subsequently buy-in, when the plan goes to implementation. A broad collection of stakeholders is key to success. These stakeholders can include: auto dealerships who sell or lease the EVs, utility providers who maintain the power grid, commercial enterprises such as retail and liquid fueling stations, education and health services campuses, other government entities (municipal, county, state, tribal, federal), and Clean Cities coalitions. Given such a diverse team of stakeholders, a central hub and point of contact (POC) should be identified early as the single touchpoint for information, technical support, and oversight[2]. This single POC naturally fits a local government's role in the development and implementation of an EV plan. However, other team stakeholders may be just as suited for the task or to share the task, such as a utility provider.

CHARGING STATIONS DEPLOYMENT PLAN, SITING, AND DESIGN

One of the key takeaways from the robust and comprehensive 2012 DOE Clean Cities report was that local governments have great potential to influence the adoption and development of EV and EVSE within their jurisdictions[3]. Much consideration and attention should be given towards local ordinances and administration that can ease the burden of EV adoption or EVSE development. Out-of-date policy, rules, or regulations can become a disincentive for EV adoption and EVSE investment from the public and private parties alike. As such, the City of Tacoma should review and consider zoning changes that may restrict EVSE installation or use, parking designation and preferences for EVs, permitting streamlining for EVSE development, and building code changes that may be incompatible with strategy goals.

INCENTIVES AND GRANTS FOR EVS AND EVSE DEVELOPMENT

Incentives for EV adoption and EVSE investment are where the rubber meets the road for an EV and EVSE development plan. Implementation of the development plan should include a series of incentives to encourage adoption and investment by public and private parties alike. This will require creative and ingenious incentive solutions to promote adoption to the public as well as investment from private entities. Some incentive solutions to encourage EV adoption have included a sales tax reduction or exemption and rebate for purchase or lease of a new EV. Creative solutions such as a rebate for a registered/partner dealer for each sale or lease of an EV have worked in certain markets[4]. For a dealership (and their customers) to benefit from the rebate, the dealership was required to register to participate in the incentives program. The registration ran for a fixed period, and if the dealership was unable to meet a quota of rebates, their share expired and was redistributed to another dealership. In the case of Vermont, this worked well to promote buy-in and participation from the dealerships. In the instance of rebates, incentives programs are only as good as the source of funding. The larger the sum of money to offer in incentives and the more creative the program, the more likely the public and private parties will respond to the incentive in the intended manner. An incentive program may require different sources of funding, both public and private, in order to be a successful motivator. Similarly, EVSE development incentives will require the same creativity. Rebates and reduced utility rates are frequently used incentives during early infrastructure development to help stimulate the network development and offset business losses.

This report is structured around three major categories of EV charging locations: residential, workplace, and public. In each of the following chapters, we discuss why the investment in electric vehicle supply equipment (EVSE) is valuable in the given location category, and use social and spatial characteristics of Tacoma to recommend sites for charging infrastructure. Following this, we present a range of possible policies. First, we review the types of charging station options, followed by current incentives for EVSE installation and owner-renter structures, and an estimate of the cost of installing EVSE based on different local circumstances. After that, a quick cost-benefit analysis suggests how the financial gains from chargers are distributed based on different cases. Based on this, we present an incentive assessment that elaborates how different rebates and other incentive approaches can effectively increase the attractiveness of investing in chargers. The results of these methods come together in a framework in which different policy options can be optimized based on the higher objectives of the City of Tacoma. Within this framework, we compare strategies optimizing either efficiency or equity. We conclude by sketching an additional approach that focuses more on quick wins and can be a valuable addition to the policies presented.

The analysis performed in this report is based on many assumptions that had to be made since detailed data on the situation in Tacoma was not available for many variables at the time of the analysis. Thus, to get more accurate results, we recommended creating a detailed Tacoma EV readiness data inventory, which could be based on surveys of EV readiness status distribution, income distribution, ownership structure and the interest of residents to actually invest in EVs.

TACOMA CHARACTERISTICS

Tacoma Residential EV Status

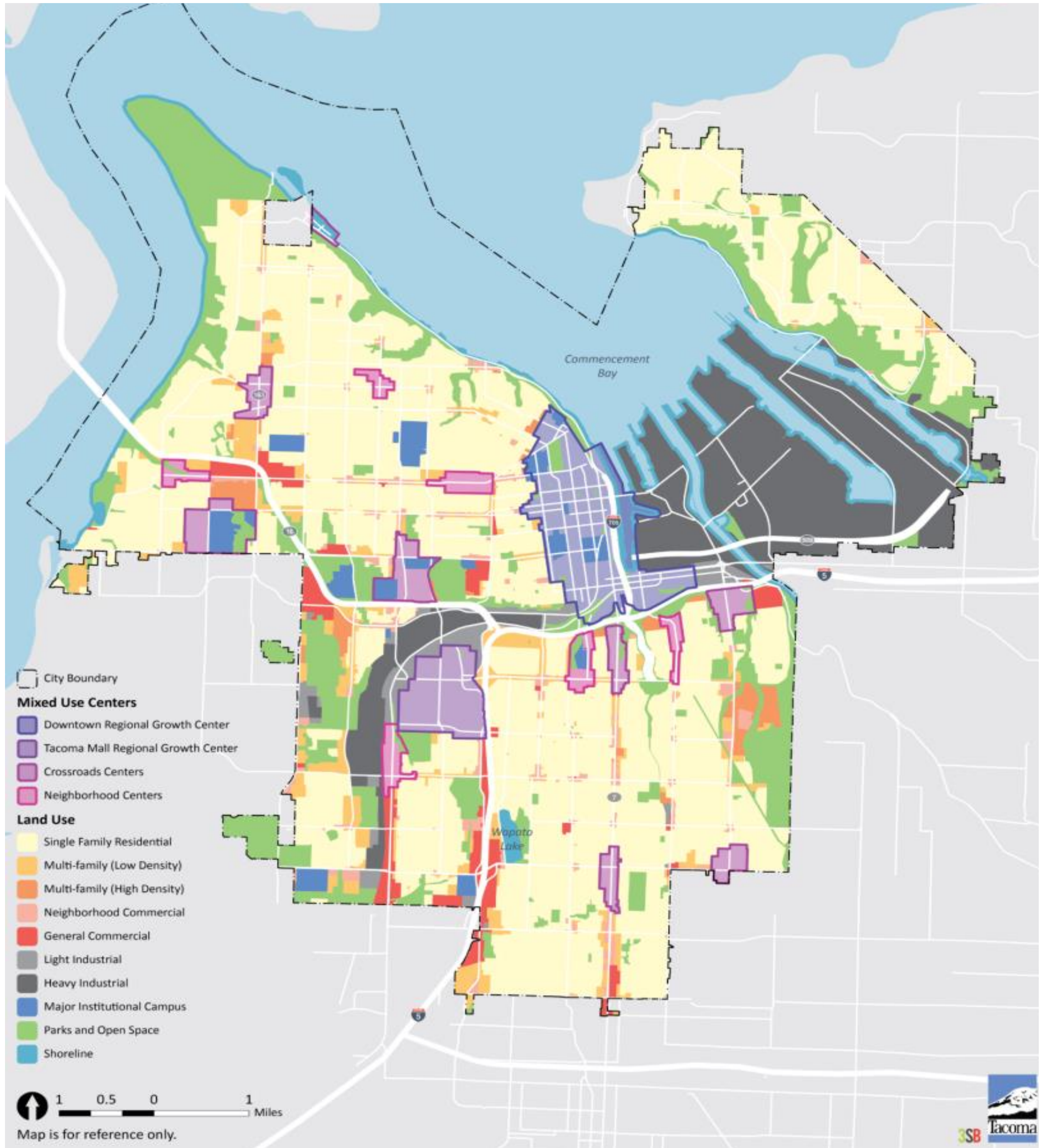
In Tacoma, over 75% of the lands are zoned residential. Most citizens live in the single-family dwellings. Understanding characteristics of occupants and their charging behavior is important for expanding EV adoption. Prior research in other cities has shown that 85% of all charge events occur at home and 50% of EV owners charge exclusively at home.

The number of plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs) registered in Washington State increased by 70% between mid-2014 and the end of 2015. Currently, 523 EVs are registered in Tacoma. If Tacoma is to achieve the vision of 2000 plug-in vehicles by 2020, it will need to further increase EV adoption. Therefore, it is important to know which factors influence the adoption of EVs among residents of Tacoma. In this section, we estimate the expected rates of EV adoption based on residents' demographics in each ZIP code.

First, the number of EVs registered by each ZIP code forms the basis of a model based on residents' demographics from Census data. To examine the current status of EV adoption in Tacoma, we estimate the expected adoption rate of EVs (expected percentage of EVs compared to the number of vehicles in the area) in each ZIP code using a zero-inflated negative binomial model and compare this with the current adoption rate of EVs. The difference between expected and actual number of EVs in each ZIP code is then visualized. Figure 2 show areas, shaded in green, where actual EV adoption exceeds the predicted adoption. Likewise, grey areas are those where actual EV adoption fall short of the levels expected based on socio-demographic characteristics.

In Tacoma, a higher proportion of residents in multi-unit dwellings own EVs (13%) than the proportion across all households (11%); yet, residents of multi-unit dwellings are underserved by EV chargers.

Figure 1. Map of zoning districts in Tacoma



Most of the ZIP codes in Tacoma have more EVs than expected. According to the socio-demographic characteristics of each ZIP code that were significant in the final model, the EV adoption rate increases as the number of well-educated residents increase in each ZIP code. The population density of a ZIP code has a negative effect on the rate of EV adoption. The EV adoption rate in a ZIP code rises as the percent of high-income households increases. Employment per household positively affects the rate of EV adoption in each ZIP code. The percent of children (under 18 years old) in each ZIP code has a negative effect on the EV adoption rate.

Multi-Unit Dwellings in Tacoma

As the American Community Survey (ACS) reports, 30,662 housing units in Tacoma are located in multi-unit dwellings (MUDs), making up 35% of the total housing units in the city[5]. Furthermore, according to the Tacoma residential building permit records, the number of permitted MUD units is 5 times higher than permitted single-family units[6]. However, the current infrastructure in electric vehicle supply equipment (EVSE) in MUDs is far from meeting the needs of these residents. Several factors influence future strategies for increasing EV adoption in MUDs.

1. **Electric vehicle supply equipment (EVSE) in MUDs is not emphasized.** Among all the electric vehicle (EV) charging stations in Tacoma that are listed on the plugshare website[7], only one station is installed at a MUD (Copperline Apartments). Since the availability of home charging will greatly influence people's willingness to purchase EVs, more effort and investment needs to be put on incentivizing EVSE in MUDs.

2. **Demand for home charging is high, especially in MUDs.** As the 2017 Puget Sound Regional Council (PSRC) Household Travel Survey data shows[8], Tacoma shows a higher proportion of EV ownership in MUDs (13%) than across all surveyed households (11%). Even though these results are overestimated due to self-selection bias (the amount of EVs currently registered in Tacoma is less than 1% of the total number of registered vehicles), it still provides evidence that MUD residents have a significant demand for EVSE infrastructure.

Figure 2. EV adoption predictions for each ZIP code

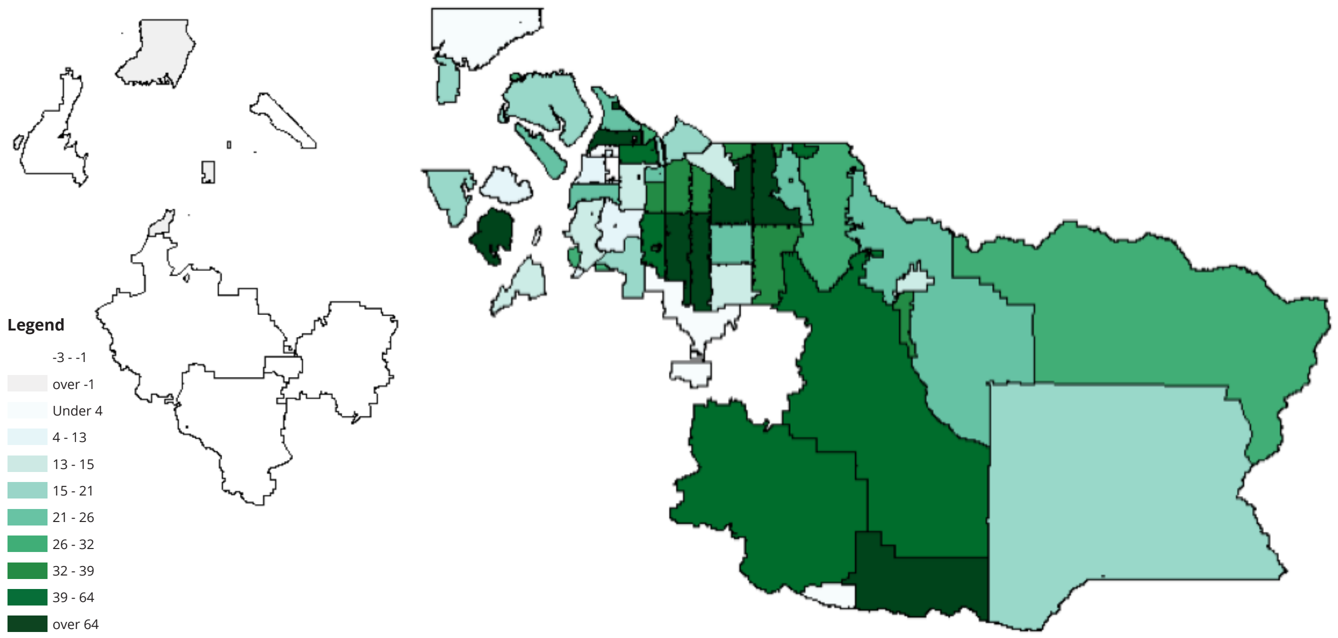
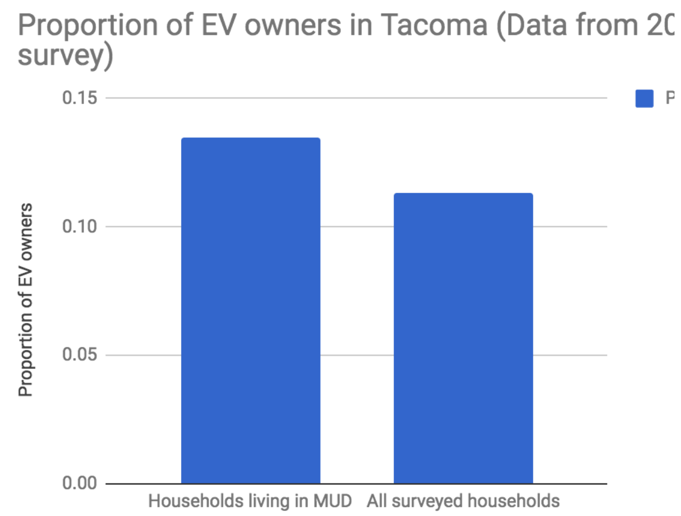


Figure 3. Proportion of EV owners in Tacoma



DATA FROM 2017 PSRC SURVEY

Figure 4. Cluster analysis of social characteristics of MUD residents

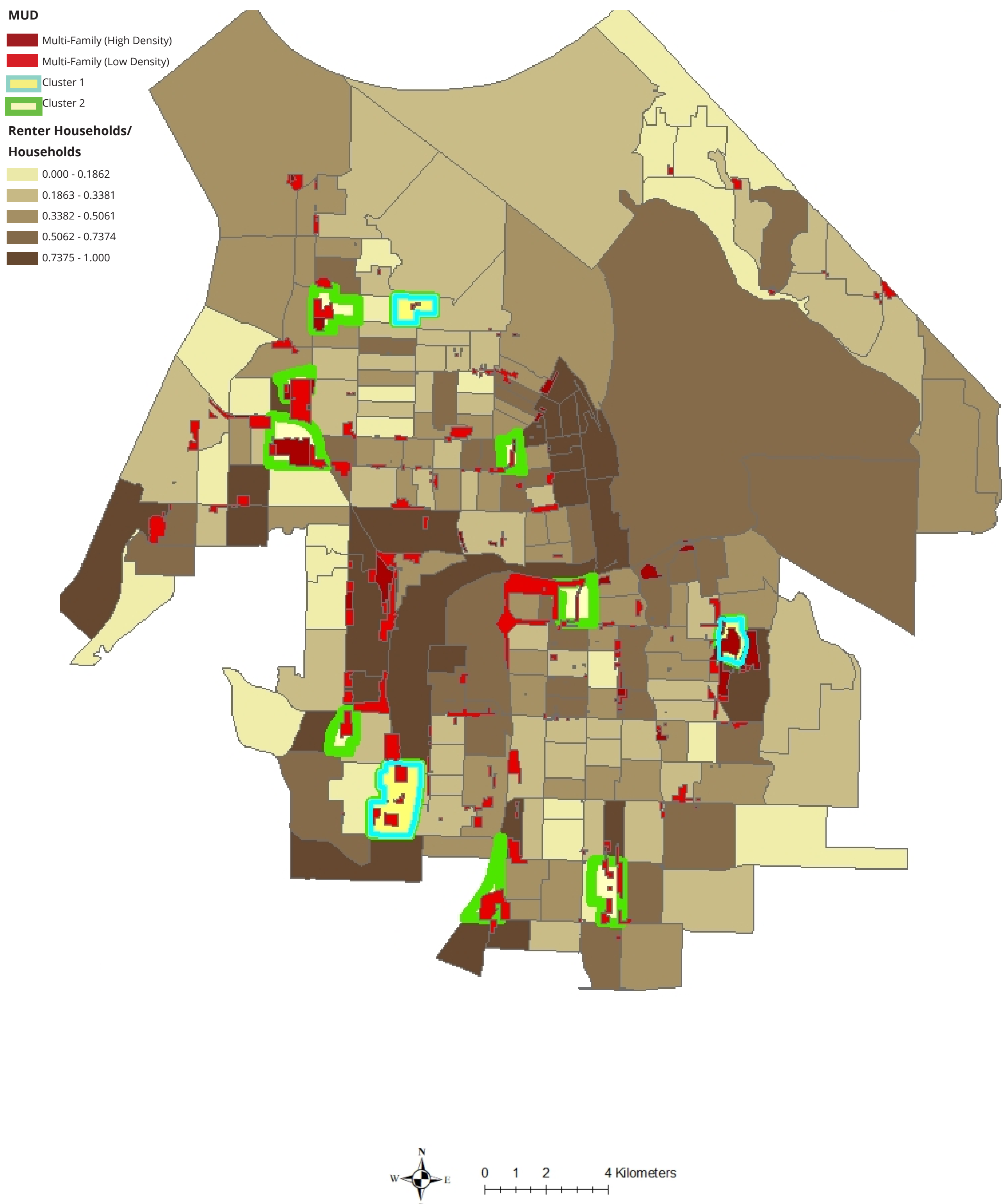
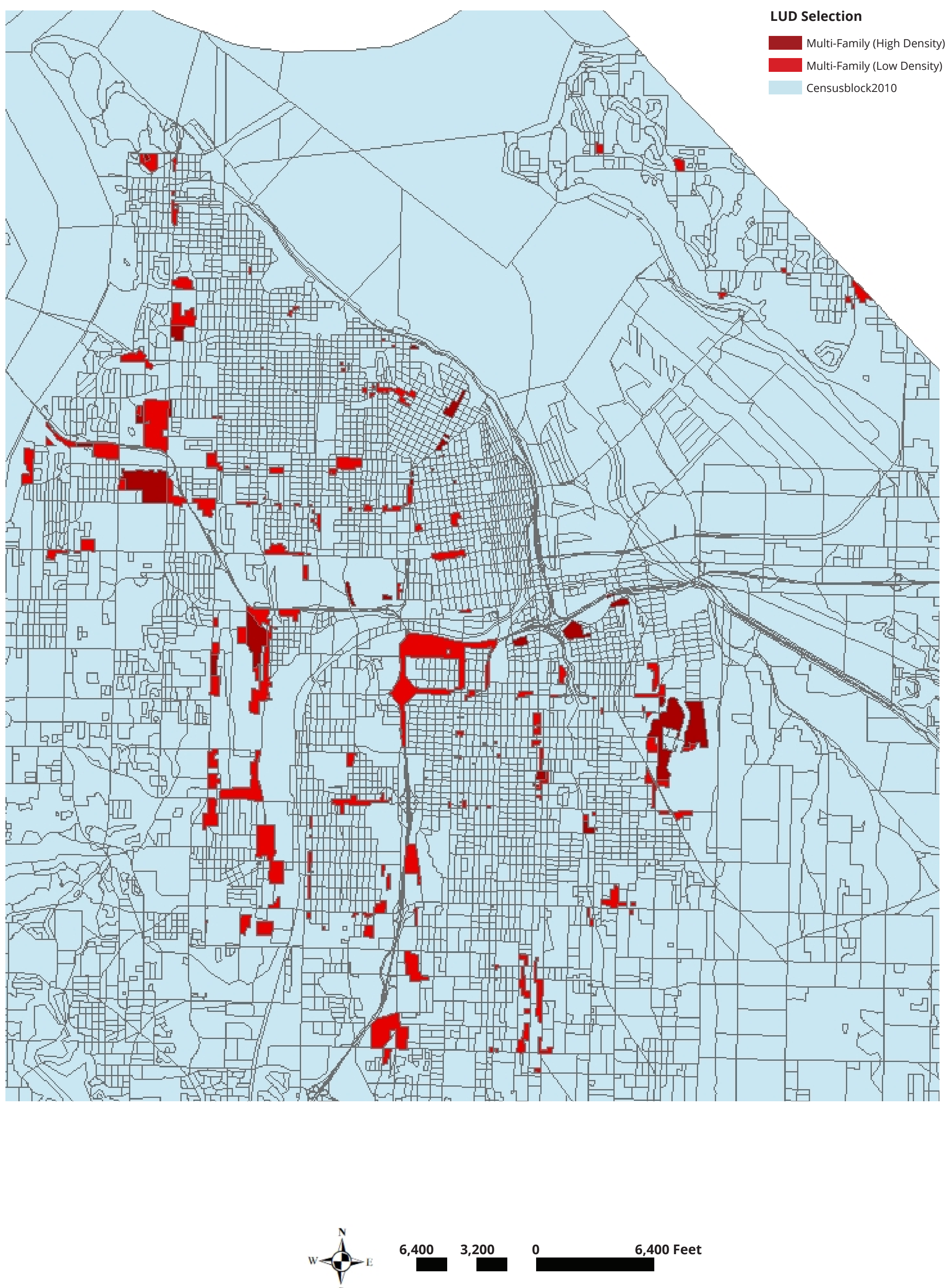


Figure 6. MUD parking in Tacoma



3. **MUDs have the potential to provide more equitable and economic EVSE structure.** Blocks with MUDs are likely to have higher population density and a higher proportion of rental housing. Therefore, in order to achieve social equity in EVSE accessibility, the city should consider suitable charging solutions for MUDs in addition to public, workplace, and single-family residence charging. Moreover, based on a performed cluster analysis, two clusters of MUD-intense blocks (with blue and green outlines), as shown in Figure 4, are found to have different social characteristics. Compared to Cluster 1, Cluster 2 has a higher population density, lower average income, lower education level, higher building age and a higher proportion of rental housing. The government needs to develop different strategies to address EVSE installations for the two clusters.
   Compared to single-family residences, MUD charging stations are likely to have a higher utilization rate due to higher population density, thus making them a more economical option. MUD residents' trips that originate from the residence are distributed throughout the day, as is illustrated by Figure 5, which suggests that charging events are likely to be distributed further throughout the day, which could cause the distribution of usage rate of each charging station to be spread.

4. **MUDs in Tacoma have suitable parking for installing EVSE.** Lack of parking space is usually a barrier to installing charging stations in MUDs. In Tacoma, however, areas with MUDs are widely dispersed across the city and about 95% of MUDs exhibit sufficiently large surface level parking for residents, which is shown in Figure 6. The only area that was found to have insufficient on-premises parking is the historic downtown. Overall, there are sufficient parking spaces in MUDs for installing EVSE and it is recommended that the city focuses on MUDs with surface level parking.

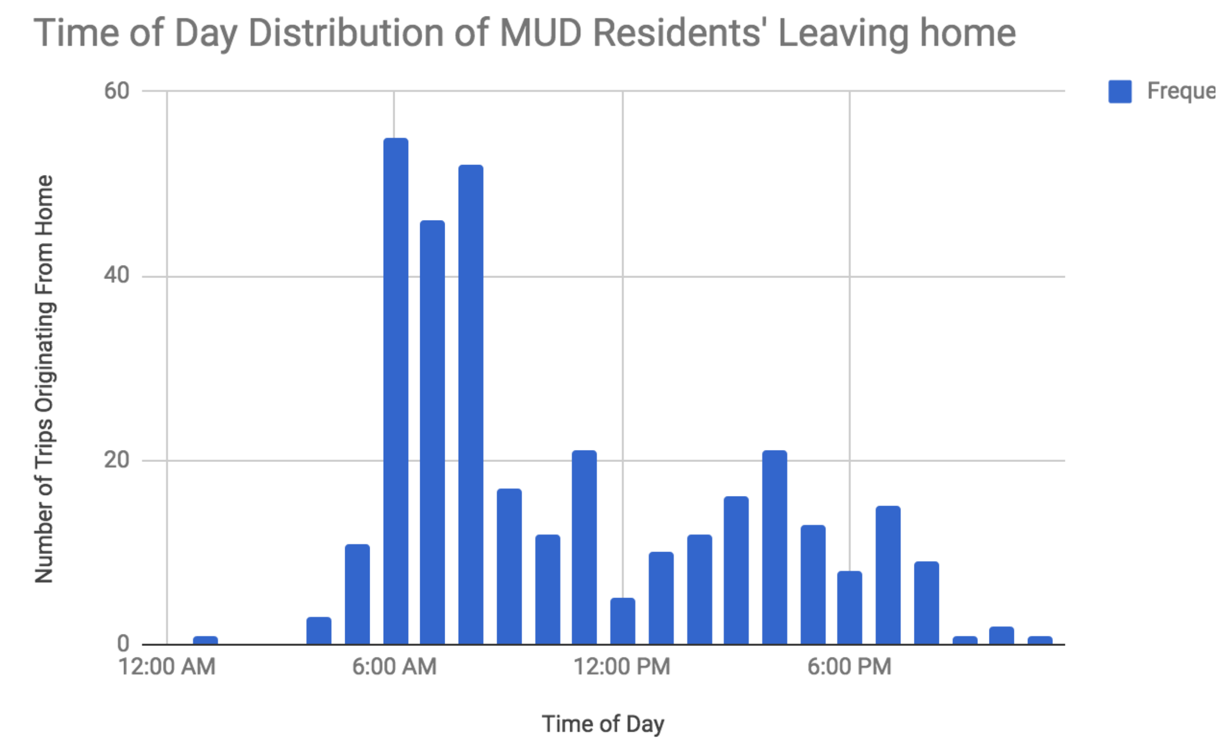
CONSIDERATIONS

Following the background and initial analysis outlined above, several questions could be considered for recommendations about which incentives are best choices for Tacoma to increase the EV adoption rate. These questions are as follows: Which level of charging stations should be emphasized? What are some strategies used by other cities in regard to EV infrastructure? Does Tacoma need to treat renters and people who have to park on street differently? Are the incentives cost-effective for different stakeholders like Tacoma Power?

Table 1. Results of logistics regression (MUD-intensive blocks vs. other blocks)

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	-7.0291502	1.0766785	-6.528551	0.0000000
Pop. Density	0.0001444	0.0000783	1.844661	0.0650868
Renter	3.7222820	1.5444505	2.410101	0.0159481
*** AIC is 72.75**				

Figure 5. Time-of-day distribution of MUD residents leaving home



DATA FROM 2017 PSRC SURVEY

Challenges Related to Uncertainty

Among the main sources of problems when defining a strategy for EVSE infrastructure is uncertainty related to the EV-readiness level of the buildings and lack of information about what kind of upgrades would need to be made at every building to allow charging[9]. This leads to a very large variance in the expected cost for installation and operation of chargers. Cost differences can be related to the complex layout, as well as the age of the complex and consequently its electrical grid and EV readiness. Furthermore, local constraints such as a need for disabled parking or fire alleys restrict where chargers can be located. In general, the organization of the parking space has a large impact on the solutions that can be implemented. Assigned parking spaces make individual chargers appropriate, while unassigned parking spaces require shared charging facilities.

All of these factors result in considerable variation in the estimated cost of the installation of operational EVSE charging stations. To illustrate this further, the decision tree shown in Figure 7 displays the charging options based on the preferences and decisions of the owners and residents. Considerations for complexes with unassigned parking lots differ from the ones for assigned parking lots. While for assigned parking lots, every unit of the MUD could just get its own connection, similar to practices used in single-family housing, unassigned parking lots would often require the definition of charging zones with shared chargers. Especially for the latter case, multiplex chargers could be of high value. Subsequent sections of this report provide some estimates on the cost of installing the different elements. The following section provides a cost-benefit analysis, which attempts to show under what circumstances different acquisition and installation costs can be justified through lower recurring costs.

Charging Station Options

EV charging stations can be grouped into 3 categories: Level 1 (L1), Level 2 (L2), and DC Fast Charging (DCFC). The categories have increasing power output and thus can charge a vehicle faster. However, there are increasing costs with each category, and certain electrical configurations may be required in order to provide the power to the car. Typically, only

Figure 7. Options for EVSE charging infrastructure in MUDs[10]

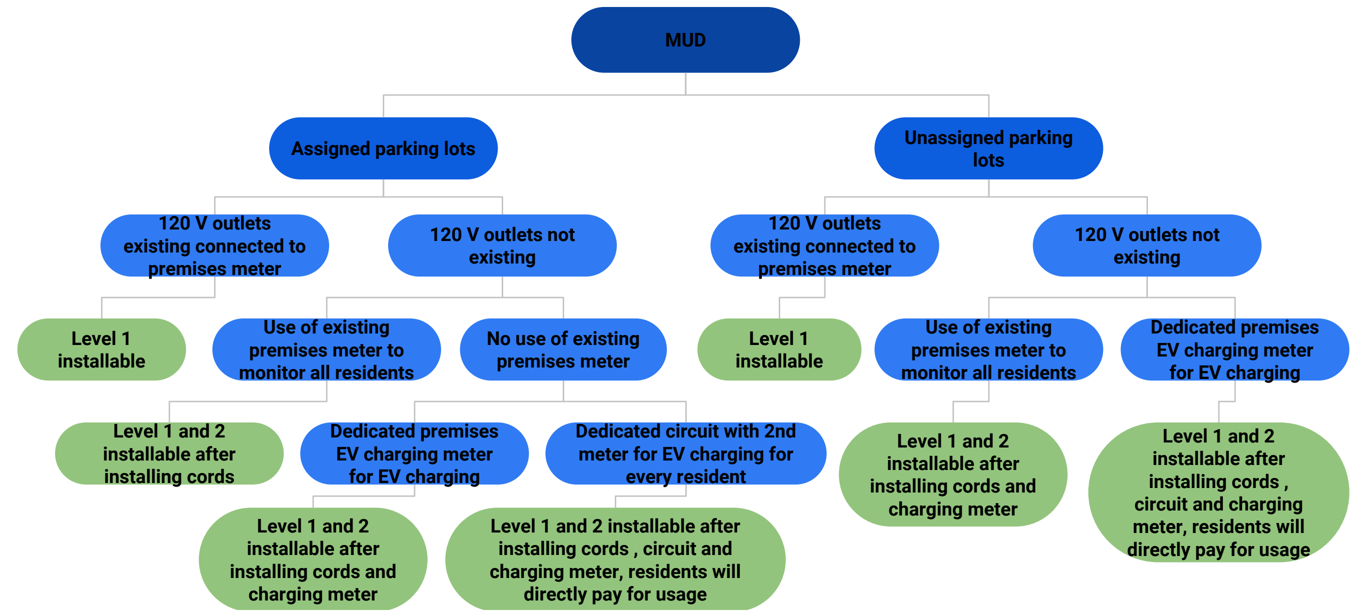


Table 2. Charging level information

Charging Level	Power Supply	Charger Power	Miles of Range for 1 Hour of Charge	Charging Times From Empty to Full* BEV	Charging Times From Empty to Full* PHEV
Level 1	120VAC Single Phase	1.4 kW @ 12 amp (on-board charger)	~3 - 4 miles	~17 Hours	~7 Hours
Level 2	240VAC Single Phase up to 19.2 kW (up to 80 amps)	3.3 kW (on-board)	~8 - 10 miles	~7 Hours	~3 Hours
		6.6 + kW (on-board)	~17 - 20 miles	~3.5 Hours	~1.4 Hours
DC Fast Charge Level 2	200 – 450 VDC up to 90 kW (approximately 200 amp)	45 kW (off-board)	~50 - 60 miles (~80% per 0.5 hr charge)	~30 - 45 Minutes (to ~80%)	~10 Minutes (to ~80%)

Source: California PEV Collaborative (CG3-2)
**SAE "Charging Configurations and Rating Terminology", Society of Automotive Engineers Hybrid Committee, version 031611, 2011*
SAE Assumptions: BEV = 25kWh usable battery; PHEV = 8kWh usable battery; Calculations reviewed and edited by EPRI.
Battery Electric Vehicle (BEV) assumes a 25 kWh usable battery pack size; for purposes of this table SAE data reflect a charging scenario of "empty to full" where charging starts at 20% State of Charge (SOC) and will stop at 100% SOC.
Plug-in Hybrid Electric Vehicle (PHEV) assumes an 8 kWh usable battery pack size; charging starts from 0% SOC since the hybrid mode is available.

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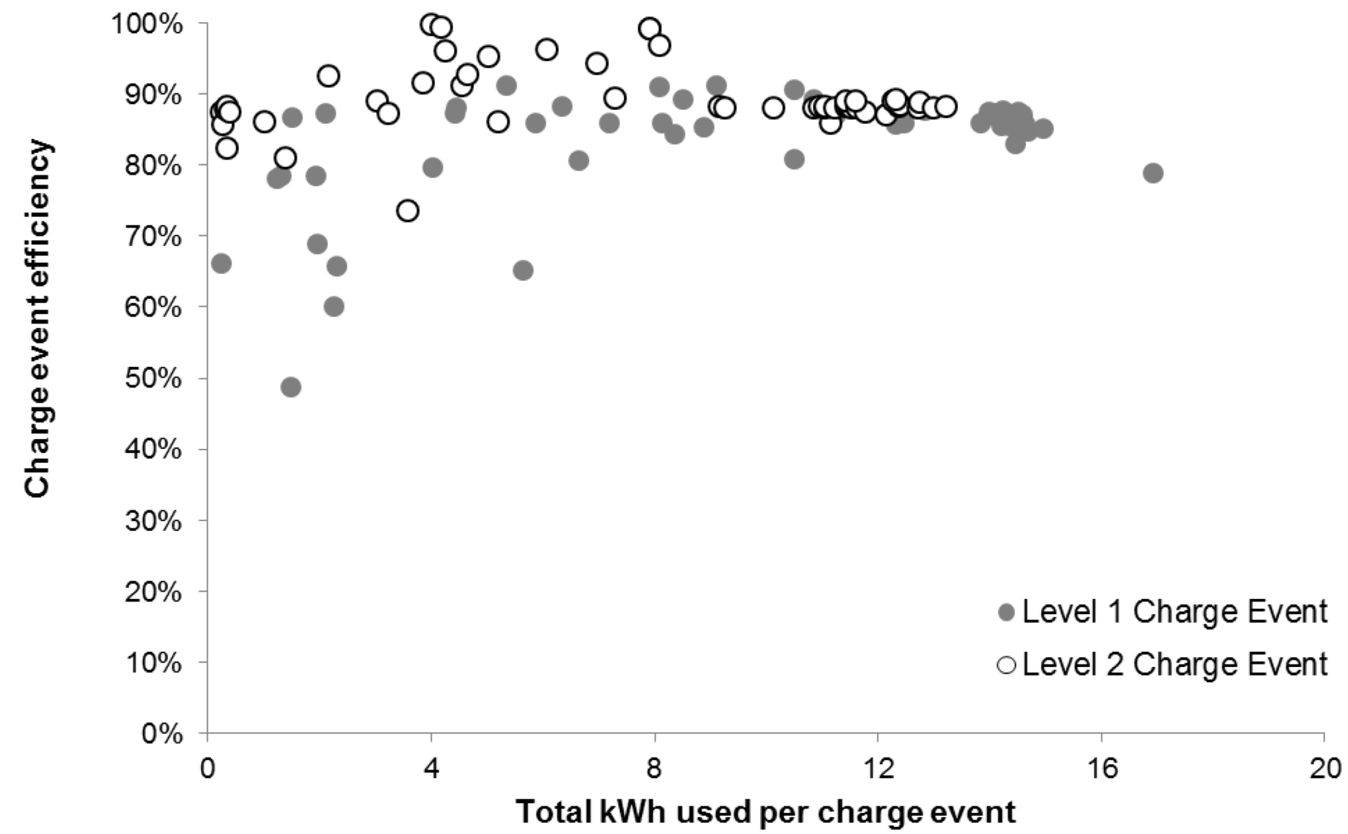
L1 or L2 chargers are suitable for home use due to cost and power requirements. Table 2 displays some relevant information regarding the different chargers. For reference, an L1 charger draws power similar to a toaster, an L2 charger draws about as much power as a clothes dryer, and a DCFC can draw about as much power as an average convenient store consumes.

With an EV purchase, an L1 charger will usually be included. However, it is possible to buy additional L1 chargers, either for convenience or because another may have better performance than the included stock charger. It is also possible to purchase an L2 charger for home use. In addition, a consumer can purchase a portable L2 charging cord, though an L2-capable station is still needed to provide the power. There are several factors that could influence whether a consumer relies on L1 or L2 charging at home. For instance, the additional cost of an L2 charger, capacity and range of the EV, and typical driving needs and behavior could influence the decision to purchase an L2 charger over an L1 charger. There are potentially other factors as well, but further study would be needed to determine exactly what factors significantly contribute to a decision regarding charger choice.

Given that the market share of EVs is still somewhat low, cities still have the ability to guide consumers to make certain decisions about their EV. The following paragraphs discuss the advantages and disadvantages of the two charging levels for home use, and conclude with a recommendation for which charger the City of Tacoma should prioritize incentives.

Several studies have shown that L2 chargers operate more efficiently than L1 chargers. For instance, Sears et al., found L2 6% more efficient than L1 chargers, and also found a 13% higher efficiency for low-energy charging, which they defined as less than 4 kWh[11]. Another study by the Vermont Energy Investment Corporation found an average benefit of an additional 2.7% efficiency with L2 chargers and a 12.8% increase in efficiency for low-energy use, which they defined as less than 2 kWh, as shown in the Figure 8[12].

Figure 8. Levels 1 and 2 charging efficiency[13]



This efficiency difference, coupled with the decreased total charging time, makes L2 charging an attractive choice. However, the decreased charging time with increased power usage causes some concern for balancing the electric grid network. Lower energy consumption spread out over a longer time period would be easier to manage and certainly cause fewer spikes in demand. The spikes in demand would likely become less of an issue as more EVs are purchased in Tacoma, though. In addition, EV technology is improving, and cars are being outfitted with ever-larger batteries, which would mean that the amount of time needed to charge even with a Level 2 charger may go up in the future.

The City of Tacoma needs to find a balance between preparing for the future and optimizing for current conditions. For this reason, it is still recommended to prioritize incentives for those wishing to purchase an Level 2 charger. One way to structure the incentive is to provide a sales tax rebate for the base model of EV purchased, provided an Level 2 charger is also purchased. According to the US Department of Energy, both Level 1 and Level 2 charging are appropriate methods for home-based charging[14]. When it comes to chargers for MUD, prior research generally recommends Level 2 charging since the power output of most of these chargers can be configured to balance the power availability and the number of users. Additionally, the range gained after an overnight charge by a Level 2 charger is adequate for most daily drivers. Due to the higher electricity price, the higher installation cost can be amortized relatively quickly. DCFCs, however, require quite significant investments, high voltage, and other prerequisites that are usually not available in residential construction. Some Level 2 chargers use smart charging cycles to delay the charging periods based on optimized cost to account for different electricity rates depending on the time of the day (discussed in greater depth later in this report). Another option is so-called "multiplex" chargers, which allow charging multiple vehicles in parallel. This option could be of particular interest for MUDs with multiple EV owners[15]. However, the applicability of these charging options is limited by the differences in technical challenges that appear on site. However, if an installation of Level 2 chargers appears to be too costly or inappropriate for the given application, Level 1 charging is the minimum requirement for a widely distributed EVSE infrastructure[16].

Current Incentives

19 out of 50 states in the US have home incentives provided by local governments and utility companies for charging stations including rebates, tax credits, and permit waivers[17]. (Washington is not among that number due to the recent expiration of the state sales tax credit.) Besides different content, these three types of incentives differ as to who provides them, what phase of EV infrastructure they impact, and how feasible they might be for Tacoma.

Rebates are typically provided by utility companies in the form of direct or indirect financial support, usually ranging from $150 to $750. The general design is that citizens sign up with the related power contract, and power companies promise to provide a free L2 charging station or financial aid for the purchase phase or installation phase of EV charging station. For example, Anaheim Public Utilities EV Charger Rebate Program offers up to $500 to EV users who install Level 2 chargers at their homes. But each person is limited to one rebate. Clearview Energy has multiple strategies to encourage people to install a Level 2 charger, including free charging during certain time periods (from 7 PM on Fridays to 7 AM on Mondays) and a $75 rebate for buying charging stations. It could also be possible for power companies to charge a different electricity rate for EV charging, which could form an incentive itself.

Tax credits are typically provided by state governments, and they range from $75 to $1000. Many tax credits expire after a certain time period. For example, Louisiana offered a credit of up to 36% for the purchase and installation cost of a Level 2 charging station – until June 30, 2018. Oklahoma residents are able to get one-time income tax credit for up to 75% of the cost of an electric vehicle charging station, but the credit must be claimed by January 1, 2020.

Most cities require construction permits for the installation of EV charging stations. Waiving the fees for these permits, such as has been done by the city of Anaheim, is another is another low-cost way for city governments to incentivize EV adoption[18]. Given that the State Building Code Council has since 2016 required new multi-family construction to provide EVSE infrastructure for at least five percent of parking spaces[19], this fee waiver would be beneficial.

While Washington State currently offers purchase and leasing tax exemptions ($2,600 - $3,100) for some electric vehicles[20], based on precedent practice, incentives from utility companies are more effective than incentives directly from city or state government. On the one hand, by collaborating with charging station manufacturers and having more customers sign up for a multiyear energy plan, utility companies could see revenue gains. Other than utility companies, with a given of budget, it still needs to be explored whether a city government could cost-effectively reduce sales tax on EV or provide incentive in some other way.

Incentive Options for Different Ownership Scenarios

There are some special considerations for residential homes in Tacoma, specifically in regards to EV adoption and feasibility. Two important situations that require consideration are rental properties and those homes with no dedicated parking.

Tacoma is a city with a high percentage of residential zones[21]. Except the harbors of New Tacoma and the commercial centers in southwest and central Tacoma, most of the districts are residential, and more than 65% of the residential houses are single-family dwellings[22]. As discussed above, charging at home is convenient and inexpensive, and most people might choose to do more than 80% of their EV charging at home[23]. Promoting accessibility of residential charging stations could be a promising direction of encouraging EV adoption.

However, there are different issues for families who rent their house, especially when they wish to install Level 2 chargers. Upgrades or adjustments to the house are often needed. Not being able to make such decisions themselves, renters would need to get permission from the landlord. As most incentives and policies (e.g., discounts in electric charges, installation fee rebate) target property owners, renters have comparatively little help switching to an EV. Only about ¼ of single-family homes in Tacoma are renter-occupied (see Table 4), but this still amounts to about 15,000 homes, a very large group of potential EV adopters[24]. It is therefore important to consider possible solutions for offering incentives to landlords of single-family homes as well as MUDs.

Some states and cities take actions on policy and legislation to these ends. In Colorado a tenant "may install, at the tenant's expense for the tenant's own use, a Level 1 or Level 2 electric vehicle charging system on or in the leased premises." Meanwhile, the landlord "may require reimbursement

Table 3. Comparison of single-family and rental household structures in three states

States	Colorado	Oregon	Washington
EV ownership (up to 2017)	About 11,238	Over 11,910	About 28,000
Percentage of single-family dwellings	70%	69.1%	65%
Percentage of renter-/owner-occupied houses	64.4% owner 35.6% renter	61.4% owner 38.6% renter	74% owner 26% renter

Table 4. Household unit type by tenure

Property Type	Lakewood		Tacoma		County		Washington	
	Owners	Renters	Owners	Renters	Owners	Renters	Owners	Renters
All units	45%	55%	51%	49%	62%	38%	63%	37%
Single Family*	74%	26%	74%	26%	79%	21%	81%	19%
2-4 units	5%	95%	9%	91%	9%	91%	12%	88%
5 or more units	4%	96%	5%	95%	5%	95%	11%	89%
Mobile homes, other	65%	35%	59%	41%	74%	26%	75%	25%
* Detached and attached								

2009-2013 AMERICAN COMMUNITY SURVEY

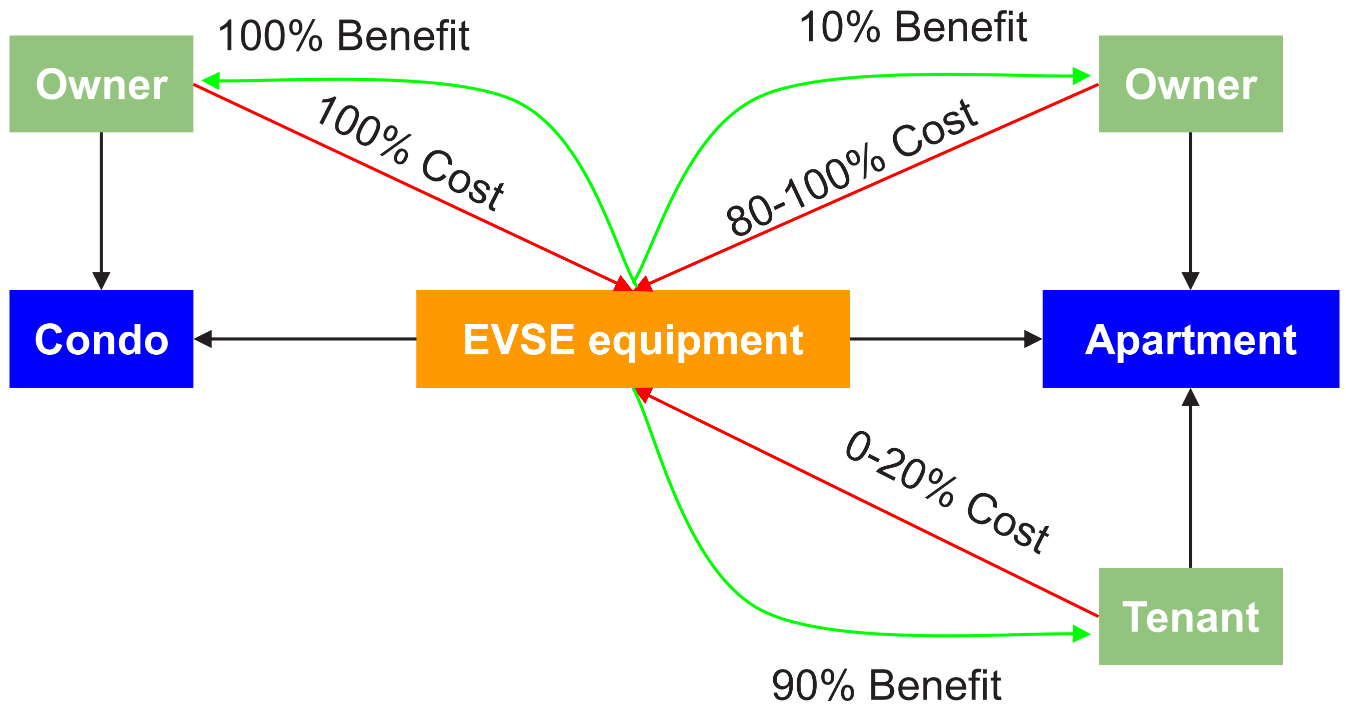
for the actual cost of electricity provided by the landlord that was used by the charging system or, alternatively, may charge a reasonable fee for access." [25] This statute guarantees that renters have the right to install an EV charger if desired, and at the same time protects the economic interest of the landlords from potential loss during the installation process.

Similarly, Oregon gives legislative support to renters who are interested in having access to a home charging station. A tenant "may submit an application to install an electric vehicle charging station for the use of the tenant, employees of the tenant or customers of the tenant...in, or accessible to, any parking space assigned to the tenant or the rental unit of the tenant," and a landlord "may prohibit installation or use of a charging station installed and used in compliance with the requirements of this section only if the premises do not have at least one parking space per rental unit." To protect the landlord, the statute also clearly states, "a charging station installed under this section is deemed to be the personal property of the tenant, and the tenant is responsible for all costs associated with installation and use of the charging station." [26]

Financial incentives present different challenges. Figure 9 illustrates, the cost-benefit split varies significantly between owner-occupied houses or condos and rental units. (HOAs, covenants, and other factors may influence the options and behaviors of condo owners, but for the purposes of this simplified comparison, we treat condos as single-family houses.) While the investment for an installation of EVSE charging at a condo directly delivers its utility back to its investor, this is not the case for rentals, since a tenant normally cannot simply decide to install a new meter, make updates to the panel, and other needed renovations without investment on the side of the landlord. Thus, the main investor behind EVSE installations is the landlord, while the tenant receives the majority of the short-term benefits. The landlord might receive a slightly higher rent or increase the attractiveness of their property. However, the main challenge for governments crafting incentives is to put special emphasis on making the investment attractive to non-residing owners of the complexes.

For Tacoma, targeting rented houses might not be the priority in pursuing EV adoption now, as the lower hanging fruit is the owner-occupied population. However, it might be a future direction, especially given equity concerns.

Figure 9. Expected cost-benefit split for condos and rental apartments



COST-BENEFIT ANALYSIS

It is necessary to consider how many of chargers would be owned by MUDs in the target scenario of 2,000 registered EVs by the year 2020. Given the fact that roughly 30% of the Tacoma housing units are in MUDs, and assuming proportional per capita adoption, 600 of these EVs should be owned by MUD residents if the target should be achieved. According to a study that investigated the US residential charging potential for EVs[27], roughly 38% of households (particularly in urban areas) are basically capable of a charger installation. Considering that this is based on the assumption that around 79% of houses have dedicated parking facilities, and that the spatial map analysis that was presented in the introduction showed that around 95% of all MUDs in Tacoma have dedicated parking available, it is assumed that the EV capability of households can be adjusted as well. This would result in a charging capability rate (EV ready sites) of around 46% of MUDs. If this capability split would also apply to Tacoma and the corresponding MUD residences of to-be EV owners, it could be expected that 276 of the targeted EVs will be owned by residents of EVSE-capable MUDs, while 324 EVs will be owned by residents of currently EVSE-incapable MUDs. The cost-benefit analysis will be based on these numbers (276 and 324) for the total cost estimation.

Charger Cost Estimation

Table 5 gives an overview of the estimated cost of installing equipment to make a site EV-ready, based on average data from HomeAdvisor[28]. It needs to be noted that these are average values that show a large variance due to the variable conditions at each building. Table 6 shows cost estimates for the installation of EVSE infrastructure at EV-ready sites for different charging solutions. These prices were taken from online stores AeroVironment, Inc., and ChargeLab, with permit fees coming from the City of Tacoma[29 30]. In all cases, a local electrician should be consulted to identify a full scope of work depending on the current infrastructure and desired outcome.

Based on the information above, the expected total cost of equipping the selected number of residents with an EVSE infrastructure can be estimated. Table 7 shows the results of the calculations based on the

Table 5. Cost estimates for EVSE installations at non-EV-ready sites

Costs of getting EV ready*				
New Breaker Box	**Labor**	**Permit Fees**	**New Meter**	**Total**
$75	$800	$135	$200	$1,210

*highly variable, depends on site conditions

Table 6. Cost estimates for EVSE installations at EV-ready sites

Installation of Level 2 chargers in EV-ready sites*					
	Material	**Labor**	**Permit Fees**	**Operation**	**Total**
Level 2 (stand alone)	$640	$1,200	$210	Electricity	$2,050
Level 2 (stand alone, smart)	$780	$1,200	$220	Electricity, App	$2,200
Level 2 (2 plugs)	$2,900	$1,200	$350	Electricity	$4,450
Level 2 (2 plugs, smart)	$3,100	$1,200	$350	Electricity, App	$4,650
Level 2 (4 plugs, smart)	$5,700	$1,200	$430	Electricity, App	$7,330

Table 7. EVSE installation cost estimates for 2020 EV target

Action	**No. of units**	**Cost per unit**	**Total cost**
non-EV ready MUDs			
EV-readiness of non-EV ready MUDs	324	$1,210	$392,040
Charger installation (assuming regular, Level 2 chargers)	324	$2,050	$664,200
EV ready MUDs			
Charger installation (assuming regular, Level 2 chargers)	276	$2,050	$565,800
Total cost			**$1,662,040**

assumption that regular level 2 chargers are installed for each vehicle.

As the table shows, the cost to equip MUDs with enough EVSE charging stations to achieve the 2,000 EVs target is roughly $ 1.7 million. Of course, this assumes that residents will acquire EVs if there are chargers. Therefore, this is a best-case scenario. This information will be used to determine the structure of the policy incentives in the following sections.

Owner/Renter Scenarios

To assess how incentives can be applied to achieve the EV targets, we analyzed how the expected benefits of a charger (fuel cost reduction) compare to their cost, and calculate a break-even point. This break-even point is contingent on the individual occupancy situation (condos or single-family households, apartments, owner-renter relationships, etc.). Assuming annual fluctuation of gasoline and energy prices and an annual discount factor of 6%, we looked at four different cases:

Case 1: Condo or single-family household. Owner invests in the installation of one charger for personal use.
Case 2: Mixed Condo / Rental apartments (condo owner owns 5 additional units in the building and rents them out to tenants). Owner invests in multiple chargers and uses one of them.
Case 3: Rental apartments. Landlord invests in a set of chargers (in this case 6 chargers), while not using any of them for personal use and receiving a commission of 20% of the benefits generated through the chargers.
Case 4: Rental apartments. Sharing chargers with case 3 above - 12 renters are sharing 6 installed chargers (2 renters share 1 charger)

For all cases, we assumed the site was charger-ready and therefore required $2,050 to install the charger. We assumed the annual vehicle miles travelled to be 10,230 miles per vehicle[31] and an average fuel efficiency of 33 MPG (the NHTSA fleet standard applied in 2017[32]). Thus, an internal combustion engine (ICE) vehicle requires 310 gallons of fuel on average per year. The total cost was calculated to be $772 per year based in a fuel price of $2.49 / gallon[33]. For EVs it is assumed the same mileage and a fuel economy of 30 kWh / 100 miles (e.g. 34 kWh/ 100 miles for Tesla models S - 90D, 30 kWh/ 100 miles for Nissan Leaf, 32 kWh/ 100 miles for Kia Soul). Thus, the annual energy requirement is 3069 kWh. Based on a price of $0.077/kWh[34] the annual cost is calculated as $236.30, which results in an annual savings of $535.70 per EV. In the graphs for each case (Figure 10-15), net present value (NPV) is plotted along with present value (PV) and future value (FV). The time is takes for the NPV to reach the PV – that is, to reach the break-even point – is the discount payback period (DPP).

For Case 1 (Figure 10), break-even is reached in about five years, a fairly direct Return-On-Investment (ROI). This is a case similar to single-family housing EVSE.

For Case 2 (Figure 11), the break-even is not reached until 20 years after the initial investment. Case 3 assumes that the landlord does not live in the building and receives a commission of 20% of the installation cost, in the form of increased property value and/or rent increases that are possible due to the increased attractiveness of the property. In this case the break-even point also does not occur until around 18 years, as Figure 12 shows.

Since Case 3 assumes assigned parking spaces and therefore that each charger will be used by only one tenant, we looked at an alternative approach (Case 4) for 12 rental units that share 6 chargers. In Case 4, the break-even can be reached within 10 years, as Figure 13 shows. Cases 2 and 3 clearly indicate that the break-even point for rental apartments is difficult to reach under normal market conditions. Thus, if the city of Tacoma aims for making EVSE attractive to rental complexes, there will need to be decisive incentives to motivate landlords to invest. Even after taking into account the possibility of shared chargers, as in Case 4, it is still unlikely that landlords would install EVSE without additional incentives. And as outlined above, these scenarios assume EV-ready buildings; the time until break-even would be even longer for non-EV ready buildings.

In conclusion, to get a benefit through the installation of chargers at MUDs similar to the benefits at single-family households, it is necessary to create a mechanism to collect commissions for the benefit coming from EV chargers, perhaps like that proposed in Case 3, where the landlord collects 20% of benefit generated from the renters using chargers. Moreover, rather than one assigned charger, sharing chargers with other renters, like in Case 4, would enhance the pay-off dynamics and lead to an earlier expected break-even point.

Incentive Options

As the previous cost-benefit analysis shows, in order to make the EV transition as attractive for MUDs as for single-family households, there should be support for MUD owners who would be investing their private funds for the charger installation. Taking into account the previous case analysis, a DPP of 5 years should be targeted if it is aimed at achieving a similar benefit as for Case 1. This section investigates how high the incentives would have to be to achieve this goal for Cases 2, 3, and 4.

For Case 2, the incentive would have to be at least 80% of the upfront cost. Figure 14 shows that an incentive of 50% would still not be enough.

For Case 3, the results are very similar, as shown in Figure 15. Hence, both Case 2 and Case 3 would require an incentive to cover around 80% in order to receive a DDP comparable to what single-family household or condo owners receive.

However, if the commission theoretically increases to 50%, the incentive could be relaxed from 80% to 40% to achieve a DPP of 5 years. With the same commission of 50%, having no incentive still results in a DPP of 8 years(see Figure 15). This shows that collecting a commission fee is more effective than incentivizing the upfront cost of installation of chargers.

A 60% incentive against upfront costs in Case 4 results in a DPP of 4 years, which can also be achieved through changing the commission fee to 50% as Figure 17 shows. It also confirms that commissions are more effective to reach the goal of a shorter DPP than incentivizing the upfront

Figure 10. Case 1, Break-Even (condo), (FV: future value; PV: present value)

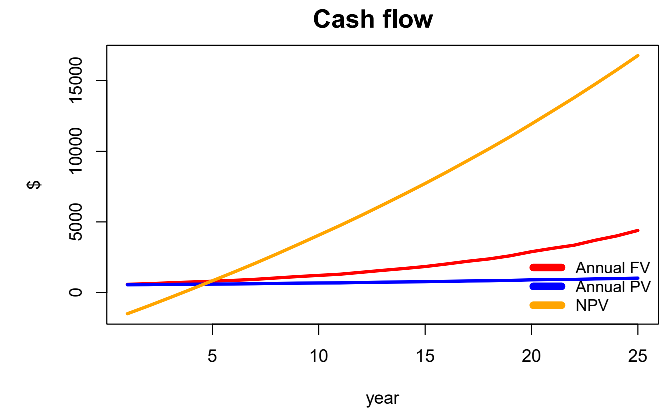


Figure 11. Case 2, Break-Even (mixed condo-rental apartment)

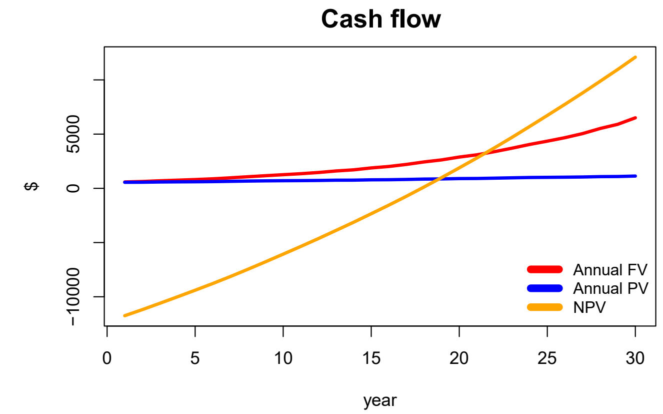


Figure 12. Case 3, Break-Even (rental apartments)

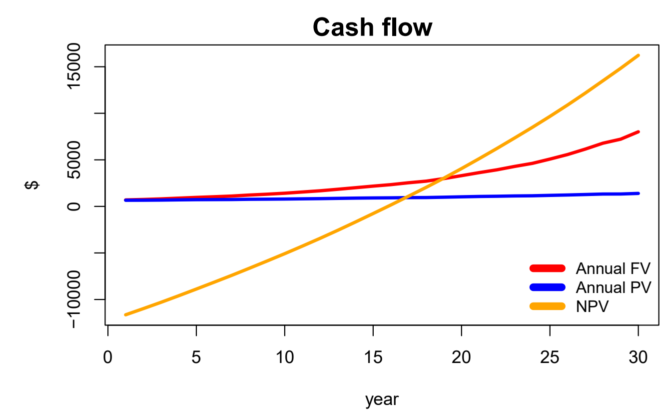
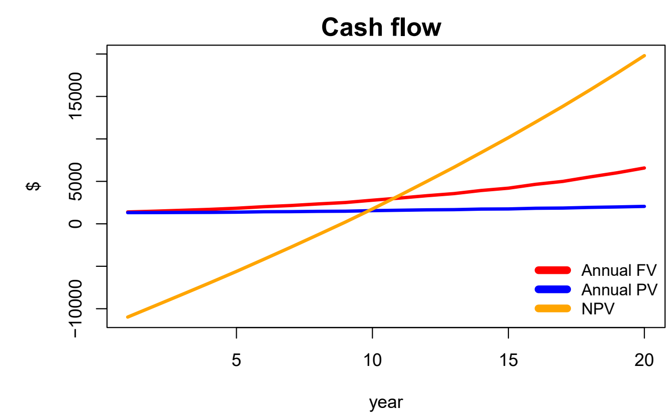


Figure 13. Case 4, Break-Even for Case 3 with shared chargers (rental apartments)



cost. However, it is necessary to take into account that increasing the commission fees will heavily decrease the benefit to the renter of the apartments, which can result in equity issues for lower income groups as this could make switching to an EV infeasible for these groups. Thus, it is not recommended to motivate landlords solely with increased commission fees.

Furthermore, we found that a charger shared by two tenants is as effective as collecting commissions. Increasing the number of users for a given charger can enhance the mechanism for shortening the DPP. By optimizing the utilization rate of chargers depending upon the local conditions, a landlord can reduce the commission rate and still get the same results, thus delivering added value to both the renter and the landlord.

Figure 14. Incentive estimates for Case 2

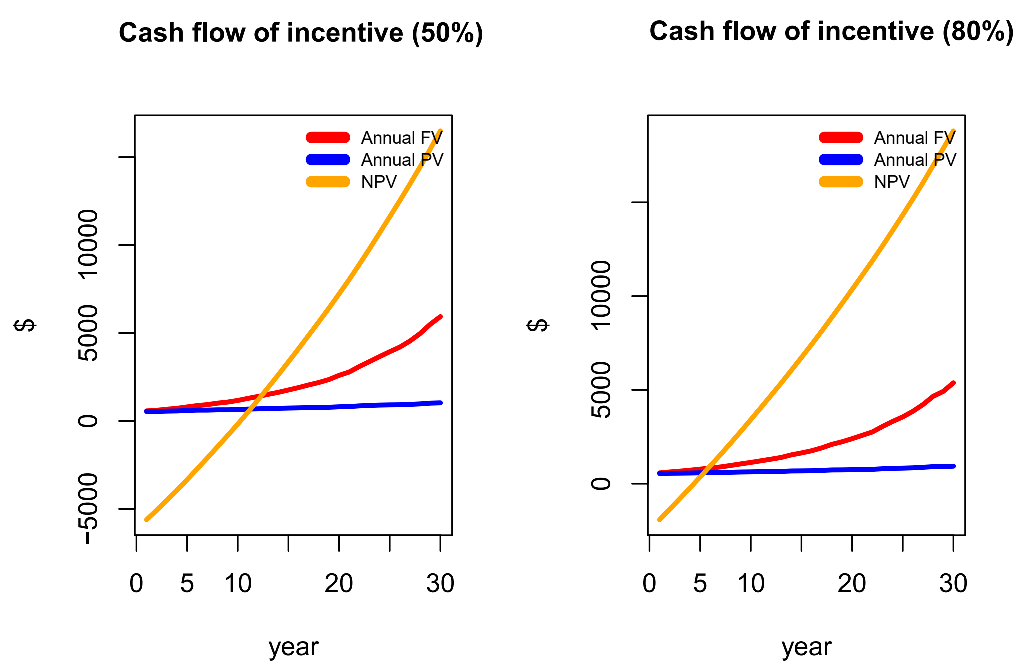


Figure 15. Incentive estimates for Case 3

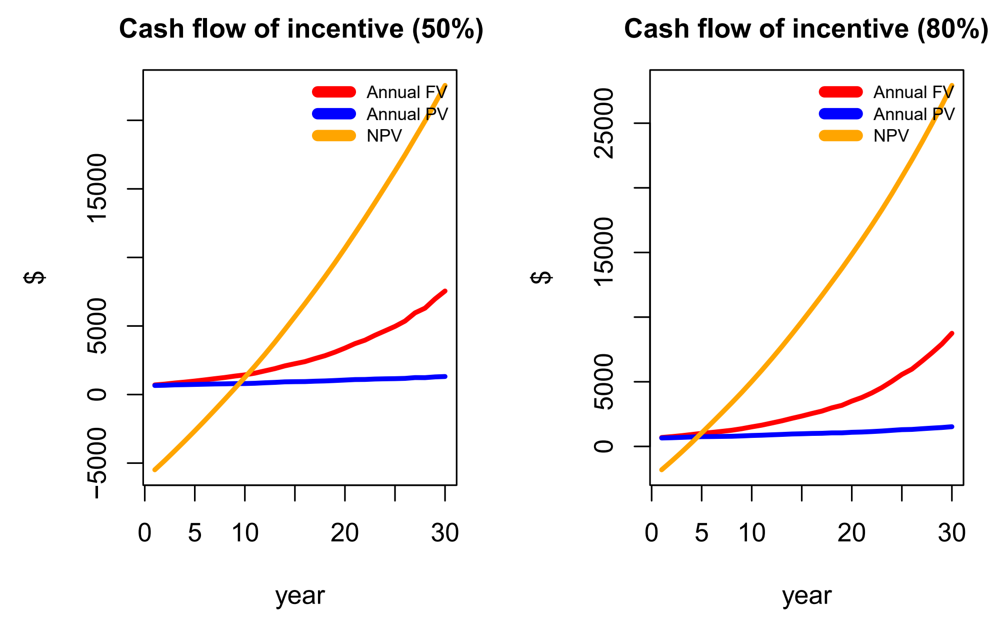


Figure 16. Incentive estimates for Case 3

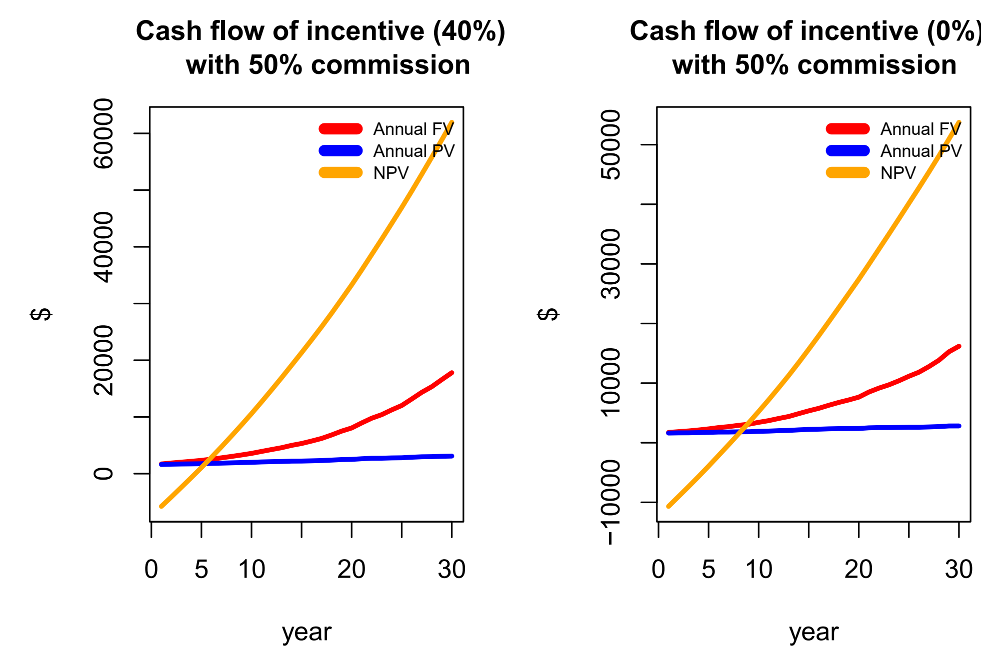


Figure 17. Incentive estimates for Case 4

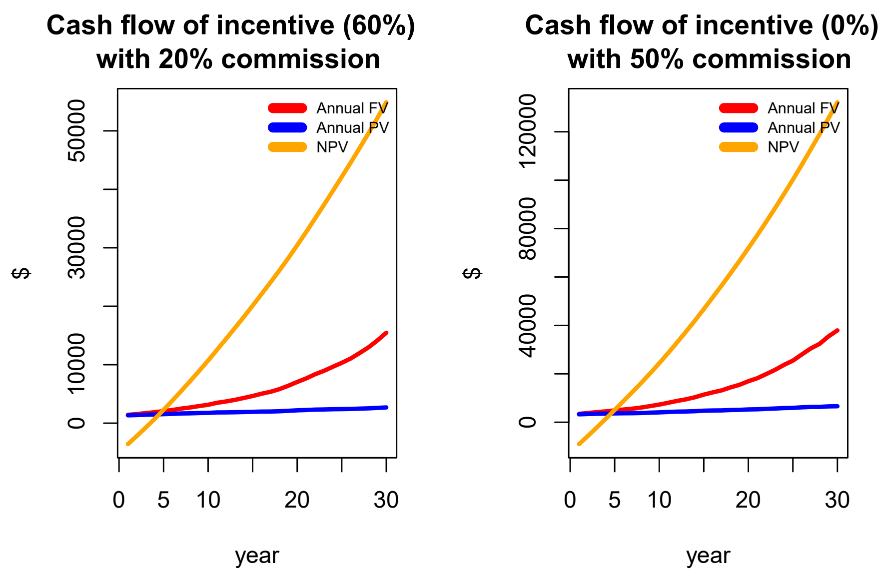


Table 8. Summary of incentives needed for each scenario (DPP targeting 5 years)

Scenario	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Case	Case 2 Mixed condo	Case 3 Rental apartment	Case 3 Rental apartment	Case 4 Rental (sharing charger)	Case 4 Rental (sharing charger)
Commission rate	0%	20%	50%	20%	50%
Rebate rate needed to achieve a DPP of 4 years	>= 80%	Around 80%	Around 40%	Around 60%	0%

POLICY ANALYSIS

Policy Framework

Assuming that the monetary capacity to motivate charger installation is limited, it will be necessary to explore other options and to focus the direction of the incentives that can be granted. As already mentioned, the City of Tacoma aims at finding solutions that achieve their goals most effectively and equitably. Based on which of these two parameters is seen as more important, different policies could be designed. After having shown in the cost-benefit and rebate analyses that similar results can be gained through different approaches, we decided to present two options, one optimizing equity and the other optimizing efficiency. Conditional on the available budget, it could even be possible to combine them into one approach. This approach follows the idea of a fairness model that balances equity and efficiency for policy making. McCoy[35] applied the model to health delivery fleet management, but it could be applied to this case as well. The basic model defines two objective functions (one to maximize efficiency and one to maximize equity) that are applied to a set of capacity constraints. Applied to this case, depending on the parameter **α** >= 0, either the efficiency or effectiveness function would

$$f(x) = \begin{cases} \sum_{i=1}^{n} \beta_i \frac{x_i^{1-x}}{1-\alpha}, & \alpha \neq 1 \\ \sum_{i=1}^{n} \beta_i ln(x_i), & \alpha = 1 \end{cases}$$

$$\begin{aligned} &\text{maximize } f(x) \\ &\quad \text{s.t. } \sum_{i=1}^{n} c_i x_i \leq m \\ &\qquad\quad x_i \geq 0,\ i = 1, 2, ..., n. \end{aligned}$$

be applied with **β** describing the relative utility of installing a charger at unit **x**. Through changing the value of **α**, the balance between efficiency and equity can be controlled. The available budget is determined by the parameter **m** that restricts the cost over all units. **C** represents the cost of installation per case **i**.

The residents of Tacoma MUDs can be separated into two clusters. Households that belong to one cluster (cluster 2) on average have a significantly lower education level, lower income, lower rental rates, and high proportion of unmarried households. Due to these factors, this group is more likely to live in less well-equipped and older buildings, which require larger investments to install EVSEs.

Supporting these residents by subsidizing an update of these buildings to EV readiness would give better access to electric mobility to less privileged groups of people and would therefore be an equitable approach. This could be reached through assigning rebates to specific actions that could be taken to update a house, such as an update of the electric circuits, or the equipment of parking lots with plugs and cables. Thus, incentivizing basic building updates would reduce discrepancies between the buildings and could motivate landlords and condo owners to pursue the last steps, such as the installation of a charger, on their own.

The other cluster (cluster 1) is characterized by higher income levels, higher proportion of families, smaller MUD complex sizes, and a higher proportion of condos. This group is much closer to the typical EV owner characteristics[36] and thus the likelihood for these people to actually invest in the installation of EVSE and the acquisition of an electric vehicle is greater. In addition to this, the residences of higher income groups are more likely to be newer and are therefore more likely to already be EV-ready. Targeting policies and incentives at this group is therefore likely to be the more efficient approach, if the aim is simply to maximize the number of chargers and electric vehicles on the road.

However, a relaxation of the capacity constraint (i.e., assignment of a higher budget) would allow the equity target to be achieved while holding the efficiency at a high level. The following section shows how the effect of the different approaches can be estimated.

Again, we assumed the installation of stand-alone Level 2 chargers ($2,050 installation cost) with a budget limited to 100 chargers (i.e., $205,000). For the eleven MUD block groups that were defined in the cluster analysis for Tacoma, three of them can be considered higher-income cluster (1), while the remaining 8 block groups have the characteristics of cluster (2). To keep this analysis simple, we only consider the ownership structure Cases 1 and 2 from above (i.e., owner-occupied condos and mixed condo/rental). The aim of the analysis is to check how different sociodemographic and ownership structures in MUDs affect the outcome of the selected policy application in terms of efficiency and equity. Each block group was weighted in proportion to its population, assuming that the EVSE demand is proportional to the population as shown in the Figure 18.

Figure 18. Summary of incentives needed for each scenario (DPP targeting 5 years)

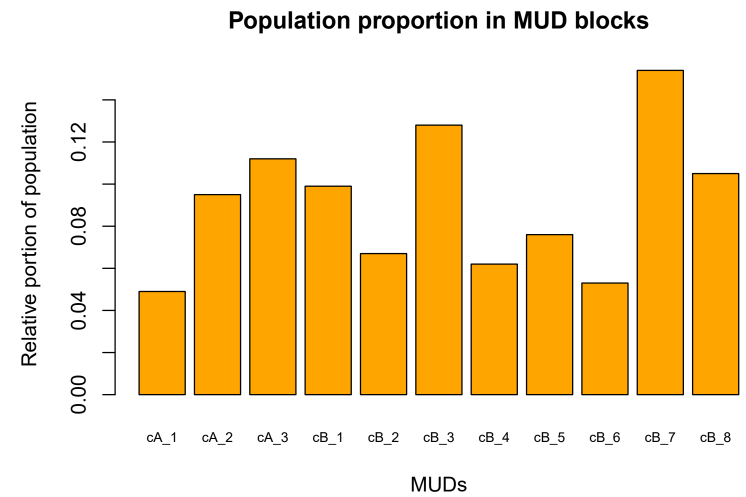
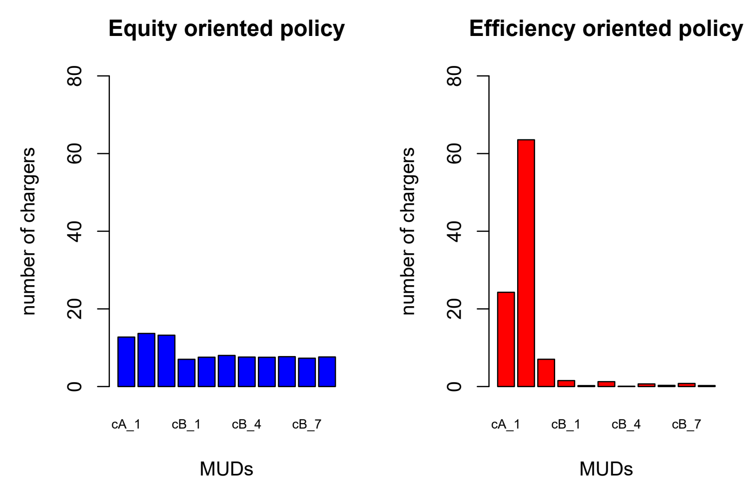


Figure 19. Efficiency and equity-oriented policies for the limited charger allocations given 100 chargers



The efficiency-oriented policy seeks to maximize the benefit by focusing more on efficiency. By concentrating the 100 new chargers in blocks cA_1, cA_2 and cA_3 (all cluster 1), the maximized benefit in terms of saved energy costs turns out to be $446,695 over a 20-year time horizon (left in Figure 19).

Equity and Efficiency Oriented Policies

Taking into consideration the previous analysis, the objective of the equity strategy is to support MUDs through decreasing the financial gap that motivates landlords and condo owners to successfully install EVSE charging. This will reduce the variance in EV readiness levels in between the MUDs in Tacoma. Rental apartments often require more attention than condos when it comes to upgrading to EV-readiness. Therefore, the focus of the equity-oriented approach lies on providing support for basic upgrades to buildings and distributing them across as many complexes as possible, instead of just supporting the installation of chargers for condos and rental apartment complexes. The cost-benefit analysis has shown that rental apartments require between 50% and 80% upfront cost incentives to make the investment as attractive to landlords as it is to condo owners, even if the building is already EV-ready. Since shared chargers can significantly shorten the DPP and decrease a need for commissions, slightly lower rebates, in between 30% and 50%, could be effective.

As Table 9 shows, the objective of the equity strategy focuses mostly on incentivizing rental apartments. The percentages in the table represent the amount of the upfront cost the incentive should cover. This follows the logic of providing higher incentives where low ROI might be preventing landlords from investing.

The objective of the efficiency strategy is to maximize the number of charging stations in the city of Tacoma and thus offer EVSE to as many MUDs as possible at a limited budget. This should be achieved through the installation of smart charging devices at buildings that are well equipped to support these chargers. Since the analysis above showed that rental apartments would require a much higher incentive investment than condos, it is more efficient to focus on condos.

As outlined in Table 10, the incentives focus on motivating the installation of chargers. The idea is that every dollar invested will lead to the installation of a charging station. Since condos already have a projected DPP of less than 6 years, a rebate of 20% should be sufficient. However, to foster the use of smart charging stations these will be incentivized at a rate of 30%.

The cost estimates for each approach are summarized in the tables below. Table 11 illustrates the equity approach, and Table 12 the efficiency approach.

Table 9. Equity-oriented EVSE strategy incentives

Incentive (Rebate)	**Condos**	**Rental Apartments**
Streamlined permit process with fee waivers	X	X
Update to EV readiness • Equipping assigned parking spaces with electricity and plugs • Equipping unassigned parking spaces with electricity and plugs • Installation of dedicated parking space meters	20%	50%
Installation of regular Level 2 charging stations	20%	30%
Optional C-PACE city financed and operated EVSE[37]	•	X
Annual property tax reduction for EVSE installations	-	10%

Table 10. Efficiency-oriented EVSE strategy incentives

Incentive (Rebate)	**Condos**	**Rental Apartments**
Streamlined permit process with fee waivers	X	X
Installation of regular charging stations (cap at $600 per plug)	20%	20%
Installation of smart station (cap at $1000 per plug)	30%	30%
Special electricity fare for EVSE usage	20%	20%

Table 11. Equity policy cost estimates

Action	MUD type	Assigned cost	Rebate	Policy cost	Est. no. of residences*	Total action cost
Upgrade to EV readiness	Apartments	$1,210	50%	$605	275	$166,375
	Condos	$1,210	20%	$242	49	$11,858
Installation of regular level 2 charging stations	Apartments	$2,050	30%	$615	509	$313,035
	Condos	$2,050	20%	$410	91	$37,310
Property tax cut	Apartments	$3,130**	10%	$313	509	$159,297
Total cost					600	**$687,875**

*based on the estimated splits between EV-ready and non-EV-ready buildings and cluster analysis outcomes
**based on an average MUD unit value of $253,000[38] and average property tax of 1.237%[39]

The cost of applying the equity policy can be estimated to around $690,000 ($1,150 per charger installed) and the efficiency policy at $310,000 ($516.67 per charger installed). Optimizing for equity brings a higher cost for the city (in this case 120% higher) to reach the same number of installed chargers. The cost estimates are based on averages and cannot account for uncertainty; while they are suitable as an outlook on the expected costs, they should not be used for direct budget allocations. Based on Tacoma's objectives, the city can decide which approach appears to be the most appropriate for them. In case of a higher budget and an aim to achieve more than 600 new EVs through MUDs, of course both policies can be applied simultaneously or in a two-step approach optimizing for efficiency in a first phase and for equity in a second phase.

FURTHER CONSIDERATIONS

Peak Demand

44 utility companies in America provide discounted rates, rebates or other incentives to increase electric vehicle adoption. Moreover, the time-of-use rates (rate changes depending on a certain time a customer uses electricity) provided by over 200 utility companies across the country serve as a similar incentive and make EV charging more affordable[40].

It is self-evident that the increasing EV adoption has significant social benefits like reducing greenhouse gas emission. From the perspective of utility companies, encouraging EV users to charge at home can also bring direct and indirect benefit for them. In the short run, utility companies may spend some money on upgrading electricity infrastructure if the increasing electricity demand caused by EV charging is overloading the current capacity. But in the long run, the cost of generating electricity will shrink with the increasing share of EV, as the upfront cost for upgrading would have gone.

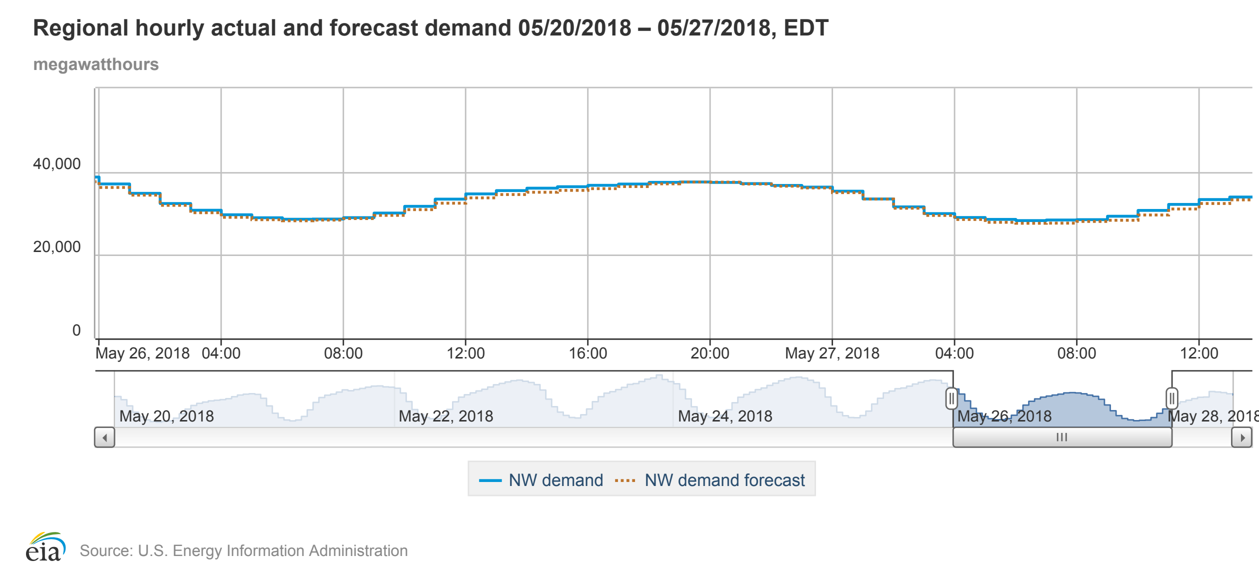
The demand disparity between peak hour and off-peak hour impacts the electricity cost. Encouraging off-peak EV charging not only could make charging at home more affordable but also could reduce the cost of utility generation, transmission, and distribution infrastructure[41].

Table 12. Efficiency policy cost estimates

Action	MUD type	Assigned cost	Rebate	Policy cost	Est. no. of residences*	Total action cost
Installation of regular level 2 charging stations	Apartments	$2,050	20%	$410	305	$125,050
	Condos	$2,050	20%	$410	55	$22,550
Installation of smart level 2 charging stations	Apartments	$2,200	30%	$660	204	$136,640
	Condos	$2,200	30%	$660	36	$23,760
Total cost					600	**$308,000**

*estimated based on the cluster analysis results and on the assumption that 40% will opt for a smart charger

Figure 20. City of Tacoma typical daily electricity demand



US ENERGY INFORMATION ADMINISTRATION

As illustrated in Figure 20, in Tacoma the electricity demand from midnight to early morning is lower than demand during the daytime. This is because citizens fall asleep and turn off many electrical products overnight. To reduce the difference, many utility companies have instituted a time-of-use program (TOU), which gives a lower rate to people who use electricity at night.

Figure 21 shows how electricity demands change with and without a TOU program. The graphic on the right shows the EV charging load with off-peak incentives in San Diego. It is possible that San Diego's program has been too successful – there is a spike in power usage at midnight. But programs like this can be adjusted to shift demand from typical afternoon peaks to other times of days and achieve flatter overall electricity demand.

Based on a series of assumptions (Nissan Leaf 6.6 kW, battery size 30 kWh, Level 2 charger, 4.5 hours, every EV charging once in a day with 2,000 EVs), we estimated the impact on the electricity consumption profile in Tacoma of two scenarios: 1) uniformly distributed charging through a day and 2) only charging from midnight to 6am.

Considering the amount of electricity consumption in the city, adding 2,000 EV to the grid is not particularly significant (Figure 23). On the other hand, if the City were to add 20,000 EVs to the grid, there would be a more dramatic influence on the city's energy consumption profile (Figure 24).

Figure 23. Electricity consumption profile estimation adding 2,000 EVs in Tacoma

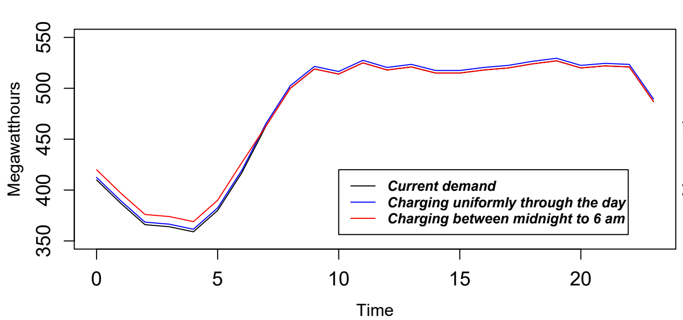


Figure 24. Electricity consumption profile estimation adding 20,000 EVs in Tacoma

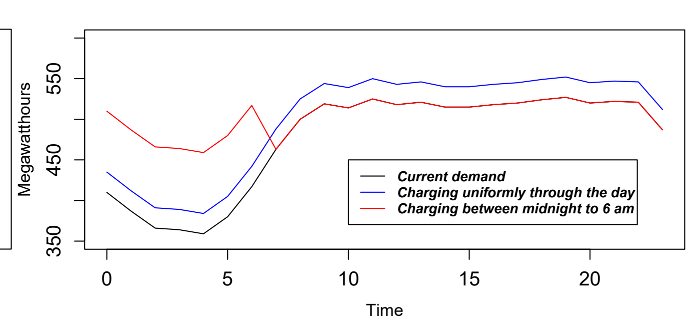
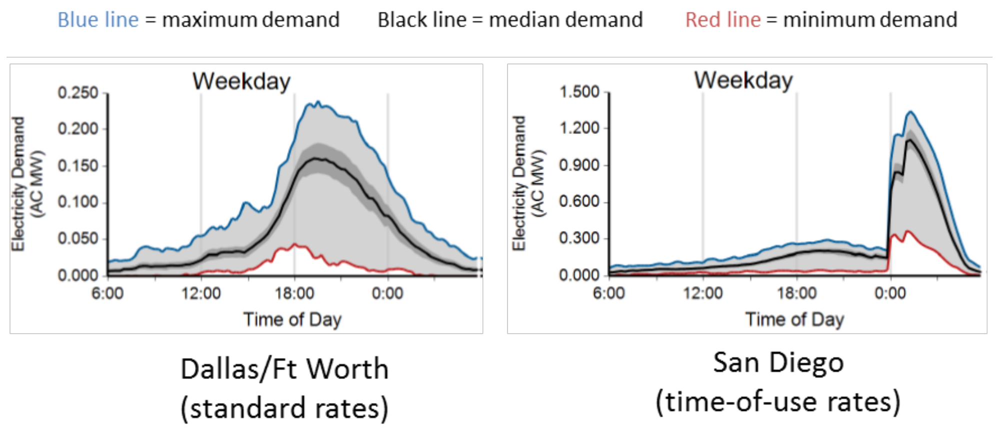


Figure 21. EV charging load in Dallas/Ft Worth and San Diego area



EV PROJECT

Figure 22. Time-of-use strategies from different utility companies

fleetcarma	State	Special EV Rates	TOU For All Customers	Pay for Smart Meter	Separate Meter Required For EV Rate	Higher Monthly Delivery Charges	Weekday Winter Off-Peak Hours	Weekday Summer Off-Peak Hours
ComEd	IL		●				Hourly Pricing	Hourly Pricing
ConEd	NY	●	●		●	●	12am - 8am	12am - 8am
Dominion	VA	●	●		●	●	11pm - 5am / 11am - 5pm	10pm - 10am
DTE	MI	●	●		●	●	7pm - 11am	7pm - 11am
Duke	NC		●			●	12pm - 7am	7pm - 1pm
FP&L	FL		●			●	10pm - 6am / 10am - 6pm	9pm - 12pm
GA Power	GA	●	●				11pm - 7am	11pm - 7am
NES	TN						NA	NA
PG&E	CA	●	●	●*	●*		8pm - 5pm	9pm - 10am
Portland GE	OR		●				10pm - 6am	10pm - 6am
PSE&G	NJ		●			●	9pm - 7am	9pm - 7am
SCE	CA	●	●	●	●		6pm - 12pm	6pm - 12pm
SCL	WA						NA	NA
TXU**	TX		●			●	10pm - 6am	10pm - 6am

* PG&E offers two EV rates, only one of which requires paying for a separate meter.
** TXU offers either free nights or free weekends.

FLEETCARMA

Smart Charging

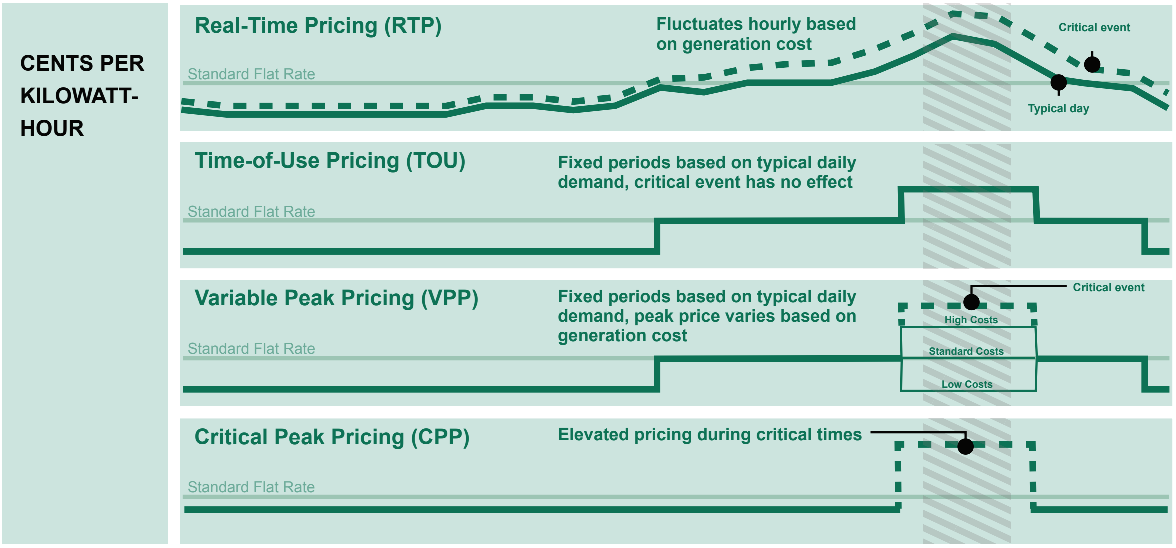
For Tacoma, another problem related to EV adoption is the burden on charging infrastructure and electric utility grids. A major concern is that the local distribution grid may not be sufficient when electric cars are widely adopted, especially when large numbers of EVs charge at the same time[42]. Together with power demand from other household sources, power demand modification and management might be necessary. For EVs, power pricing from the utilities and promotion of smart chargers would be possible options. For the latter, some EV companies such as Nissan Leaf and Chevy Volt have already added the function of delayed or scheduled charging directly into their production, which could be a strong competitive alternative for smart chargers and a future direction for EV products[43].

Utilities could possibly manage customers' demand using price so that more people could be attracted to purchase smart chargers. Offering EV owners discounted rates for charging their vehicles during the night might decrease the power demand in peak hours during the day. Some possible options for electric tariff types are shown in Table 13 and Figure 25. Some studies have explored the relationship between price cut and demand shift. Results show that day-ahead notification and very large price differences, e.g., 400% to 600% times greater during peak hours than off-peak hours, could lead to reduced demand[44 45]. A study in Washington, D.C., indicated that using Critical Peak Pricing (i.e., introducing the new tariff during periods of critical high usage), at a six-times-greater price in peak hour, resulted in a power demand decrease of 9.7%.

Table 13. Electric tariff types in the US[46]

Price regime	Definition	Granularity	Timeliness	Uncertainty	Reflection of generating costs
Flat-rate	Time-invariant rates	None	High	None	Low
Time-of-use (TOU)	Predetermined rates that vary by time of day, day of week, or week of year but do not vary in the short run according to generating costs	Low	High	None	Moderate
Critical peak pricing (CPP)	Flat rates that increase by predetermined amounts for specified lengths of time when generating costs exceed thresholds	Moderate	Moderate	Moderate	Moderate
Variable critical peak pricing (VPP)	Rates that vary during CPP events according to generating costs	Moderate	Moderate	Moderately high	Moderately high
Real-time pricing (RTP)	Rates that vary (typically) hourly to reflect contemporaneous generating costs	High	Low	High	High

Figure 25. Electric tariff types and pricing options[47]



Public Charging Stations

Public electric vehicle charging infrastructure is a critical component of promoting and increasing electric vehicle adoption rates. Washington State set an aggressive goal to meet 50,000 registered EVs by 2020. While the state is progressive and forward-thinking with policy and legislation, the bulk of the responsibility in attaining this goal rests with municipalities. Local jurisdictions face a challenging and complex set of problems, barriers, and information gaps in trying to realize and implement an electric vehicle and infrastructure development plan. But these same obstacles contain opportunities for local governments to influence change and promote adoption and investment in EVs. The City of Tacoma and its partners will have the benefit of over a decade of lessons learned and best practices from dozens of other regions, municipalities, and governments to pull from in the development of their own strategy. This section of the report aims to guide the public infrastructure element of the LCY 2018 project and sift through the common best practices to devise a strategy for Tacoma and its partners. Additionally, we used current vehicle registration data and PSRC household survey data to project future EV penetration and trips at the ZIP code level in Tacoma. Drawing on zoning analysis at the parcel level within each ZIP code, we propose specific charging infrastructure locations to best meet future demand. The overall goal is to provide Tacoma with predetermined candidate locations that the City and its partners can invest EVSE in when funding is made available.

Devising a development plan and strategy for public EV infrastructure is not a novel concept in 2018. Many regions, governments, and local jurisdictions have taken up this effort and positively influenced adoption and investment. To use the terms of Everett Rogers's diffusion of innovation theory, we are past the innovators and well on our way into the early adopters. However, behavior of electric vehicle owners has not changed significantly. Research indicates that over 80% of electric vehicle (EV) charging takes place at home[48]. The US Department of Energy's National Plug-In Electric Vehicle Infrastructure Analysis (2017)[49] assumes that this charging behavior will not significantly change through 2030 and uses 88% home charging in its models. This leaves 12% of EV charging to take place outside the home. The availability of public EV charging infrastructure is linked to EV adoption rates. When surveyed in 2017 by the National Renewable Energy Laboratory, the public perceived a low availability of vehicle chargers and listed this as a barrier to adoption[50]. The presence of public charging infrastructure gives drivers the confidence that they can charge when needed, increases consumer awareness of electric vehicles, and helps to mainstream EVs in consumers' minds as a viable transportation option[51]. Across the U.S., cities with the highest EV market share have four times as many public charging stations as other cities[52].

> Across the US, cities with the highest EV market share have four times as many public charging stations than other cities.

OBJECTIVES AND TASKS

The objectives for the public infrastructure aspect of this project were twofold: identify where EV charging infrastructure should be located within the City of Tacoma, and identify the types of investments in EV charging infrastructure that should be prioritized at the local level in order to encourage further adoption of EVs and EVSE development.

To meet these project objectives, the public infrastructure team was charged with two overarching tasks: develop a strategy to meet the project objectives and identify the impacts of the proposed strategy. While intentionally broad in scope, the project tasks allowed for generous leeway in the development of a strategy to meet the City of Tacoma's objectives.

METHODOLOGY OVERVIEW

Selecting the charging stations in Tacoma can prove challenging due to the wide range and variation of economic, population, and transportation infrastructure variables. In order to make the site selection problem more practical and feasible, we divided the City of Tacoma into nine zones based on the assigned postal ZIP codes. Using the nine ZIP code zones, we selected sites through the process summarized below in Figure 26. For each ZIP code, we estimated the number of vehicles per day needing to be charged at public infrastructure based on the 2015 Household Survey Data[53] gathered by PSRC. Additionally, we estimated the capacity of current public charging infrastructure for each ZIP code. The difference between demand and current capacity is regarded as the EV charging demand. Finally, we used GIS analysis to find the best sites for new stations based on spatial criteria explained more below.

DEMAND ESTIMATION

We used PSRC 2015 Household Survey Data (HSD to estimate the number of trips into Tacoma for each ZIP code. It should be noted that trips with home, workplace, or temporary activity related purposes were omitted since we assumed these travelers would not use the public charging infrastructure. The 2015 HSD sampled 2,419 households, so we use this data to calculate and predict the total trip numbers by mapping the survey household number to whole household number.

Based on current registered automobile numbers and the growth rate of Washington State[54] automobile registrations, as well as WSDOT's goal of 50,000 EVs by 2020[55], the EV penetration rate for the year 2020 would be 1.63% of the total number of vehicles in Washington. Based on WSDOT's report of the West Coast Green Highway[56], there were 27,858 registered EVs in Washington by the end of 2017, indicating a current EV penetration rate of 0.95%. In that report, EV penetration is assumed to grow linearly and is calculated as 0.23% per year. In order to make the calculation simpler and account for the potential additional EV ownership stimulated by EV friendly policies of Tacoma and the state, in our analysis we assume an EV penetration rate of 2% by 2020 with a growth rate of 0.25 % per year. The EV penetration by 2025 and 2030 then winds up being 3% and 4% respectively. Note that this number could vary considerably but is probably conservative, given that EVs are becoming more and more popular.

Figure 26. Charging station site selection method

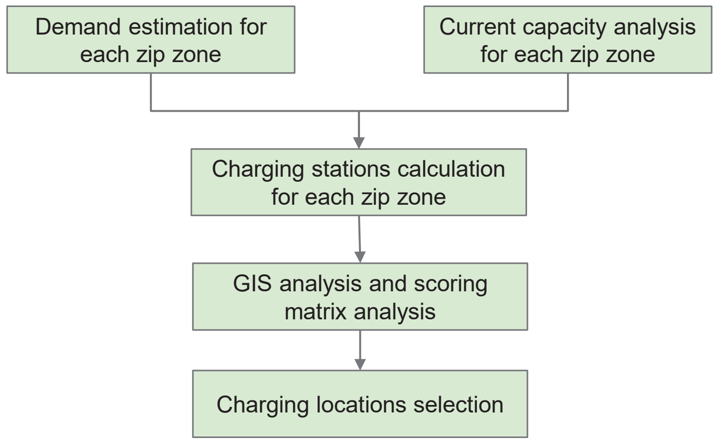


Table 14. Range of EVs needing to be charged per day

Year	2020		2025		2030	
Bound	lower	upper	lower	upper	lower	upper
98402	66	197	104	278	145	362
98403	46	137	72	193	101	252
98404	43	128	68	181	95	236
98405	197	591	313	834	495	1087
98406	141	424	224	598	312	780
98407	86	257	136	362	189	473
98408	98	295	156	417	217	544
98409	234	702	372	991	517	1292
98416	13	39	20	5	28	71
98418	3	9	5	12	7	16
98421	24	73	39	103	54	134
98422	16	47	25	66	35	87
98443	7	21	11	30	16	39
98444	3	9	5	12	6	16
98445	56	167	88	236	123	307
98446	3	9	5	12	6	16
98447	6	17	9	24	13	32
98465	3	9	5	12	6	16
98466	41	124	66	175	91	229

Based on the above assumptions and pre-calculations, the upper bound and lower bound of the EVs needing to be charged per day for each ZIP code is shown in Table 14.

Because analyzing all three years is time consuming and the analysis process is the same for each year, we use only 2020 as an example in the following analysis. The assumed EV penetration rate is 2% and public charging rate 15%. The EVs requiring public charging according to this scenario are summarized in the Table 15.

CURRENT CAPACITY

To optimize the new infrastructure to be installed, there needs to be a rigorous comparison between the current capacity of the existing infrastructure and the demand. This would lead to a better network of EVSE and a far more efficient charging grid structure as well as minimization of the costs being incurred. The first step therefore, is to gather data pertaining to the existing EVSE options in the City of Tacoma. However, in order to estimate the current capacity and demand, as well as analyzing the gap between them, we need to take into account the charging specifications of different levels of EVSE[57]. Additionally, insight is required into the amount of battery approximately charged in a given EV model in a specified amount of time to fully understand the demand problem.

Table 16 shows the number of hours required to charge a battery of different EV models completely for a particular EVSE level and type of EVSE charger. Using this information about the charging time of different levels of EVSE is determined for a range of EVs, it is possible to estimate the current capacity of existing infrastructure in each ZIP code.

For the ease of analysis, only the ZIP codes completely within the City of Tacoma are listed in Table 17 and depicted in Figure 27. The color shading in the map below illustrates the intensity of EV trips per day into the given ZIP code. This data is useful in formulating the demand particular to a given ZIP code and subsequently in determining the required EVSE infrastructure. Again, because this part of the analysis focuses on public charging, we excluded work and home-based trips.

The analysis also assumes that influx trips consisted of a round trip commute of about 20 miles. This 20-mile commute amounts to approximately one-fourth of a fully charged average EV battery. An

Table 15. EVs to be charged per day in 2020

Zip	98402	98403	98404	98405	98406	98407	98408	98409	98416	98418
No.	98	68	64	295	212	128	148	351	19	4
Zip	98421	98422	98443	98444	98445	98446	98447	98465	98466	
No.	36	24	11	4	83	4	9	4	62	

Table 16. Charging attributes for different EVs

MODEL	Rate (KW)	kWh	Level 1	Level 1	Level 2	Level 2	Level 2	Level 2	Level 2	Level 2	Level 2
BMW Active E	7	32	23	23	8.5	6.5	5.5	4.5	4.5	4.5	4.5
BMW i3 2014-2016	7.4	23	16.5	16.5	6	5	4	3	3	3	3
BMW i3 2017 60Ah Battery	7.4	23	16.5	16.5	6	5	4	3	3	3	3
BMW i3 2017 90Ah Battery	7.4	32	23	23	8.5	6.5	5.5	4.5	4.5	4.5	4.5
Chevy Bolt	7.2	60	43	43	16	12.5	10.5	8.5	8.5	8.5	8.5
Chevy Spark	3.3	23	16.5	16.5	7	7	7	7	7	7	7
Coda	6.6	31	22	22	8	6.5	5.5	4.5	4.5	4.5	4.5
Fiat 500E	6.6	24	17	17	6.5	5	4	3.5	3.5	3.5	3.5
Ford Focus EV	6.6	23	16.5	16.5	6	5	4	3.5	3.5	3.5	3.5
Ford Focus EV 2017	6.6	33.5	24	24	9	7	6	5	5	5	5
Honda Clarity EV	6.6	25.5	18	18	6.5	5.5	4.5	4	4	4	4
Hyundai Ioniq	6.6	28	20	20	7.5	6	5	4	4	4	4
Kia Soul	6.6	27	19.5	19.5	7	5.5	4.5	4	4	4	4
Jaguar i-Pace	7	90	64.5	64.5	23.5	19	15.5	13	13	13	13
Mercedes B-Class B250e	9.6	28	20	20	7.5	6	5	3.5	3	3	3
Mitsubishi i-Mi EV	3.3	16	11.5	11.5	5	5	5	5	5	5	5
Nissan Leaf 2011-12	3.3	24	17	17	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Nissan Leaf 2013-16 S	3.3	24	17	17	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Nissan Leaf S 2013-15	6.6	24	17	17	6.5	5	4	3.5	3.5	3.5	3.5
Nissan Leaf S 2016	6.6	24	17	17	6.5	5	4	3.5	3.5	3.5	3.5
Nissan Leaf S 2016	6.6	30	21.5	21.5	8	6.5	5	4.5	4.5	4.5	4.5
Nissan Leaf 2017	3.3	30	21.5	21.5	9	9	9	9	9	9	9
Nissan Leaf 2017	6.6	30	21.5	21.5	8	6.5	5	4.5	4.5	4.5	4.5
Nissan Leaf 2018	6.6	40	28.5	28.5	10.5	8.5	7	6	6	6	6
Smart Car	3.3	17.6	12.5	12.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
Smart Fortwo ED 2017	7.2	17.6	12.5	12.5	4.5	3.5	3	2.5	2.5	2.5	2.5
Tesla Model 3 Standard	7.7	50	35.5	35.5	13	10.5	8.5	6.5	6.5	6.5	6.5
Tesla Model 3 Long Range	11.5	70	50	50	18.5	14.5	12	9	7.5	6	6
Tesla Model S 60 Single	9.6	60	43	43	16	12.5	10.5	8	6.5	6.5	6.5
Tesla Model S 70 Single	9.6	70	50	50	18.5	14.5	12	9	7.5	7.5	7.5
Tesla Model S 85 Single	9.6	85	60.5	60.5	22.5	17.5	14.5	11	9	9	9
Tesla Model S 90 Single	9.6	90	64.5	64.5	23.5	19	15.5	11.5	9.5	9.5	9.5
Tesla Model S 60 Dual	19.2	60	43	43	16	12.5	10.5	8	6.5	5	4
Tesla Model S 70 Dual	19.2	70	50	50	18.5	14.5	12	9	7.5	6	4.5
Tesla Model S 85 Dual	19.2	85	60.5	60.5	22.5	17.5	14.5	11	9	7.5	5.5
Tesla Model S 90 Dual	19.2	90	64.5	64.5	23.5	19	15.5	11.5	9.5	8	8

additional assumption for analysis was that the average dwell time for a trip was roughly two hours at public places; hence, one-fourth of the calculated infrastructural difference is actually required to meet all the demands. This would reduce the projected difference in the current capacity of existing infrastructure and the demand to one-fourth of the calculated values. Table 19 depicts the number of EVSE plugs needed to meet the demand gap in each ZIP code.

Figure 27. Influx of EVs per day in different ZIP codes

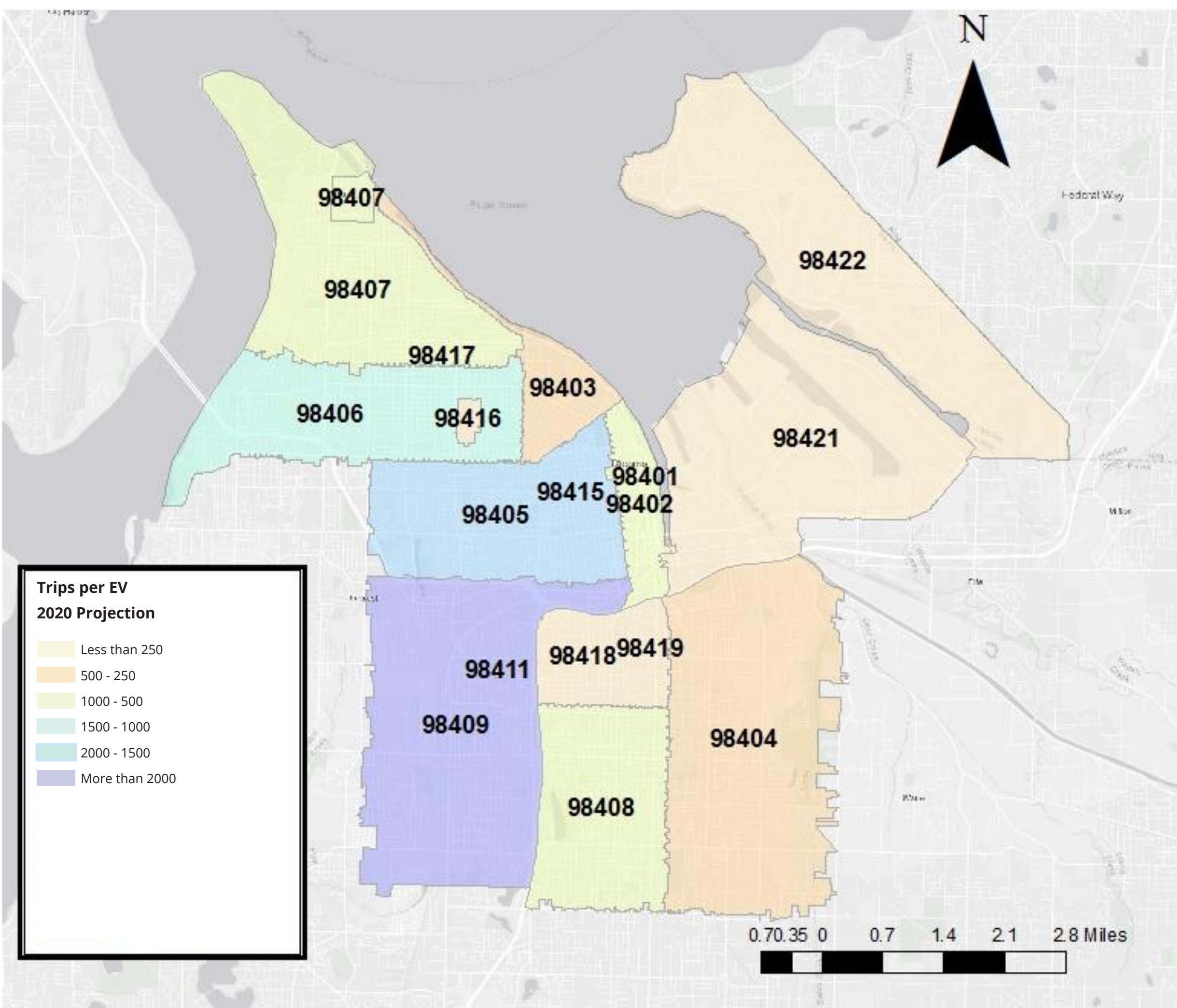


Table 17. Capacity of current infrastructure per ZIP code

Zip Code	Number of charging Plugs			Estimated number of vehicles that can be charged every day
	Level 1 (24 Hrs)	Level 2(8 Hrs)	DCFC(30 Mins)	
98402	0	19	0	29
98421	0	11	0	16
98403	1	3	0	5
98409	7	10	6	162
98405	1	2	0	4
98407	2	5	0	9
98408	0	1	0	2
98406	0	2	0	3
98416	0	0	0	0
98418	0	0	0	0
98422	0	0	0	0
98404	0	0	0	0

Table 18. Upper and lower limits of EVSE infrastructure needed per charging level per ZIP code

Zip Code	vehicles that can be charged	Demand	Plugs Required	Level 2	DCFC
98402	29	99	70	47	3
98421	16	37	21	14	1
98403	5	69	64	43	3
98409	162	351	189	126	8
98405	4	296	292	195	12
98407	9	129	120	80	5
98408	2	148	146	98	6
98406	3	212	209	140	9
98416	0	20	20	14	1
98418	0	5	5	4	1
98422	0	24	24	16	1
98404	0	64	64	43	3

Table 19. Additional EVSE needed per charging level per ZIP code

Zip Code	Level 2 Plugs	DCFC Plugs
98402	12	3
98444	Not in Land Use Area	
98421	4	1
98403	11	3
98409	32	8
98405	49	12
98407	20	5
98408	25	6
98406	35	9
98416	4	1
98418	1	1
98422	4	1
98404	11	3

LOCATION EVALUATION

One of the main objectives of this study is to determine suitable locations in the Tacoma urban area for the installation of future public electric vehicle charging stations. Based on analysis, the optimal locations for public infrastructure should target one of the three types of potential users using the corresponding criteria:

- Corridor Users, by evaluating closeness to highway
- Commuters, by considering the location of the existing park-and-ride facilities
- Opportunity trips, by considering the location of commercial centers, hospitals, grocery stores, government buildings, schools, and parks

Public charging infrastructure must be easily accessible, support adequate electric power, and have existing parking availability[58]. In our analysis we considered the location and concentration of commercial and governmental parcels; the proximity of highways; location of park-and-rides; and existence of parking infrastructure. Because the information was not available, we did not assess available electrical grid coverage. If this information becomes available, future studies could include suitability analyses for different levels of charging.

Our location evaluation consists of two components, a Suitability Analysis and a Scoring Matrix. The Suitability Analysis is a GIS-based process that results in suitability score indicating the best locations for EV charging infrastructure based on four criteria: distance to highways, distance to existing EV charging stations, density of existing EV charging stations, and commercial density. The Scoring Matrix helps to quantify a recommendation for specific EV charging technology (Level 2 or DCFC) based on detailed characteristics of the candidate site. Both the Suitability Analysis and Scoring Matrix are described below.

SUITABILITY ANALYSIS

In order to capture street-level data, we used 30ftx30ft cells as our unit of analysis. We considered these key factors in the evaluation of EVSE location:

- **Commercial and governmental parcel density:** Captures the level of attractiveness of the area to non-work and non-home related trips.

Figure 28. Raster calculation process

Proximity to EVSE	Density of EVSE	Commercial and governmental density	Closeness to highway
• Raster based on Euclidean distance • Reclassify by distance threshold	• Raster based on kernel density • No. of stations per EVSE considered • Reclassify by ½ SD	• Parcel subset • Raster based on point density • Parcel size is considered • Reclassify by ½ SD	• Create street network • Service area for 0.5 miles for joints with the highway • Service area polygon to raster • Reclassify by ½ SD

- **Proximity to highway:** Captures the area located 0.5 miles[59] driving distance from a highway exit.
- **Proximity and density to EV charging stations:** This helps us identify areas that are currently not well served.

More information about the source data and the steps taken in the analysis is available in Appendix II.

In the final step, we used the overlay method to calculate a "Suitability Score" using this formula:

Suitability score = (0.55 * Commercial Density) + (0.15 * Proximity to EVs) + (0.15 * Density of EVs) + (0.10 * Closeness to Highway)

The weights assigned to each of the four layers were chosen based on previous research on the location of EV infrastructure[60]. Figure 29 shows the result of the weight overlay calculation. The results of the Suitability Score were reclassified based on percentiles to obtain seven categories ranging from 1 (lowest suitability) to 7 (highest suitability).

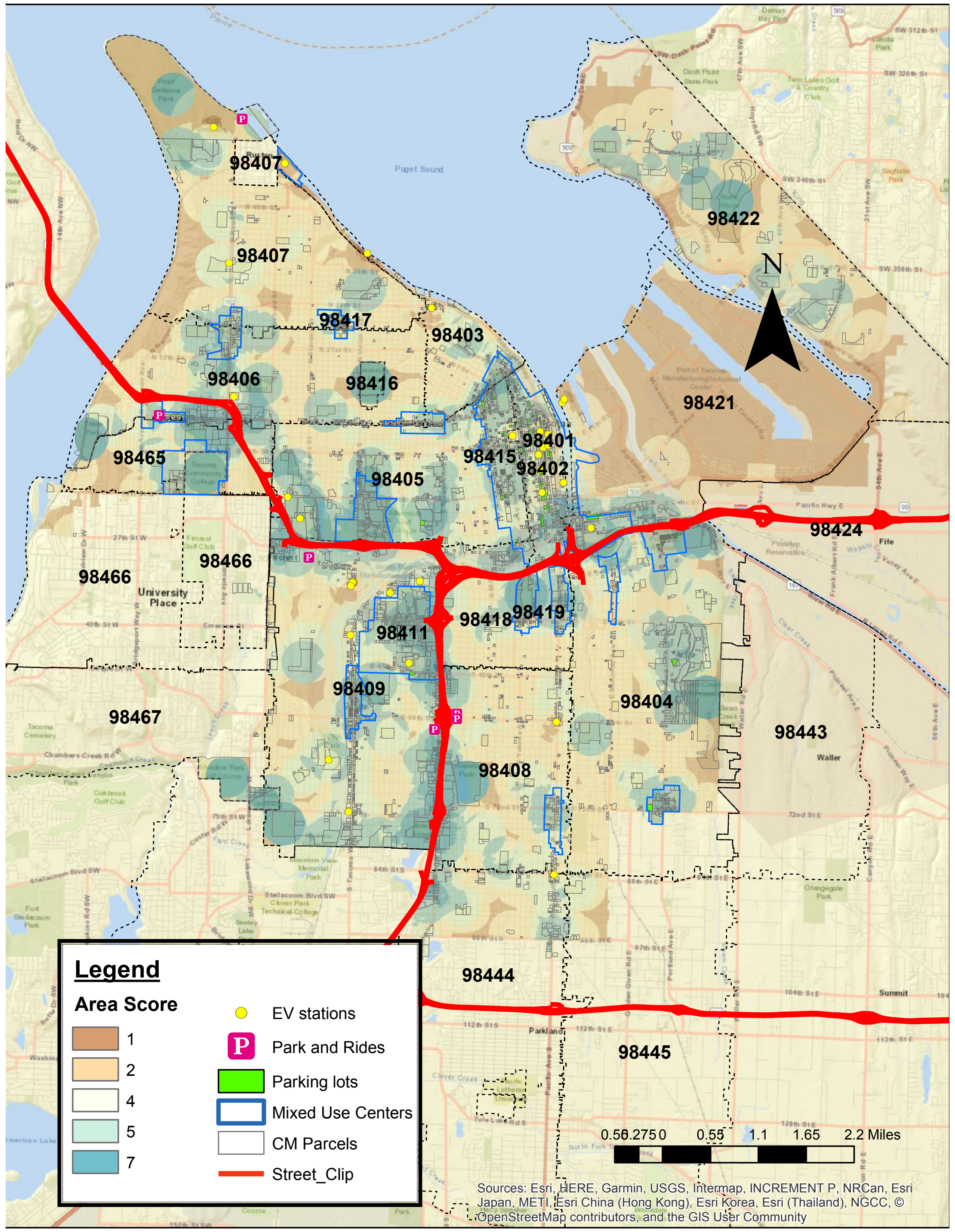
SCORING MATRIX

We then used a scoring matrix to help quantify and prioritize candidate sites. The tool aims to balance commercial with public locations and commuter with corridor locations. The scoring tool has a total cumulative point value of 60, with higher scores gaining a higher level of recommendation. Scores ranging from 44 to 60 earn a "highly recommended" rating. Scores between 30 and 44 earn a "recommended" rating, whereas scores below 30 are rated "not recommended."

The scoring matrix considers five criteria: venue, parking, dwell time, power infrastructure, and proximity[61]. Scores for venue are based on volume of anticipated users (or customers in the case of commercial) and trip duration (for example, mixed-use centers receive a high score of 10 for their high customer traffic and longer anticipated stays). Scores for venue are penalized for shorter anticipated stays and fewer users. The objective is to increase potential for EV charging by targeting locations with lots of users who stay long enough for charging to be an option.

The parking criterion accounts for the different parking arrangements at a venue. These are surface lots, parking garages, curbside / street parking, and a combination of the previous. Scores for parking are based on notional cost and ease of installation based on findings from the California Public EVSE Installation Lessons Learned Report (2011)[62], as well as other case studies found in the literature. Higher scores are given to cheaper and easier parking arrangements for EVSE installation. Scores for dwell time are based on the charging pyramid found in AFDC Charger Selection Guide (2018)[63], as well as the amount of time required to charge to ½ charge per the Ready, Set, Charge California Guide to EV-Ready Communities (2011)[64]. A dwell time of less than one hour for public charging is best met with a DCFC charger, for example, while dwell times of more than an hour can be served by Level 2 chargers. For this analysis, only L2 and DCFC will be considered suitable for public EVSE infrastructure. (For long dwell times (in excess of four hours), which are most likely at home, at the workplace, or long-term parking scenarios, Level 1 chargers are adequate.)

Figure 29. Suitability spatial analysis results



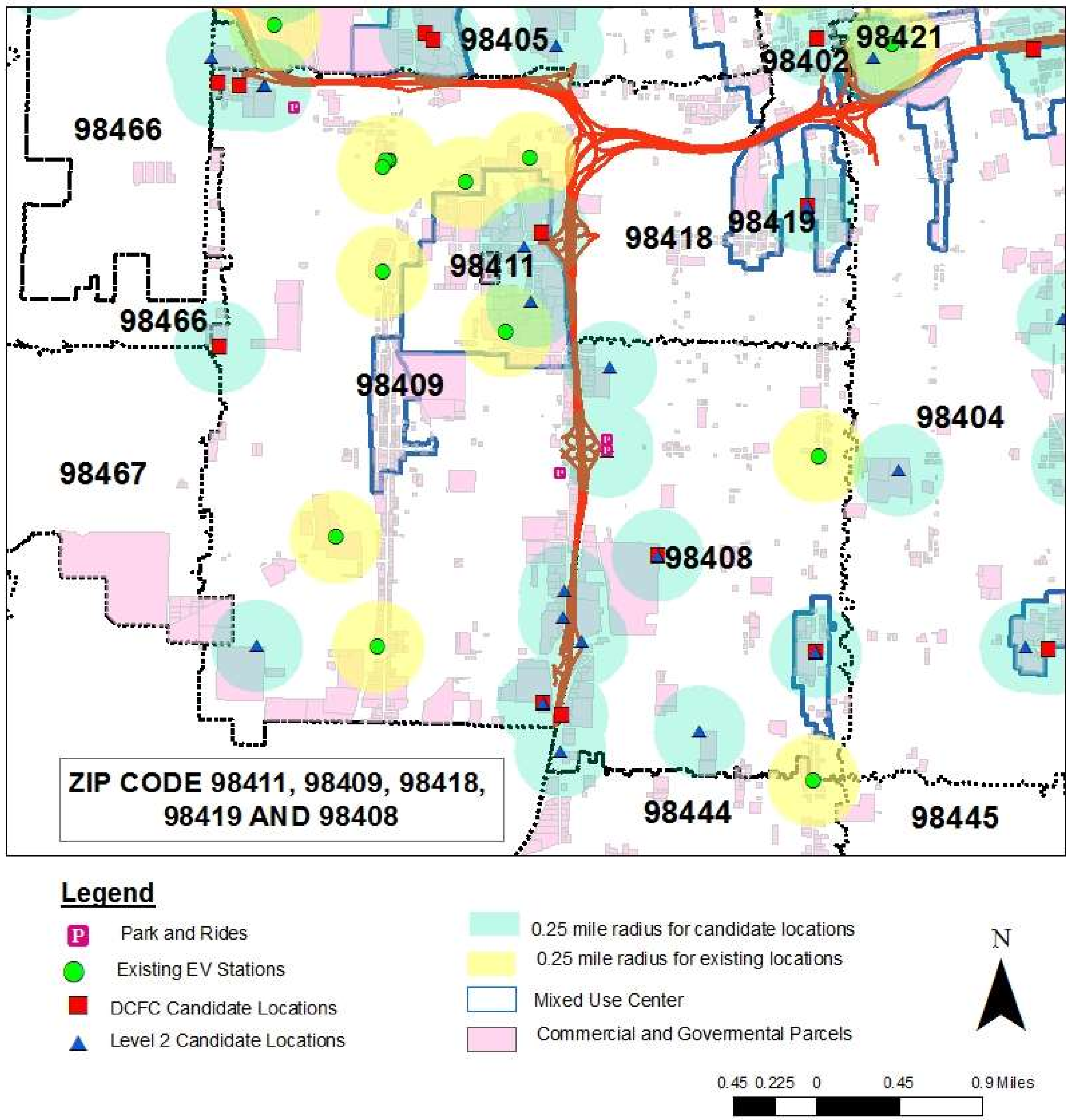
The power criterion considers the two most common service voltage combinations of three-phase 60-Hertz power available in the US: 208/120 VAC and 480/277 VAC[65]. Of note, residential power in the US is more commonly 240/120 VAC due to being single-phase. Consideration of the power available at a candidate location is important because each EVSE charger level has different requirements. For public applications, Level 2 EVSE requires 208 VAC and DCFC requires 480 VAC. Scores for power infrastructure consider the known power level at a site matched against the desired charger level for the EVSE. Scores are penalized for a mismatch or if the power available is unknown since this will increase EVSE installation costs and time.

The proximity criterion considers clustering of EVSE as well as closeness to a highway or interstate interchange. Clustering proximity of 500 yards (approximately ¼ mile) is used to mimic the Traditional Neighborhood Development distance[66] for walking. Proximity to a highway interchange is marked at ½ mile to match the distance model set by WSDOT when locating corridor EVSE during the development of the West Coast Electric Highway[67]. We scored this criterion in such a way as to penalize clustering when not intentionally desired, as well as to penalize close proximity to a highway interchange when not intentionally desired. The motivation for this scoring method was to encourage distribution of EVSE along the likely destination points. However, corridor EVSE is important to reduce range anxiety and promote the use of EVs for commuting. Similarly, clustering of EVSE also has application when demand in a single location is high, though it also runs the risk of causing EVSE to be underutilized when poorly clustered, hence a score penalty.

RECOMMENDED CANDIDATE LOCATIONS

Our recommendation for candidate EV charging locations includes 98 stations in the 12 ZIP codes of analysis in order to meet the projected EV charging demand in these areas. Since one of goals of this project was to consider equity when choosing the candidate locations, sites were not solely chosen to meet the projected demand of trips to the area but also to cover the commercial high density at a more granular scale.

Figure 30. Recommended sites in areas around the Tacoma Mall



The candidate locations for the ZIP codes 98409 and 98418 provide an example. The projected EV demand for 2020 is approximately 351 and 5 vehicles in 98409 and 98418, respectively, charging once every four days based on the assumptions describe above (2% penetration rate and 15% public charging rate for 2020). To meet demand, our recommendation is to implement nine Level Two and 2 DCFC chargers, as shown in Figure 30.

COSTS FORECAST

The costs associated with installing and operating EVSE can vary widely, since cost is dependent on the EVSE charging unit features, site characteristics, the level of dedicated electrical circuit capacity, and labor costs. It is difficult to compare or predict EVSE unit costs since actual costs of a given project will depend on the specific needs and constraints of the charging station and its owners and users. Because cost is variable, we describe cost ranges in Tables 20 and 21.

Installation costs include the cost for connecting the EVSE to the electrical service. These costs also capture such considerations as establishment of new electrical service or upgrades, provisions for meeting certain standards such as the Americans with Disabilities Act (ADA) requirements, traffic protection, signage, lighting, permitting and inspection, as well as engineering review and drawings. A simpler installation will be at the lower end of the cost range while a more complex installation requiring extensive trenching, boring, or modification of electric panels will move toward the middle or higher end of the cost spectrum.

Operation and maintenance (O&M) costs include the power consumption and demand charges, EVSE network subscription to enable third party features, management time and billing transaction costs, as well as any preventative and corrective maintenance repairs costs. O&M can be a highly variable cost that is subject to local influences and arrangements. Historical records of existing EVSE or survey of third party EVSE owners and maintainers can best estimate O&M costs, though these are also likely to evolve as the sector matures.

The following are some recommended tips derived from best practices and lessons learned for minimizing the costs of installing EVSE:

Table 20 (Left). EVSE hardware and acquisition cost range

EVSE Type (single port)	Cost Range
Level 1	$300-$1500
Level 2	$400-$6500
DCFC	$10000-$40000

Table 21. EVSE installation cost range

EVSE Type (single port)	Cost Range
Level 1	$0-$3000
Level 2	~$3000 ($600-$12700)
DCFC	~$21000 ($4000-$51000)

EVSE unit selection

- Select an EVSE unit with the minimum level of features required, a wall mounted EVSE unit, if possible, so that trenching or boring is not needed.
- Select a multi-port EVSE unit if feasible to minimize installation costs per charge port.

Location

- Choose a location in close proximity to the electrical service to minimize the need for trenching or boring and the costs of potential electrical upgrades.
- Choose a location that already has space on the electrical panel with a dedicated circuit.

Long-term planning

- Avoid utility demand charges by balancing charging time windows with other electricity usage and working closely with your utility.
- Upgrade your electrical service for your anticipated long term EVSE load and run conduit to your anticipated future EVSE locations. This will minimize the cost of installing future units.

FUNDING AND BUSINESS MODELS

As part of any EV and EVSE development strategy, the business case for investment should be touched upon. According to Ensto (2018)[68], there are five main business models for EV charging models: regional fast charging networks; local, small business initiatives; commercial EV charging; EV fleets and enterprises; and municipalities and sustainable e-mobility.

Regional Fast Charging Networks

This model is dependent on consumer-facing businesses with existing or planned EVSE candidate locations. Such businesses stand to gain competitive advantage from marketing and branding opportunities, and can include EV charging as part of their customer experience.

There are incentives and grant funding opportunities to support this type of investment. For instance, WSDOT launched a pilot program to strengthen and expand the West Coast Electric Highway network by deploying DCFC infrastructure along highway corridors in Washington State (WSDOT, 2015[69]). As part of this initiative, there were two projects that include the following organizations and businesses:

- **Eastern Washington Project:** the project lead is a public utility consortium, Energy Northwest on behalf of Electric Vehicle Infrastructure Transportation Alliance (EVITA). This project is conducted in collaboration with Greenlots and EV4, two companies that install and operate electric vehicle charging infrastructures.
- **I-5 Corridor Project:** The project leader is Forth, formerly Drive Oregon, an electric vehicle advocate group based in Portland. Forth has partnered with EVgo and SemaConnect, both of which are EV charging vendors.

Local Small Business Initiatives

As more drivers begin to adopt EVs, accessibility needs of these users also change. For towns, cities and attractions that rely on highway access for visitors, EV infrastructure becomes more and more important. This business model requires coordination between small business and groups, which can be led by chambers of commerce, business improvement districts (BIDS) or similar organizations. According to Ensto, this model is important for businesses or organizations that have to maximize revenue from peak seasonal traffic and it is ideal for mid-sized towns that are popular tourist destinations or commuter towns. Partnering with chambers of commerce or BIDS could open up new sources of funding for stations located in local commercial areas.

Commercial EV Charging

This business model refers to EV charging infrastructure hosted by businesses such as retailers, shopping centers, hotels, fast food outlets, parking providers, and other kinds of business with off street parking.

The benefits of charging stations for different types of businesses include attracting new customers with higher purchasing power; increase time spent in store; worth-of-mouth marketing; reaching sustainability goals and potential competitive advantage from positioning as a “green” company; and improving customer satisfaction. Commercial EV charging can also be used as workplace charging infrastructure for staff and the businesses’ own fleets (discussed further in the next chapter).

In 2014, some of the retail organizations moving into the EV charging space were Walgreens, Kohl’s, IKEA, and Walmart. Walgreens was one of the most aggressive, with more than 400 operational EV charging stations. Kohl’s had EV charging in 32 locations with 85 chargers total. IKEA planned 55 locations with charging stations, while Walmart had EV charging stations at 29 sites across six states[70].

Typically, retailers do not take ownership of the charging station but instead partner with an EVSE provider like Beam Charging, which installs and maintains the station and shares revenue with the lot owner whose prime parking spots it is using[71]. That is also the case of hybrid model of public utilities that own and maintain charging EVSEs installed by third-party vendors: Pacific Gas and Electric (PG&E) is an successful example of this business model[72].

Other Business Models

The remaining two business models discussed by Ensto (2018) are EV fleets and enterprises, and municipalities and sustainable e-mobility. Additionally, other examples of private investment and advocacy in EV charging infrastructure are:

- **Investment by automakers to build a network of EV chargers for their clients:** This group includes companies such as Volkswagen, BMW, Daimler, Ford and Tesla[73].
- **App-based services and sharing economies with companies such as Chargie**[74]
- **Advocacy groups:** As an example, EV100 is a global initiative bringing together forward-looking companies committed to accelerating the transition to electric vehicles and making electric transport the new normal by 2030. Baidu, Deutsche Post DHL Group, Heathrow Airport, HP Inc., IKEA Group, Lease Plan, METRO AG, PG&E, Unilever, Vattenfall are the 10 first members of EV100[75].

Workplace Charging Stations

Workplace charging makes up the final component of urban EV charging infrastructure, and while it is a small component, it is still critical. This section of the document outlines the method, cost and impacts of increasing EV charging infrastructure in workplaces including a quantity assessment, based on predicted EV usage, and a location assessment, based on a workplace readiness index and a workplace desirability index. Workplaces received a score for each index, which we then used to determine the top workplaces for the City of Tacoma to invest in. Cost is discussed in terms of cost for all stakeholders involved, including the City of Tacoma, employers, employees, and parking lot owners, a discussion continued in the Pricing and Sharing Strategies section. The final section assesses the impact of the workplace charging in terms of ROI as well the impact on eVMTs and GHG emissions.

Accurately predicting the locations and necessity of a charging event is hard because of the inherent uncertainty in daily routines and vehicle use. So, researchers at National Renewable Energy Laboratories (NREL) have developed a tool for projecting the requirements of EV infrastructure. The tool EVI-Pro[76] was developed at NREL in collaboration with California Energy Commission and has been used to predict the number and locations of charging stations for the state of California[77], Massachusetts[78], Ohio[79] and cities like Seattle. The foundational assumptions for EVI-Pro use are as follows:

- Future PEVs will drive in a manner consistent with the present-day gasoline vehicles.
- Consumers will perform most charging at their homes.
- Charging at work/public Level-2 and corridor/community DCFC stations will be used as necessary to maximize eVMT.

These same obstacles contain opportunities for local governments to influence change and promote adoption and investment in EVs.

Based on these assumptions, the methodology used by EVI-Pro is as described below:

Stage - 1 Inputs

- The vehicle mix and attributes, i.e., the percentage of BEVs, PHEVs, HEVs, etc. in the current vehicle fleet as well as their characteristics like range, charging power, etc. are determined.
- Infrastructure attributes, i.e., the number, location, and type of existing EV infrastructure are determined. These include all residential, public and workplace, level-1, level-2 and fast chargers.
- Travel data, i.e., the average daily travel pattern of the population, is determined at county, city and census tract level. This consists of the GPS waypoints from current usage of ICE vehicles.

Intermediate Processing - 1: All the stage-1 inputs are then fed to the EVI-Pro model, and it performs driving and charging simulations for all vehicles in the region.

Intermediate Results - 1: These simulations result in the participation rates, charging loads as well details about individual charging sessions in the fleet.

Intermediate Processing – 2: The intermediate results from the previous stage are then used for spatial-temporal post-processing for estimating the potential of the shared use of the EVSE infrastructure.

Intermediate Results – 2: This results in EVSE density and EVSE utilization for the given area.

Final Results: The EVSE density is then scaled based on the PEV sales projections to get the EVSE counts and locations for the city/region of study.

The methodology is as shown in the Figure -31 below. However, due to the data-intensive and rigorous nature of this study, it takes around three to six months to conduct this study and costs around $50-100k making it out of scope for the current study.

As a first approximation of the exact demand, EVI-Pro Lite, a simpler online free-to-use version of the tool EVI-Pro allows, anyone to get the projected number of charging plugs of various types for any PEV goal. The tool considers the city of Tacoma as part of "Seattle" region, so it was necessary to scale the PEV goal of Tacoma to PEV goal of Seattle. So, if currently there are 600 PEVs in Tacoma, and a total of 14800 (as reported in the EVI-Pro-Lite database) for the Seattle region; this means that if the PEV goal of Tacoma is 2000, then the PEV goal of Seattle region should be (2000 / 600) * 14800 ~ 49334. Using this as the PEV goal for Seattle, we get the results shown below from the EVI-Pro-Lite (Figure-32). Scaling the demand for Seattle region back to Tacoma, we get the number of workplace charging plugs as 1053 * (2000 /49334) ~ 43. Therefore, the City of Tacoma roughly needs 45 plugs of Level-2 charging at workplaces with 7.2 kW of power per plug.

Once the number of workplace charging stations needed for Tacoma has been determined, the next step is to place them. For this, we calculated a worksite suitability index, a measure of how suitable a worksite is for locating a charging station. We calculated the index for ten worksites for which the data was easily accessible, but this method could be extended to more worksites around the city. A refinement on this initial selection of worksites, the worksite desirability index, is described later. The desirability index is based on employee surveys and tendering process to be conducted by the city for the employers.

WORKSITE SUITABILITY INDEX

To identify the most appropriate places for future worksite EV infrastructure expansion, we began with a land-use suitability analysis. Though there are lots of factors that can impact the adoption and utilization of EV infrastructure, we looked at two general categories: spatial suitability, which factors in built environment characteristics and expected service demand from the public, including the employment density, Point of Interest (POI) density, driveway density and distance to multi-family residential; and employer/employee readiness, which focuses on workplace internal factors, such as the business domain of the worksite, average income of employees, and internal demand for EV services. Final site suitability was calculated by a two-step scoring system depicted in Figure 33.

Figure 31. EVI-PRO process flow

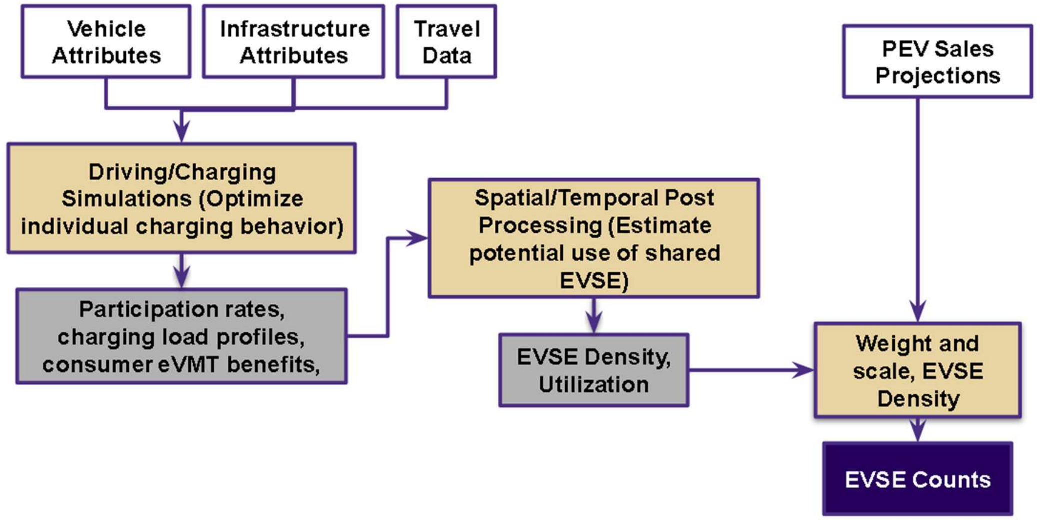
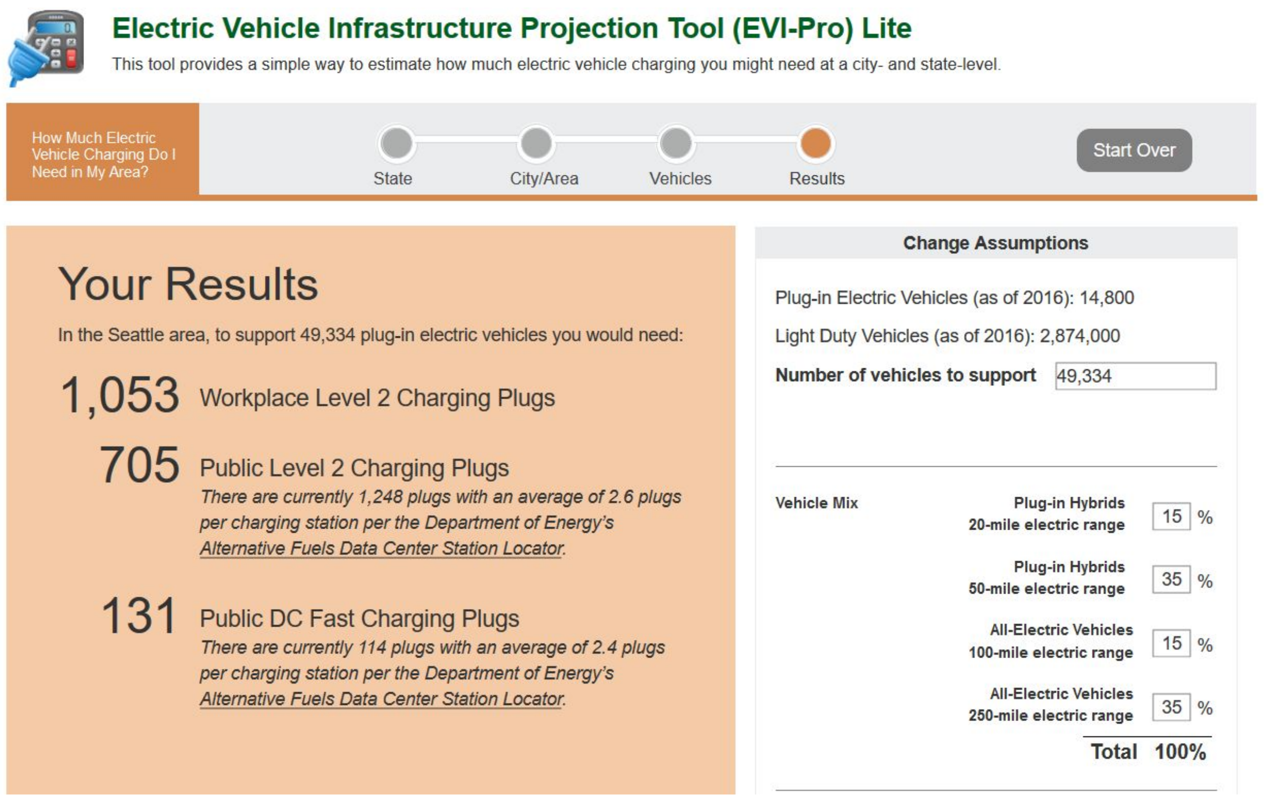


Figure 32. Screenshot of results from EVI-PRO lite for Seattle



The City of Tacoma counts 36 organizations as "major employers"[80]. Even though some worksites have many employees, their business type is clearly not a relevant target for city incentives, such as the military base. Those places are removed from the list. Worksites that are outside the city boundary are also eliminated. In the end, we generated a list of 10 candidate employers, shown by Table 22.

SPATIAL SUITABILITY

As illustrated in Figure 33, "spatial suitability" is a measure to capture how suitable a worksite is in relation to its surroundings. The following factors are considered in evaluating the "spatial suitability":

- **Distance from multi-family residences:** During our interviews with two managers of EV charging station in the City of Tacoma, both showed an interest of sharing their services to the public, rather than it being exclusive to the employees located in the property. If this is the case for most of the employers, then worksites adjacent to multi-family residences are ideal sites for expanding EV infrastructures, since those chargers can be subleased to "garage orphans" during the nighttime. Since residents need to regularly charge their EVs, it may also be a sustainable business venture for the worksites to sublease their charging place at off-peak hours by contract. Figure 34 shows areas within half mile (around 10-minute walk) from multi-family residences, areas that would be suited to MUD residents leaving their EVs in the worksite charging area and walking home.
- **Concentration of POI with high duration time:** For public facilities, especially like hospitals, schools and entertainment centers, it is important to ensure EV drivers can charge their EV onsite. Generally, people coming to those places often have long duration time. Therefore, this study collects 12-category POI in Tacoma that tends to attract visitors with long duration time, listed in Table 23. Figure 35 shows that many areas in Tacoma are close to a point of interest.
- **Density of driveways:** Another key factor that may impact the utilization of EV chargers is the traffic flow. Areas with higher traffic flow indicate the higher demand in general. Due to the lack of real-time traffic flow data, in this study driveway density[81] was used to reflect the traffic flow. Figure 39 depicts the highway and city driveway. The density was analyzed in block group level.

Figure 33. Process of the worksite suitability analysis

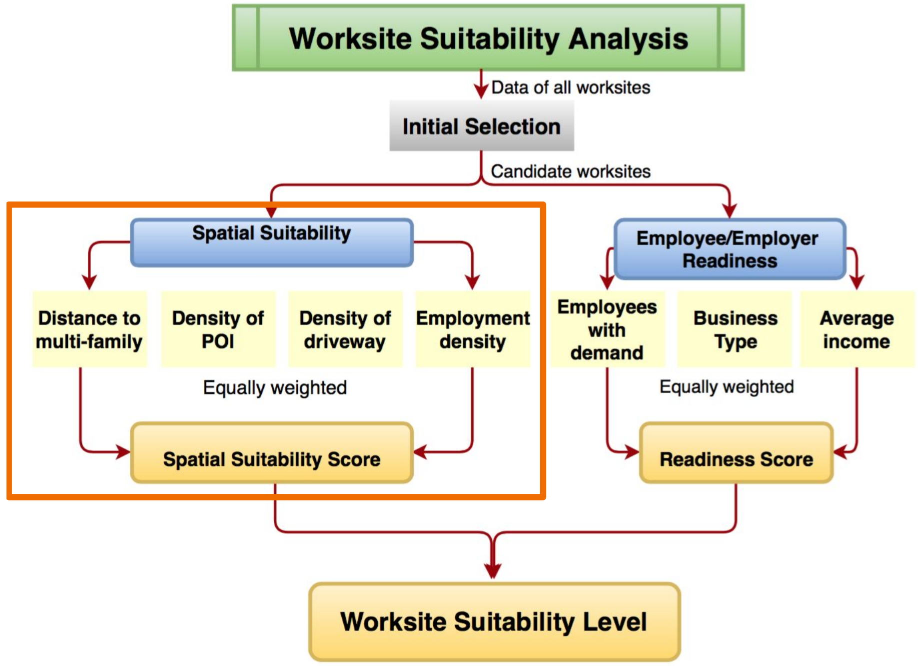


Table 22. Top ten candidates for workplace EV chraging stations

Organization	Number of Employees	Description
Multi Care Health System	7439	Health Care
Franciscan Health System	6528	Health Care
Pierce County	3058	Public Sector
Emerald Queen Casino	2082	Gaming
Puyallup Tribe	1112	Government
Davita Inc (2 sites)	1025	Health Care
Comcast Cable	1000	Communications
Kaiser Permanente (2 sites)	755	Health Care
University of Puget Sound	697	Higher Education
Tacoma Community College	660	Higher Education

Figure 34. Distance to multi-family residential zone

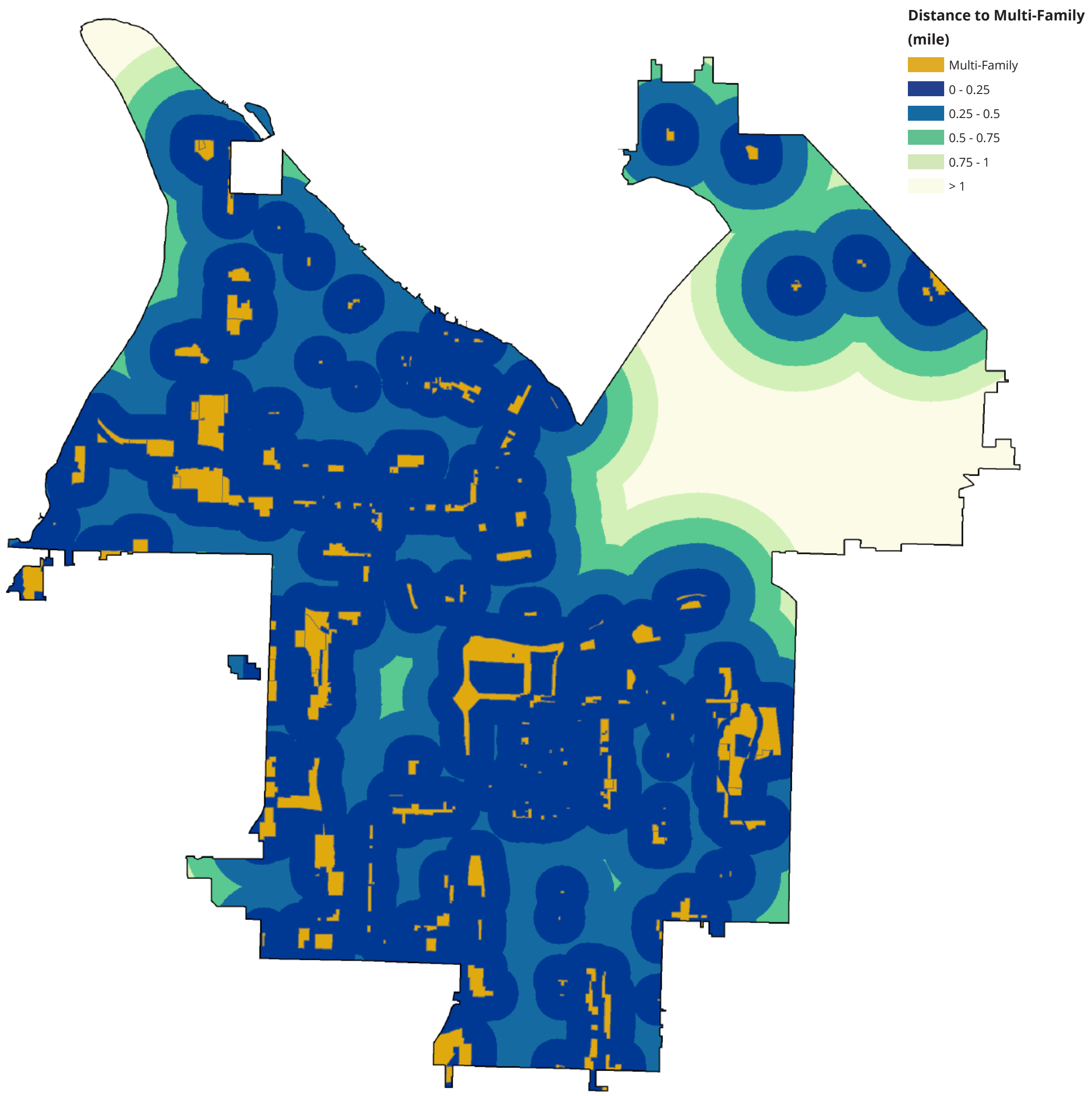
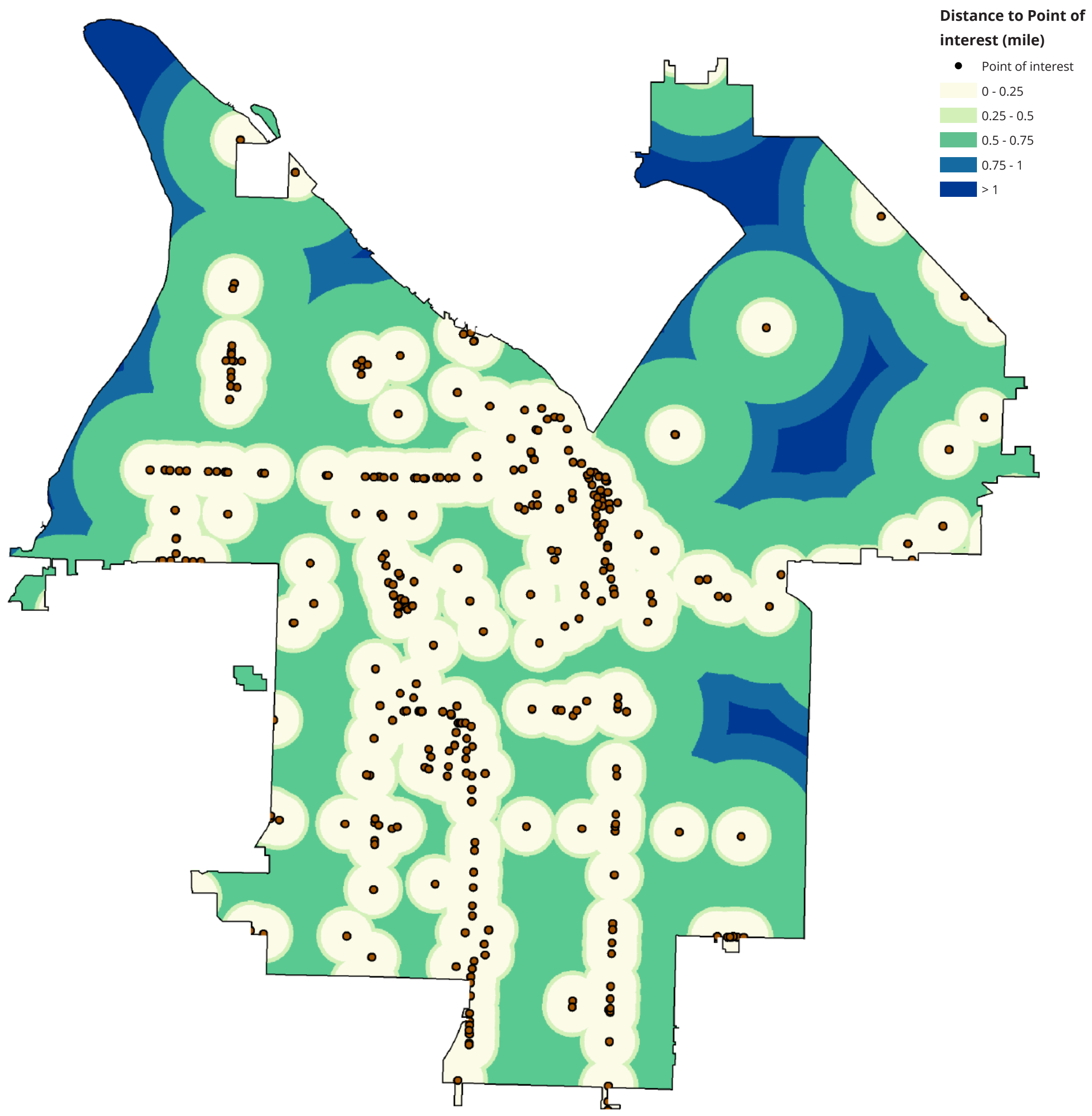


Figure 35. Proximity to points of interest



- **Employment density:** Job data was collected from 2010 Census LODES[82] data and measured at the block level. As Figure 40 shows, jobs in Tacoma are highly concentrated in mixed-use centers as well. Areas with higher employment density normally have higher demand of service and infrastructure.
- **Overall score of spatial suitability:** The four previously mentioned factors were equally weighted and measured in 30*30-sized raster in ArcGIS. We grouped overall suitability scores into five levels, as Figure 41 shows. Table 24 lists all the worksites with their weighted score.

EMPLOYER/EMPLOYEE READINESS

- **Employees commuting distance:** To avoid range anxiety, the acceptable daily commuting distance should be less than 50 miles if EV chargers are not available in worksites. Therefore, EV owners with 50-mile commuting distance are a critical group to consider. The LODES data[83] estimates the distribution of home to work commuting distance of employees in Tacoma, the four categories are listed in Figure 38. Commuters with commuting distance less than 50 miles are of our interest. Then we collected the share of commuting distance (at least ZIP-code level) of each business and the number of employees to calculate the number of employees who are more likely to be the EV charger users. Finally, we categorized the total number of employees into five levels, as shown in Table 25. The higher the level, the higher demand is more likely to expect.
- **Business attractiveness for EV infrastructure:** beyond demand from employees, visitors with long duration times represent another source of demand for workplace EV charging. However, the attraction varies among different business types. For instance, a hospital would attract more visitors than, say, a manufacturing business. Therefore, scores ranging from one to five are assigned to worksites according to their business types, shown in Table 26.

Figure 38: Jobs by distance in City of Tacoma

Jobs by Distance - Work Census Block to Home Census Block

	2015 Count	2015 Share
Total Primary Jobs	98,566	100.0%
Less than 10 miles	53,041	53.8%
10 to 24 miles	27,769	28.2%
25 to 50 miles	10,090	10.2%
Greater than 50 miles	7,666	7.8%

Table 23. Points of interest in City of Tacoma

POI	COUNTS
Business Facility	13
Amusement Park and Convention Center	5
Casino	1
Cinema	4
Department Store	28
Financial Institute	207
Health Care	9
High Education	7
Hotel	30
Performing Art	5
Shopping Complex/Special Store	140

Table 24. Worksite candidate suitability by location

Level of Suitability	Worksite Candidates
Level 2	Davita Inc (Site1)
Level 3	Emerald Queen Casino; Puyallup Tribe
Level 4	Franciscan Health System; Emerald Queen Casino; Comcast Cable; Tacoma Community College; Kaiser Permanente (Site1)
Level 5	Franciscan Health System; Pierce County Government; Davita Inc (Site2); Kaiser Permanente (Site2); University of Puget Sound

Table 25. Number of employees within 50 miles

Number of Employees within 50 miles	Level
<100	1
100-500	2
500-1000	3
1000-5000	4
>5000	5

Table 26. Business attractiveness for EV infrastructure

Type of Business	Attractiveness to Visitors
Health Care	5
Public Sector	1
Education	4
Retail	3
Manufacturing	1
Gaming	2
Government	1
Distribution	1
Transit	4
Service Business	3

Figure 36. Driveway and employment densities

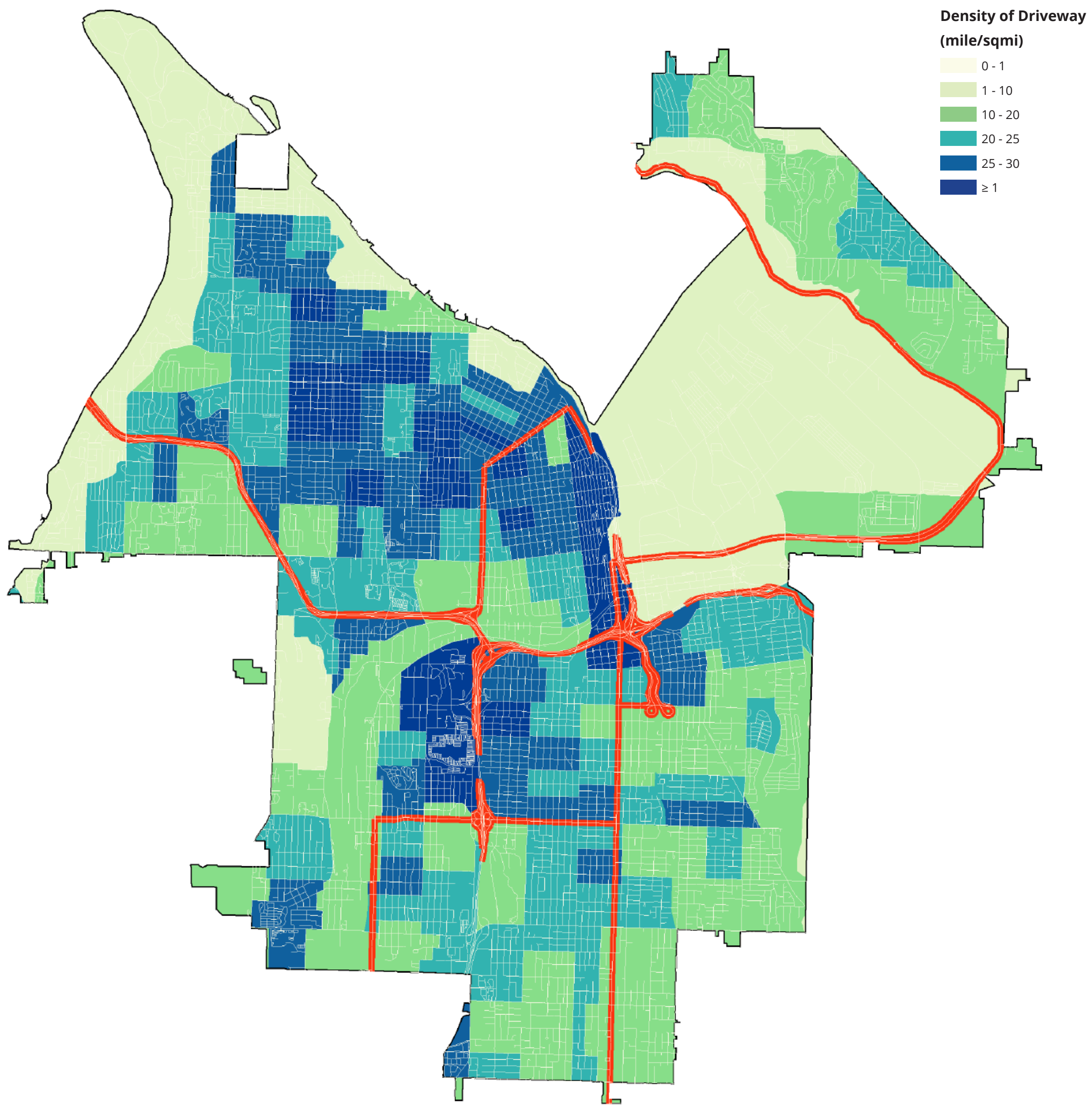
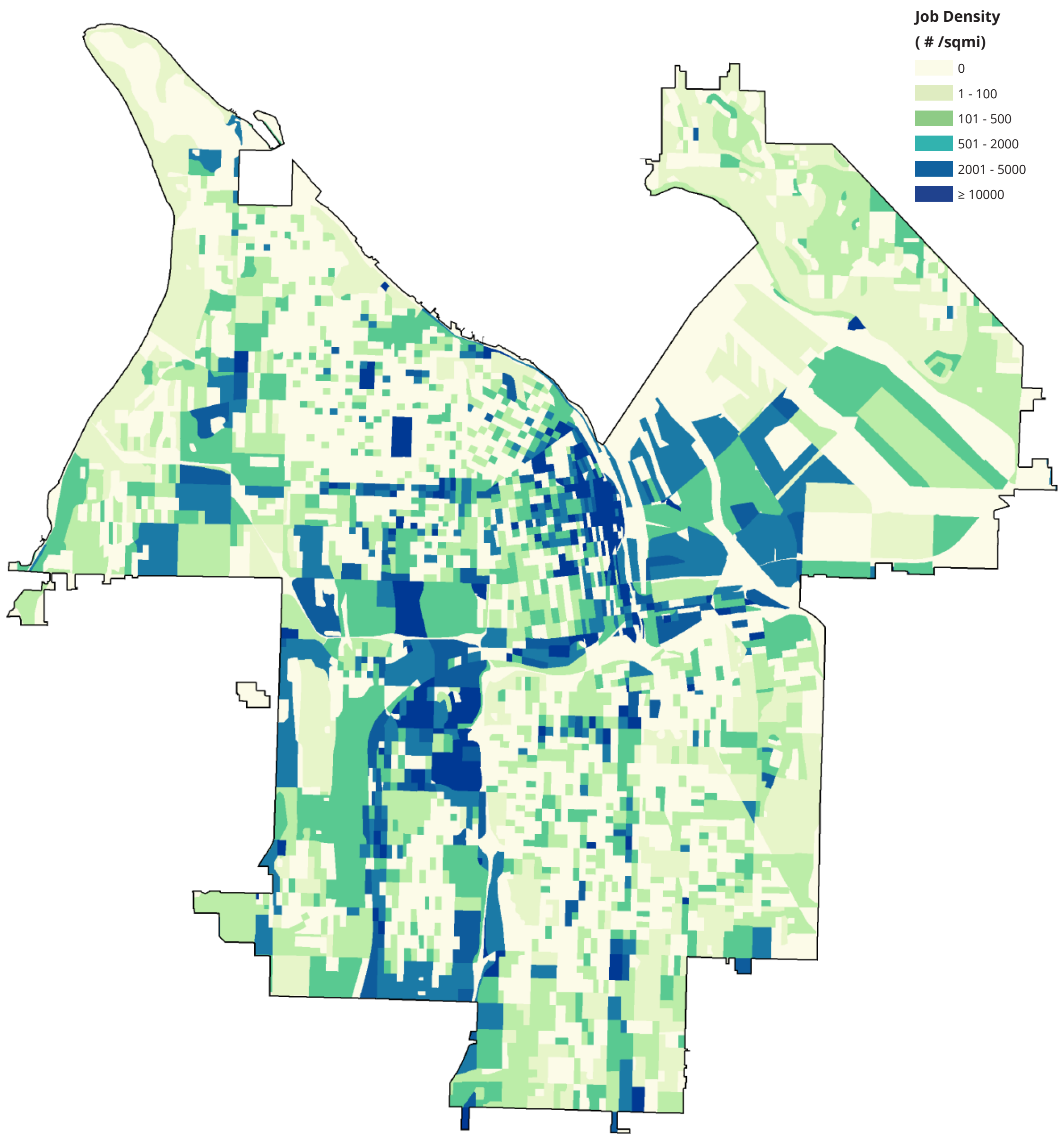


Figure 37. Job density in Tacoma



- **Average income of employees:** From the analysis of the characteristic of EV users, the majority of the EV users are in median income level. It is worth noting that high-income population has a relatively low demand for worksite chargers since they are more likely to install chargers at home. Thus, scores are signed according to the average income as Table 27 shows.
- **Overall readiness score:** The previously mentioned three factors are equally weighted and calculated as the final score. According to the final score, the overall employee/employers' readiness was categorized into five levels. Table 28 lists all candidate worksites by level.

FINAL WORKSITE SUITABILITY ANALYSIS

To determine overall suitability, we combined the results of the spatial suitability and employer/employee readiness analyses, weighting them equally. The final level of suitability of installing EV infrastructure of candidate worksites is shown in Table 29.

WORKPLACE DESIRABILITY INDEX

Although assessing the workplaces by spatial suitability and employer/employee readiness might be an appropriate way to find the suitable candidates, it may not necessarily result in optimal allocation of public funds. This is because the method cannot account for the will and demand of the employers and subsequently the employees. A study[84] conducted across 79 organizations (consisting of small organizations with 25 employees and companies like Google and General Motors) having EVSE in California indicated "going green" as the first and "request from employees" as the second most prominent reason for them to install. Thus, development of workplace charging infrastructure is by the will of the host organization to further their corporate social responsibility goals, enhance community leadership and provide employee satisfaction[85].

A Workplace Charging (WPC) toolkit (described below) will be distributed to all the employers along with an invitation to tender. All employers willing to install electric vehicle charging stations will be able to participate in this tendering process. This eliminates bias due to the organization size, type and location, giving a fair chance to all interested employers to contest for the available funds. The process to arrive at the workplace desirability index is as described in the Figure 39.

Table 27. Income interval scores

Income (K/year)	Level
Less than 20	1
20 to 30	2
Greater than 70	3
35 to 70	4
30 to 35	5

Table 28. Overall readiness

Level of Readiness	Worksite Candidates
Level 3	Pierce County; Emerald Queen Casino; Comcast Cable
Level 4	Puyallup Tribe; Davita Inc; Kaiser Permanente; University of Puget Sound; Tacoma Community College
Level 5	MultiCare Health System; Franciscan Health System

Table 29: Final suitability analysis results

Level of Suitability	Worksite Candidates
Level 2	Davita Inc (Site2)
Level 3	Emerald Queen Casino; Davita Inc (Site 1)
Level 4	Franciscan Health System; Emerald Queen Casino; Comcast Cable; Tacoma Community College; Kaiser Permanente (Site1)
Level 5	MultiCare Health System; Franciscan Health System; University of Puget Sound; Tacoma Community College

WORKPLACE CHARGING TOOLKIT FOR EMPLOYERS

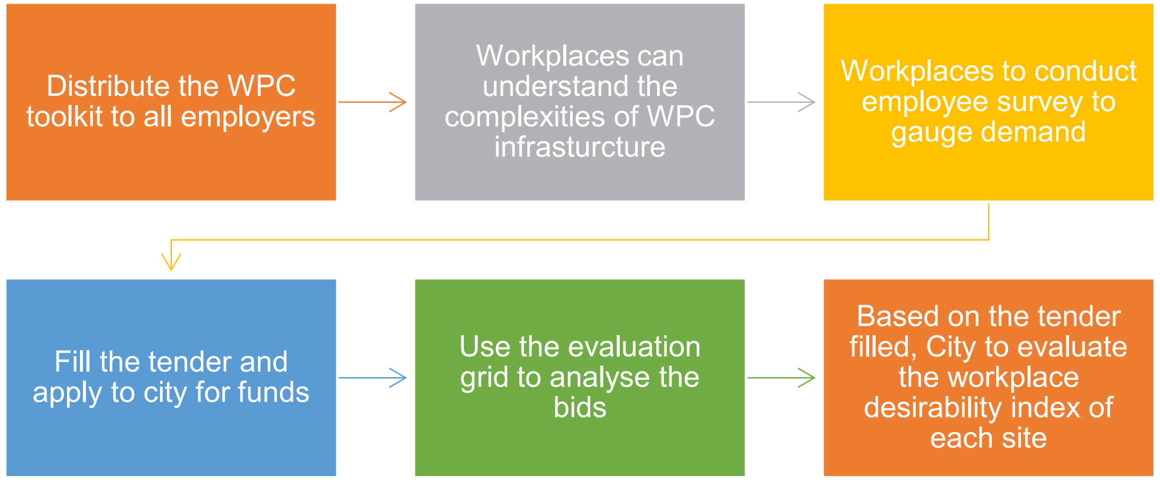
Electric vehicles (EVs) are still a new concept. While many people know about EVs, they may not fully know the details about EV charging infrastructure. This toolkit therefore, aims to educate the hosts about what an EV is and the types of EV charging infrastructure. The toolkit also contains surveys to help the employers gauge the exact level of interest in their employees as well as the specific requirement of their charging infrastructure. Also, with respect to EV charging infrastructure, there is rarely a solution fit for everyone, so the toolkit aims to help understand and estimate the cost of installing and operating the charging infrastructure. It is recommended that this toolkit be hosted online with shared edit access (e.g., Google Drive or Dropbox) to all the stakeholders including the city and workplaces, so that they can update it based on their experiences. This will ensure that the toolkit becomes more valuable with time.

Toolkit Contents

Educational content

- **Plug-in electric vehicle handbook for workplace charging hosts:** This is a well-illustrated handbook prepared by the US-DOE as part of the Clean Cities initiative. This handbook explains the basics of a plug-in electric vehicle (PEV) as well talk about the basics of charging a PEV. It discusses the benefits of workplace charging as well as how to go about planning for installing the necessary EV charging infrastructure. The handbook[86] also talks about policies for EV charging infrastructure management and gives examples of some case studies to help get some context on how to execute the installation and operation of EV charging infrastructure effectively. The illustrated and authoritative treatment of the subject makes this handbook an ideal first resource for getting the workplace charging hosts excited and informed about the complexities of the subject, so they can effectively plan for it.
- **Literature survey:** This document lists all the relevant federal and state-wide resources covering the subject, including case studies from various employers discussing their experiences with installations and policies and outcomes for effective management of workplace charging infrastructure. The idea is that the employers can refer to the specific resource whenever they need more detailed information about a subject.

Figure 39. Process to calculate the workplace desirability index



Employee survey and questionnaire (tender): The brief survey provided with the toolkit can be administered by the employers to gauge the interest of their employees with respect to the charging infrastructure. Workplace charging can be critical for people who do not have access to home charging. This survey further helps capture their willingness to pay for the said infrastructure, as well as how much will the availability of workplace charging affect their decision to own an EV. The questionnaire consists of 4 sections, with a few simple questions. The questionnaire aims to be simple, easy to understand, and would not time-consuming. The employee survey aids the employers to answer the questions in employee demand section.

Costs: A quick summary of costs incurred during installation the EV charging infrastructure is presented. For details about costs, the employers can refer to the costs resources in the literature survey.

BID EVALUATION CRITERIA

Employee Demand

Consider the employees already owning EVs and their desirability to own EVs in the future. Also consider their commute distances, travel patterns and desirability for workplace charging infrastructure. It is important to know if the employees would be ready to pay a usage fee. All these factors would allow the employer to gauge employee demand. An employee survey will help answer all these questions.

Facilities Ownership

Installation of EVSE is easy if the employer owns all three as opposed to the employer leasing the building and parking spaces. Access to electricity supply in the parking lots is also essential. Thus, evaluating the ownership is a key criterion in evaluating employer readiness for EVSE.

Voluntary Committed Cost Sharing

Voluntary cost sharing by the employer shows the employers commitment towards the EV charging infrastructure and should be highly valued. The higher the cost share the more committed a workplace is towards owning the EV charging infrastructure.

Charging Policy

- Ensuring equality in access to the charging station to all employees should be ensured by the employers.
- Charging demand management - most efficient utilization of charging station such that hogging is minimized.
- Access to charging station - if the charging stations are available for the visitors and general public apart from the employees, it would result in maximizing utility of the infrastructure. Most of the employers owning the parking lots make the infrastructure available to both visitors as well as public.

ADVANTAGES OF WORKPLACE DESIRABILITY INDEX

The concept of "workplace desirability index" is novel, and this evaluation ensures that small, medium, and large employers all have an equal chance as the number of employees is not a criterion for evaluation. In the study conducted by California Plug-in Electric Vehicle Collaborative, most of the respondent companies were small and medium companies having less than 500 employees. The studies clearly indicate that small and medium employers rely on government grants more than large employers.

Awarding grants for EVSE infrastructure based on the willingness of the employees would motivate employers to provide better incentives. It could result in a very thorough and impartial way of providing grants, as all the employers are extended an invitation to bid. Also, the data collected from this could be used for allocation of grants in the future as well.

LIMITATIONS OF WORKPLACE DESIRABILITY INDEX

The entire process could be more time consuming and involved for the City. Reaching out to many employers could be difficult. Thus, the City of Tacoma can assess the suitability and find the workplaces to allocate grants by considering spatial suitability and employer/employee readiness. But if the city has sufficient time and resources, assessing the workplace suitability by the tendering process described above could be a good alternative.

COSTS

Before beginning the deployment of the technology, it is vital to estimate costs for workplace charging. Due to the inherent nature of the task, i.e. retrofitting buildings with workplace charging infrastructure, there is a lot of variability in the cost. Table 31 presents a matrix of possible site conditions and the associated level of difficulty in installing the charging infrastructure.

Based on the specific site conditions, the difficulty of installing charging stations would be:

- **Easiest:** 1A, 2A, 3A, 4B (i.e., when "employer" owns the building, "employer" owns the parking lot, access to electricity is "yes," and no upgrades are needed)
- **Easy:** 1A, 2A, 3A, 4A
- **Moderate:** 1B, 2B, 3A, 4A
- **Challenging:** 1B, 2C, 3B

Operations and Maintenance Costs While the exact cost of operations and maintenance is dependent on the EVSE manufacturer chosen and add-on services like network reporting etc. subscribed, an estimate[87] of $500 per charging station per year can be budgeted towards these costs over the cost of electricity that is consumed per charging station.

PRICING AND SHARING STRATEGIES

This section of the report discusses strategies for how to price workplace charging. There are various ways in which workplaces charge their users. Common among them are the following:

Pricing

- **Per kilowatt-hour:** Kilowatt-hour (kWh) is the measure of energy delivered to the battery and is therefore the most customer-friendly method of charging for EV infrastructure. Four out of the 20 workplaces in the California study mentioned above adopted this method pricing users. Users are not penalized by this method even if their car cannot accept the high power provided by the charger. This method can lead to abuse of the charging spot as users are not penalized for not disconnecting as soon as they are done. Alternate methods can be adopted to prevent hogging of the parking spot in that case.
- **Per hour:** Users can be priced per hour of use of the charger. This may be one of the simpler systems to manage and is analogous to how parking spots are usually priced. However, the eight-hour time slot rate currently being used at one the City of Tacoma location is also unfair to most users, as they may end not parking for that long, or their vehicles may not be receiving power all during the eight hours.
- **Per month:** In cases where automated or timed chargers are not an option, a flat rate per month can be assessed for use of charging infrastructure. This pricing method may not be flexible or scalable as demand changes, and does not work for short-term visitors.

Sharing

Workplaces should be made accountable for effective utilization of the charging infrastructure, as uniform rules cannot be applied across all sites due to site-specific constraints. Some ways in which EVSE utilization can be increased are described below:

- **Prompt moving after charging:** Often, users end up occupying the space long after their vehicle has finished charging. This makes it hard to reuse the EVSE. Each workplace will have to

Table 30. Criteria for parking ownership

S. No \ Choice	Criteria	A	B	C
1	Who Owns the Building	Employer	Leased	
2	Who Owns the Parking Lot	Employer	Leased	Independent
3	Access to Electricity	Yes	No	
4	Upgrades Needed	Yes	No	

come up with a way to penalize "hogging" and to educate users about the importance of fair and proper use of the available infrastructure.

- **Public after-hours:** While this method may not work in worksites with restricted access to parking facilities, the EVSEs can be made public and accessible to all users after the regular work hours. This would mean that "garage orphans" or multi-unit dwellers could make use of such charging facilities in vicinity of their residence.
- **Fleet access after-hours:** Facilities that are not convenient for the public or to which public access is restricted, may allow access to an EV fleet that can charge using the infrastructure after regular work hours.

IMPACT ASSESSMENT

This section discusses the potential impacts of strategies to promote workplace EV charging. We consider three cases of utilization levels in order to quantify the impact on the returns to the City (i.e., Tacoma Power) for each charging plug. The net impact can then be found based on the number of charging plugs installed.

Case 1 - Maximum utilization, at-par pricing: A Level 2 charger at workplace can charge two cars in a day. This can be considered as the case of maximum utilization per charging station, that it is being always used during work hours. Assuming a price structure at par with the average commercial electricity rates in Tacoma:

- Cost of electricity: 7.68 c/kWh[88] (= price of charging at the workplace charger)
- Time of charging per day = 8 hours
- Power per plug = 7.2 kW
- Total Energy consumed per day = 7.2 * 8 = 57.6 kWh
- Total Energy consumed per year = 57.6 * 260 = 14,976 kWh (Assuming 260 working days per year)
- Total amount recovered per plug per year = 7.68 * 14,976/100 = $1,150

Case 2 - Maximum utilization, at-home pricing: Assuming a per unit price of 8.14 c/kWh, which is equal to the average residential price of electricity:

- Total amount recovered per year per plug = 8.14 *14976/100 = $1220

Case 3 - Medium utilization, high pricing: There can be a case made for a higher price for workplace charging. Keeping a higher rate than home charging would ensure that only people who absolutely need workplace charging, i.e., those who do not have access to home charging or in need of top-off charging, will use workplace charging. This would prevent abuse of charging infrastructure thus ensuring high availability. Assuming a higher per-unit price of 12.21 c/kWh, which is 1.5 times the price of electricity at home, and 50% utilization:

- Total amount recovered per plug = 12.21 * 14976 * 0.5 /100 = $915

Case 4 - Aspirational utilization, high pricing: This study has tried to find optimal locations and number of charging stations, based on the sole objective of achieving high utilization. The aspiration utilization case is therefore when the chargers are being used throughout the workday with some usage during non-work hours. This usage during non-work hours can be achieved by adopting some of the sharing strategies mentioned elsewhere in this report. Therefore, assuming that somebody uses the charger every night charging, we can add significantly to the utilization of the charger.

- Therefore, assuming high pricing of 12.2 c/kWh and
- Time of charging per work day = 16 hours
- Time of charging per non-work day = 8 hours
- Total hours of charging during an year = 16 * 260 + 8 * (365 – 260) = 4160 + 840 = 5000 hours
- Total Energy consumed per year = 5000 * 7.2 = 36000 kWh
- Total amount recovered per year per plug = 12.2 * 36000 ~ $4,400

Based on these numbers, capital budgeting can be attempted for the workplace charging project. One of the most accurate methods of capital budgeting is Net Present Value (NPV), which takes into account discounted cash flows. NPV calculations for a workplace charger are shown below, based on the following assumptions: The time period of calculation is assumed to be 10 years, i.e., the useful life a workplace charger is considered to be 10 years. This is conservative, and most EVSE manufacturers may claim a longer lifespan. The cost of a Level 2 workplace charger is assumed to be $15,000. Cost of capital is assumed as 10%. Further, it is assumed that returns during year 1 and year 2 are $915 (= Case 3) and returns during year 3 and 4 are $2200 (= 0.5 * Case 4) and the returns for years five thru 10 are $4400 (= Case 4). The formula for calculating NPV is:

$$NPV = \sum \frac{C_t}{(1+r)^t} - C_0$$

Therefore, NPV for workplace charging (with assumptions as stated before) = $2,832. (It should be noted that this is the NPV to the grid when it invests $15,000 for each workplace charger. This is not the NPV for the charger operator, who must bear the cost of electricity as well as operation and maintenance of the EVSE).

EVMT AND GHG EMISSIONS

Increase in Electric Vehicle Miles Travelled (eVMT) is an important measure to gauge the impact of any infrastructure development strategy aimed at increasing the adoption of EVs. In a study in Michigan, workplace charging led to an annual increase of 3,400 miles of eVMT per vehicle. Each mile travelled by an ICE produces, 404 grams of CO2. So, due to workplace charging, a total of 3,400 * 404 /1,000 = 1,375 kg of CO2 emissions were avoided per car per year due to workplace charging. So, if the City were to create 45 Level 2 workplace chargers to support 2,000 EVs, as calculated above, then for a total investment of 45*15,000 = $675,000, a total of 1,375*2,000 = 2,750,000 kg = 3,031 US tons of CO2 tailpipe emissions would be avoided. Therefore, the “green efficiency” of investment is 4.04 kg/$.

Electric car charging in parking lot in West Yorkshire. MTAYLOR848

Conclusion

As stated previously, the goal of these actions is to encourage the use of electric vehicles in Tacoma. As expected, these chargers may not be fully utilized immediately after installation as EV ownership continues to grow. The demand should rise to meet the supply, and from what can be seen in the history of EV recently, it will.

In the scope of this paper, a couple of challenges were discussed regarding the installation of EVSE for residential use. There were large variance in social characteristics, the large variance in EV readiness in between different buildings, and the large variance in cost to install chargers. Furthermore, the attractiveness for an installation is significantly different between single family households or condo and apartment complexes. This was confirmed through showing how the DPP differs in reaching the break-even of the investment for different ownership structures. Taking these findings into account and the existing policy overviews, it was decided to offer the City of Tacoma a range of options to either optimize their policies for efficiency or for equity, as it was not entirely clear what should be pursued at a higher priority. Based on a fairness model, the effects of the policy optimization were illustrated, and corresponding policy proposals were developed including a final cost estimate for each policy. It is recommended to focus on owner occupied households to maximize the efficiency of the policy in an initial stage of EV charging deployment while consider the equity in a long run. Peak demand and smart charger would need to be considered for the further analyses. Lastly, an additional option that could deliver quick wins through making use of charging at public places was provided, which could be pursued in addition to the policy proposals. Seeing as there is a significant number of residents in Tacoma, these policy proposals will increase the attractiveness of owning and operating an EV for residents and furthermore motivate them to make the switch to a more sustainable mode of mobility. This will deliver significant added value to the emissions reduction targets of the City of Tacoma. Additionally, since MUD buildings are dense, an installation can get the attention of other residents and thus cause more people to consider moving towards EVs. Together with the results of the investigations on single family charging, this should deliver a valuable contribution to the achievement of Tacoma's electric mobility targets for 2020.

The objectives for the public infrastructure (including workplace scenarios) aspect of this project were twofold: identify where EV charging infrastructure should be located within the City of Tacoma, and identify the types of investments in EV charging infrastructure that should be prioritized at the local level in order to encourage further adoption of EVs and EVSE development. To meet these project objectives, the public infrastructure team tackles two overarching tasks: develop a strategy to meet the project objectives mainly through GIS and site suitability analysis and identify the impacts of the proposed strategy. While intentionally broad in scope, the project tasks allowed for generous leeway in the development of a strategy to meet the City of Tacoma's objectives.
A final recommendation that aims at receiving more accurate cost estimates, is to pursue a thorough inventory analysis that investigates the real distributions of EV readiness, income distribution, ownership structure and expected desire to own electric vehicles within the residents, since this analysis had to make many assumptions to estimate the expected benefits, costs and dynamics. This could be achieved through surveys, sampling or enhanced census data. Further analysis should assess, whether the trade-off in cost for this inventory analysis is worth the gain in data accuracy.

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81. WSDOT GIS Database for density of driveway: http://www.wsdot.wa.gov/mapsdata/geodatacatalog/Maps/noscale/DOT_TDO/CRABRoutesGif.htm
82. LEHD Origin-Destination Employment Statistics (LODES) https://lehd.ces.census.gov/data/
83. https://onthemap.ces.census.gov/
84. Amping Up California: http://www.pevcollaborative.org/sites/all/themes/pev/files/WPC_Report4web.pdf
85. Workplace charging challenge – Mid Program Review: https://www.energy.gov/sites/prod/files/2015/12/f27/105313-5400-BR-0-EERE%20Charging%20Challenge-FINAL_0.pdf
86. Plug-in EV Handbook: https://www.afdc.energy.gov/pdfs/51227.pdf
87. $280 per plug per year of ChargePoint subscription cost (as seen in Product Description here: https://www.amazon.com/ChargePoint-CT4021-GW1-Electric-Vehicle-Charging/dp/B01A5WE0QC) and additional $220 per year per plug assumed for extended warranty
88. Average price of electricity for commercial and home use: https://www.electricitylocal.com/states/washington/tacoma/
89. https://mi-psc.force.com/sfc/servlet.shepherd/version/download/068t0000001UXynAAG
90. Tailpipe CO2 emitted by one passenger vehicle: https://www.epa.gov/greenvehicles/greenhouse-gas-emissions-typical-passenger-vehicle
91. Investment per charger is assumed to be $15000
92. https://www.psrc.org/sites/default/files/electric-vehicle-guidance.pdf
93. https://www.psrc.org/sites/default/files/electric-vehicle-guidance.pdf
94. http://www.10xe.orwww.10xe.org/Content/Files/Atlanta%20EV%20Readiness%20Study%20.pdf
95. http://www.10xe.orwww.10xe.org/Content/Files/Readysetcharge.pdf
96. https://www.afdc.energy.gov/pdfs/51227.pdf
97. http://www.pevcollaborative.org/sites/all/themes/pev/files/docs/reports/ba_pev_plan.pdf
98. https://www.afdc.energy.gov/uploads/publication/guide_ev_projects.pdf
99. https://avt.inl.gov/sites/default/files/pdf/evse/DriveElectricVermontCaseStudyMarch2016.pdf
100. http://apps.leg.wa.gov/wac/default.aspx?cite=51-50-0427
101. https://www.nrel.gov/docs/fy17osti/69031.p
102. https://www.afdc.energy.gov/fuels/electricity_locations.html#/find/nearest?fuel=ELEC
103. https://www.epa.gov/sites/production/files/2014-02/documents/tnd_design_rating_standards_2.2.pdf
104. https://www.wsdot.wa.gov/NR/rdonlyres/28559EF4-CD9D-4CFA-9886-105A30FD58C4/0/WAEVActionPlanFebruary2015Print.pdf

Appendix I: Annotated Guide to Further Reading and Background Information

The Washington State Department of Commerce in partnership with the Puget Sound Regional Council (PSRC) developed the guidance Electric Vehicle Infrastructure: A Guide to Local Governments in Washington State in 2010 in the wake of state legislation from 2009. The guidebook was developed in collaboration with Plug-In America, an EV promotion and awareness non-profit organization. In 2009, Washington State passed legislation codifying EV infrastructure laws in the Revised Code of Washington (RCW) with the goal to set benchmarks and attainment dates for EV infrastructure development. The main objective of the guidebook is to walk municipalities through the requirements as well as "addressing topics beyond allowed uses and zoning, the guidance provides options for local governments that want to go further than the minimum to support an efficient roll-out of electric vehicles and electric vehicle charging stations in their jurisdiction[92]." Additionally, the guidebook explains "the law allows jurisdictions to adopt incentives programs as well as other development regulations that do not have the effect of precluding the siting of electric vehicle infrastructure in areas where that use is allowed[93]." The guidebook outlines template ordinances and development regulations for local governments to use to facilitate and encourage EV adoption and EVSE development. As such, the guidebook is a robust collection of information specific to Washington State for the current state of EV infrastructure up to its release in 2010, to include summaries of other municipal EV infrastructure efforts and points of contact from outside of Washington.

Also in 2010, the City of Atlanta, Division of Sustainability, released their research report into the best practices of other municipalities regarding electric vehicle deployment, Electric Vehicle Deployment Municipal Best Practices report. The study was the collection of best practices obtained from request for information letters surveyed from 13 municipalities. The report is concisely broken into four, high level, best practices. There are permitting practices, local government actions, state government actions, and local business engagement[94]. The key takeaway from the Atlanta report is not solely the broad-brush best practices of other cities but also the response to surveys from the request for information letters. While not the comprehensive guide for local jurisdictions that other entities created, the Atlanta report is useful in that surveying and canvassing other cities on their lessons learned and best practices can shed light on unique insight not apparent in white paper reports.

In late 2011, the California Bay Area communities teamed together to develop Ready, Set, Charge, California: Guide to EV-Ready Communities. Like the 2010 Washington State guidebook, this guide is very robust, containing template regulations, permits, and comprehensive checklists. The guide is a fusion of other successful municipal codes, plans, regulations, and incentives that promote EV adoption and EVSE development. The guide also contains EVSE site design criteria and template community policy, action, and incentives for EV adoption and EVSE development. The guide provides step-by-step recommendations[95] for governments in developing their own EV plans. While specific to the Bay Area in particular, and California in general, the guide provides 22 primary recommendations and 12 secondary recommendations. These recommendations are pulled from the best practices and lessons learned from other local EV efforts and are broken into four primary categories: EV-Ready Community Policies, Actions, and Incentives; Sample Development Regulations and Guidance; Installation Streamlining for Residential PEV Chargers; and Charging Station Installation Strategies. While some recommended strategies are outside the scope of public charging infrastructure, others can be replicated and tailored for a specific municipality.

The US Department of Energy (DOE) Clean Cities alternative transportation initiative released the Plug-In Electric Vehicle Handbook for Public Charging Station Hosts in 2012. Clean Cities is a national effort with many participating municipalities and, as such, the handbook's content is nonspecific to any particular region but widely applicable across all regions. The handbook captures some lessons learned and best practices from other Clean City EV efforts as well as provides access to resources for current EVSE locations and incentives from the federal and state levels. One point that the handbook makes is that "governments install charging stations to benefit their jurisdictions rather than generate profits[96]". This is taken that governments have the opportunity, and obligation, to lead the adoption efforts for EV and EVSE.

Furthering upon their 2011 joint efforts, the communities in the California Bay Area released the Bay Area and Monterey Bay Area Plug-In Electric Vehicle Readiness Plan in late 2012. This plan is also specific to the Bay Area of California but provides a very thorough and comprehensive look into the then current (2012) and future state of EV adoption and infrastructure development for the region. The plan covers gaps, barriers, and identifies solutions and plans to achieve milestones and objectives, which are not entirely dissimilar to other localities faced with the challenge of promoting EV adoption and EVSE development, even six years later. What is novel about the Bay Area plan is that they look at matching EVSE with venues on the idea of trip purpose rather than trip duration. This shift in view created the notion of "opportunity charging" to target non-residential and workplace charge events[97]. This led to the matching of a preferred EVSE level to a venue based on trip purpose rather than the notional trip duration or parked dwell time. While dwell time remains a relevant metric in deciding placement of EVSE, understanding the purpose of the trip sheds better light on why the trip was initiated and can help understand travel behavior for future trips and EVSE modeling.

Following up on their 2012 handbook for public charging, in early 2014 the US DOE released their latest guide to capture all the lessons learned and best practices from the Clean Cities initiative to date. Their effort, A Guide to the Lessons Learned from the Clean Cities Community Electric Vehicle Readiness Projects, is a single touchpoint synthesizing the content of multi-state, state, regional, and metropolitan EV efforts spanning 84 Clean Cities coalitions that capture nearly 80% of where the US population resides. Their effort is the most comprehensive work linking four overarching categories of lessons learned and best practices (Assessing the Benefits of PEVs; PEV Market Assessments and Forecasts; Identifying Key Barriers and Assessing Community Readiness; and Developing and Implementing Solutions to Overcome Barriers) to specific sections of content from each of the individual Clean Cities development plans[98]. The largest and most ample section is Developing and Implementing Solutions to Overcome Barriers, which contains eight subsections to address different strategies, policies/regulations, incentives, and opportunities. These subcategories are:

- Incentives for PEVs and Charging Stations;
- Charging Stations Deployment Plans, Siting, and Design;
- Local Ordinances and Administration: Zoning, Parking, and Signage; Building Codes; and Permitting and Inspection;
- Providing Charging Stations at Multi-Unit Dwellings and the Workplace;
- Power Grid and Electric Utility Policies and Planning;
- Ensuring Support for Transportation Infrastructure;
- Outreach, Education, Training, and Marketing;
- Facilitating Stakeholder Partnerships, Implementation Plans, and Next Steps.

Each of these subcategories also includes a table to linked content pertaining to the subject contained within individual Clean cities development plans. Similar to the 2011 California Bay Area Guide to EV-Ready Communities, some strategies and sections are not within the scope of public EVSE development, however, the vast majority of content within the guide and especially the collection of lessons learned and linked best practices outlined in the guide make this resource invaluable. Within the appendix of the guide, there is a full table that identifies each Clean Cities readiness plan, its coalition partners, each plan's enclosed publications and sections, and a brief description of the publication. The US DOE have made their 2014 guide practically a one-stop shop for local jurisdictions to find the right tool, template, or model for implementing an individual EV plan.

In 2016, the Idaho National Laboratory released their Drive Electric Vermont Case Study report. The Driver Electric Vermont report contains four components that are not unlike other EV community readiness plans. These components are strategic planning and leadership; stakeholders and partnership development; education and outreach; and incentives. While also a Clean Cities effort, unlike the 2014 DOE consolidating guide this report fuses lessons learned and best practices into nine critical factors of success of the Drive Electric Vermont effort[99]. The report goes on to detail six lessons learned for mid-sized communities. Many of these lessons learned are the same or similar to the critical success factors. The mid-sized community lessons learned include state and local policy; central hub and point of contact; early and broad stakeholder involvement; established tracking mechanisms; engaging auto dealers; and EVSE infrastructure development. What is worth noting is that Vermont (as a whole) is tied with Detroit for the most EVs for a cold weather US city as of 2014. This is a significant accomplishment in boosting EV adoption is a cold region where EV market penetration is historically less than other climates. While the City of Tacoma is not a cold weather city, strategies of increased EV adoption and EVSE development that proved successful in an adverse climate such as Vermont can be of benefit to Tacoma where the rainy months outnumber the dry months.

Also in 2016, the Washington State Legislature enacted Washington Administrative Code (WAC) Title 51, Chapter 50-51, Section 427 (WAC 51-50-0427) that created updated rules pertaining to EV infrastructure. Specifically, WAC 51-50-0427 required that building code for certain groups of new construction meeting a designated minimum number of parking spaces be required to be electrically EV-ready and able to accommodate a certain percentage of EV designated parking spaces, of which one must be designated an accessible parking space[100].

In 2017, the Office of Energy Efficiency and Renewable Energy of the US DOE released their National Plug-In Electric Vehicle Infrastructure Analysis. The analysis is focused on non-residential EVSE infrastructure and meeting future demand and expectations for EVSE network coverage. The analysis does not attempt to forecast or predict future plug-in EV (PEV) markets but rather create a method and framework for meeting anticipated infrastructure demand. A central scenario of 15,000,000 PEVs (20% of light duty vehicle sales) for 2030 is used. From this central scenario, conclusions are drawn for four regions: cities, towns, rural areas, and interstate corridors. These conclusions can be used as a check and balance tool when estimating the amount of infrastructure required to meet a future demand scenario. For instance, the analysis yielded that for a city, such as Tacoma, to meet the demand for the central scenario, 36 level 2 plugs (note plugs and not stations) per 1,000 PEVs and approximately 1.5 DCFC plugs per 1,000 PEVs would be required[101]. These numbers can serve as a reference for future forecasting of infrastructure needs.

Appendix II: Explanation of GIS Data and Analysis

Collecting and preparing the data

- **Commercial and governmental business:** They refer to places like single parks, banks, schools, shops and stores, malls, restaurants, and bars in the city. The Tax Parcel shapefile from the Tacoma GIS platform was used. Only parcels with commercial and government services related usages were pulled from the database for the analysis. Zip code 98421 was excluded as it is established as heavy industrial by the City of Tacoma.
- **Road network:** This data refers to the road network of the examined area in a geospatial format. The shapefile was downloaded from the Tacoma GIS platform. It consists of polyline feature data. This shapefile was used to create an ArcGIS street network and to create a point shapefile with the highway exits to the Tacoma urban center.
- **Existing charging infrastructure:** The data was download from the EPA - Alternative Fuel Data Center[102]. The spreadsheet document was digitized and geo-coded in ArcGIS for the analysis described below.

Creating the raster maps

- **Proximity to EVSE:** The proximity of stations was calculated based on Euclidean distance. The number of stations in a finite radius was estimated using distance breaks below and above one-quarter of a mile. According to the Traditional Neighborhood Development model, one-quarter mile is a tolerable walking distance to ensure convenient accessibility to land uses from the stations[103].
- **Density of EVSE:** The number of EVSE was used in the population field, and a search of 0.25 miles was defined to create a Kernel density raster considering the number of stations per location. The raster was reclassified by a 0.5 standard deviation.
- **Commercial and governmental density:** Our analysis prioritizes areas with higher percentages of parcels attracting opportunity trips. To incorporate this factor in the analysis, the shapefiles of commercial and governmental parcels was first converted in a point shapefile. Then, a raster based on point density considering the parcel size was produced. Finally, this raster was reclassified by a 0.5 standard deviation.
- **Proximity to highway:** A service area around the highway interchanges within 0.5 miles (value that represents vehicle access for corridor's users to mimic WSDOT distance model)[104]. The cost of the network was defined as the driving distance; for which a service area was created based on the network analysis ArcGIS tool. The analysis that yields a buffer polygon buffer, which then was converted into a raster feature.