WORKING PAPER 2021-04

JANUARY 2021

City charging infrastructure needs to reach electric vehicle goals: The case of Seattle

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Keywords: Cities, electric vehicles, charging infrastructure, equity

Executive summary

Motivated by the critical need for clean air and a stable climate, many cities have set ambitious goals to significantly accelerate zero-emission vehicle deployment and are starting to plan accordingly with supporting infrastructure and policy. Seattle is an example with its commitment to have 30% electric vehicles on the road by 2030. This goal is part of Seattle's vision to address climate change and reduce transportation pollution by developing policies centered around environmental justice.

This report evaluates the electric vehicle (EV) charging infrastructure needs for Seattle to reach its EV goal. It quantifies the number, type, and distribution of home, workplace, and public charging across Seattle and assesses several sociodemographic factors to inform more equitable and inclusive deployment in the near term. The paper further shares examples of equitable EV infrastructure planning approaches and concludes with policy recommendations that cities can consider while planning and developing charging infrastructure strategies to meet their EV and equity goals simultaneously. We draw the following conclusions and recommendations from the analysis.

Cities with aggressive EV goals, like Seattle, need to rapidly deploy their charging infrastructure. Although local factors like rates of vehicle ownership, commuting and housing patterns, population density, and land use impact the specific charging infrastructure composition, cities with EV goals require substantial charging infrastructure deployment. For Seattle, the vehicle demand-based charger need projection finds that meeting its 30% EV stock by 2030 goal requires approximately 2,900 public Level 2 chargers and 860 DC fast chargers to support 174,000 EVs on the city's road in 2030, which is over five-times more than the number of public chargers

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Acknowledgements: The authors thank Michael Nicholas and Dale Hall for input on underlying data and methods. This work was done in coordination with, and data support from, the Seattle Mayor's Office of Sustainability and Environment and Seattle City Light. The authors also thank Andrea Pratt with the City of Seattle and Mike Nicholas, Dale Hall, Anh Bui, and Marie Rajon Bernard of the International Council on Clean Transportation for their critical reviews and constructive input on an earlier version of the report. Conclusions are not necessarily endorsed by the City of Seattle, and any errors are the authors' own.

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installed through 2019. In 2030, these EVs and the approximately 63,000 EV commuters from out of the city would consume approximately 1,530 MWh daily, or 10% of Seattle City Light's average daily generation. In 2020, there are about 17 EVs for each public charger, and this ratio increases to about 47 EVs per public charger by 2030 as capacity increases in a maturing market.

Home charging is a fundamental component of EV charging infrastructure, but not everyone has access to it. In our analysis based on the charging behavior of early adopters, home chargers account for close to 90% of all chargers and they provide over half of the energy to the EVs in the city. While home charging is a key pillar in the charging ecosystem, the need for more public charging options becomes more prominent as the market matures and EV adoption becomes more widespread. Home charging typically offers the lowest installation and energy cost which maximizes the economic benefits of EVs, but EV owners without access to private garages or dedicated off-street parking who rely more on charging elsewhere face greater barriers to adoption, both perceived and real. To overcome this barrier, alternative residential charging options, including curbside or streetlight chargers, that are accessible to all residents, would ideally be deployed where possible.

The distribution of charging infrastructure is important to EV adoption equity. This analysis considers two approaches to infrastructure planning: a private vehicle demand-based charger projection and a geospatial multicriteria equity analysis. Comparing the two approaches reveals relative gaps and opportunities for more equitable and inclusive near-term deployment of infrastructure by focusing on the communities and individuals that stand to benefit most. For example, targeted deployment in neighborhoods like Northgate, Olympic Hills, Delridge, and Beacon Hill will be important to expand infrastructure access and the associated economic benefits in priority communities across the city. This comparison underscores the need for a multi-pronged charging infrastructure planning approach for more effective, efficient, and equitable use of public assistance.

Cities have many tools to remove or reduce the infrastructure deployment barriers. Cities play an important role in supporting EV adoption and charging infrastructure deployment. City policies and programs can lower the EV charger deployment barriers and, when appropriate, fill the access gap and the market gap to prevent disparities from widening. For example, cities can create preferential and preapproved charger sites to promote investments in priority communities. Cities can also consider funding application-based residential curbside chargers for families meeting certain sociodemographic criteria in locations with a greater opportunity for charger sharing, such as areas with predominately apartments without off-street parking. City policies ideally would be guided by its determined role in charger deployment; whether through owning, operating, or supporting the installation. All city policies would ideally be viewed through the lens of community development and equitable access.

Table ES-1. Summary of key findings and policy recommendations.

Key findings	Policy recommendations
Seattle's aggressive EV goal means rapid charger deployment is needed	• Develop strategy to deploy 72,000 home chargers, 2,900 public Level 2 chargers, 860 DC fast chargers, and 4,100 workplace chargers by 2030 to support 174,000 EVs • Bolster and steer private sector and utility investment toward priority communities
Home charging is fundamental to EV charging infrastructure, but not everyone has access to it	• Pursue alternative residential options including curbside or streetlight chargers • Prioritize deployment in underserved areas by preapproving and streamlining • Work with drivers and residents to identify key locations for residential style charging, including application-based programs
The distribution of charging infrastructure is important to EV adoption equity	• A comprehensive multi-pronged approach to infrastructure planning is needed • Leverage equity frameworks and community networks to guide the charging strategy • Provide income-based financial assistance for public and residential chargers
Cities have many tools to remove or reduce the infrastructure deployment barriers	• Spur private investment through EV-ready codes, permitting, zoning, priority access • Create preferential and preapproved charging locations in priority communities • Identify and fill gaps in the public and residential charging network with public funds

Introduction

Motivated by the critical need for clean air and a stable climate, many cities have set ambitious goals to significantly accelerate zero-emission vehicle deployment and are starting to plan accordingly with supporting infrastructure and policy. In the United States, Denver, Houston, Los Angeles, Memphis, Sacramento, San Francisco, and Seattle have each set quantitative targets for much greater electric vehicle sales (EV) and stock over the 2025 to 2035 timeframe.[1] These EV targets range from 30% of new vehicle sales in 2030 in Houston to 100% zero-emission vehicles across the entire stock by 2050 in Los Angeles.

EVs and charging infrastructure grow in unison. Widespread charging infrastructure deployment at homes, workplaces, and public locations is critical to facilitate the transition to EVs. Home chargers currently provide the majority of EV charging and are typically the least expensive option to install and use. However, moving beyond the early market to widespread mass adoption necessitates broader charging options at workplaces and conveniently placed public locations, especially for EV drivers without home charging access such as those in apartments or without dedicated off-street parking.

A key first step in transitioning to electric mobility is setting EV adoption goals and understanding the type, amount, and distribution of charging infrastructure required to support it. At the same time, many cities are committed to providing equitable and inclusive zero-emission mobility options to all residents and communities within their jurisdictions. There is not a surefire way for cities to achieve ambitious EV goals while ensuring equitable and inclusive access, but there is a clear and critical need to center equity in the planning process. This working paper quantifies charging needs in the City of Seattle—a city that aims for EVs to make up 30% of vehicles owned by 2030, and where race and social justice is a priority in its environmental and clean transportation agenda. The analysis quantifies the number, type, and distribution of EV charging infrastructure needs across Seattle and assesses several sociodemographic factors to inform more equitable and inclusive infrastructure deployment in the near-term.

1 Anh Bui, Peter Slowik, & Nic Lutsey, *Update on electric vehicle adoption across U.S. cities,* (ICCT: Washington DC, 2020), https://theicct.org/publications/ev-update-us-cities-aug2020

This technical working paper presents two approaches to EV charging infrastructure planning: (1) a private vehicle demand-based charger projection ("charger need analysis") and (2) a geospatial multicriteria analysis based on sociodemographic and other factors that have equity and charger utilization implications ("equity analysis"). The first approach investigates the charging infrastructure needs and the associated energy demand from 2020 through 2035 under scenarios where EVs reach 30%, 50%, and 100% of passenger vehicle stock by 2030. The second approach illuminates potential near-term charger locations where public funding can yield positive equity outcomes when EVs are more prevalent. The paper further shares exemplary examples of equitable EV infrastructure planning approaches and offers policy recommendations that cities can consider while planning and developing charging infrastructure strategies to meet their EV and equity goals simultaneously.

Analysis

Adapting an approach applied in previous studies,[2] we assess the home, workplace, and public charger needs for the private vehicle demand-based charger need analysis based on Seattle's goals for EV market growth through 2030. EV stock is a primary input to the analysis and is informed by the EV uptake rate and a vehicle stock-turnover model. Charging behavior in early EV markets and average charger utilization are primary inputs to estimate the number of chargers needed. The following summarizes the key methodological steps.

The charger need analysis can be summarized into three separate components: (1) EV fleet composition, (2) charging energy demand projection, and (3) charging infrastructure projection. The charger types included in the charger need analysis are shown in Table 1. For this analysis, workplace chargers serve only the EV commuters at workplaces, and public chargers are assumed to serve both the public as well as commuters who do not have workplace charger access.

Table 1. Types of chargers included in the analysis and their technical specifications.

Charger type	Voltage	Typical power (kW)	Assumed energy per charging session in 2020 (kWh)	
			BEV	Plug-in hybrid EV
Home Level 1	120 V AC	1.2-1.4	11.5	6.5
Home Level 2	208 - 240 V AC	3.3-3.6	11.5	6.5
Workplace	120 - 240 V AC	1.2-6.6	15.5	7.5
Public Level 2	208 - 240 V AC	3.3-6.6	5.5	3.25
Public DC fast	400 - 1,000 V DC	50 or more	16	N/A

Electric vehicle fleet composition

Figure 1 shows the EV sales share and EV stock share in Seattle by 2035 for the 30% EV stock by 2030 scenario (orange) and 50% EV stock by 2030 scenario (green) where the hashed lines represent EV share of vehicle stock and the solid lines represent EV share of new vehicle sales. Based on underlying vehicle retirement characteristics and

2 Chih-Wei Hsu, Peter Slowik, Nic Lutsey, *City charging infrastructure needs to reach 100% electric vehicles: The case of San Francisco,* (ICCT: Washington, DC, 2020), https://theicct.org/publications/sf-ev-charging-infra-oct2020; Michael Nicholas, Dale Hall, Nic Lutsey, *Quantifying the electric vehicle charging infrastructure gap across U.S. markets,* (ICCT: Washington, DC, 2019), https://theicct.org/publications/charging-gap-US.

stock turnover model,[3] the EV share of new vehicles is about 40% in 2025 and about 85% in 2030 under the 30% EV stock by 2030 scenario. For the 50% EV stock by 2030 scenario, EVs account for about 90% of new vehicle sales by 2025 and 100% by 2027. New EVs include both battery electric and plug-in hybrid electric vehicles, with a shift from new sales being 75% battery electric in 2018 to 100% by 2030. These scenarios reflect a rapid increase in EV share of new vehicles across Seattle.

The citywide vehicle sales are allocated to each zip code based on observed vehicle ownership patterns and population size.[4] For commuters living outside of Seattle that commute into the city, we assume EV adoption in the Seattle metropolitan area lags the city trend by three years.

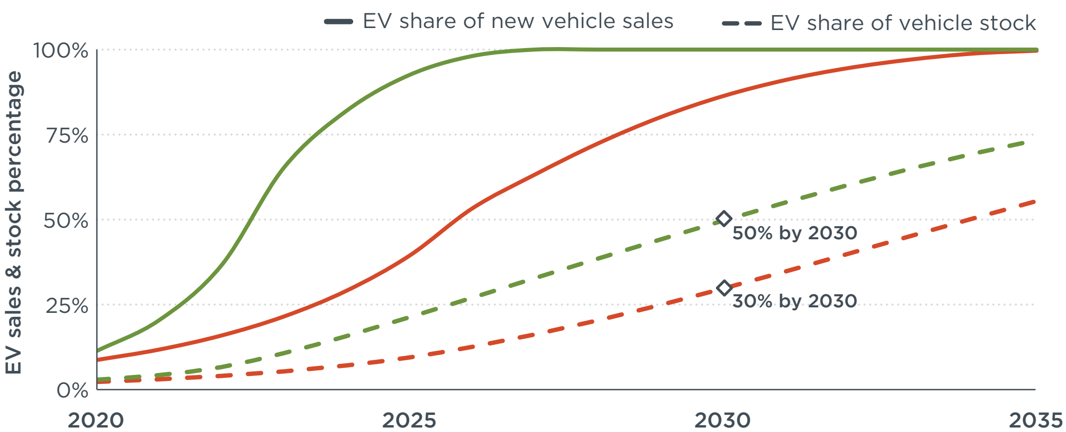

Figure 1. Seattle EV sales and stock projection for the 30% EV stock by 2030 (orange) and 50% EV stock by 2030 (green) scenarios.

Several additional assumptions are important in the vehicle stock turnover model of old vehicles retiring and new vehicles entering the fleet. The analysis assumes that annual LDV sales are reduced by 2% each year to reflect Seattle's goal of reducing the number of LDVs on the road by 27% by 2030.[5] However, this rate of decline is insufficient to fully reduce LDV stock by 27% by 2030, suggesting that policy measures such as an early vehicle retirement program are needed to achieve this goal. Figure 1 does not show the 100% EV stock by 2030 scenario because doing so requires an EV sales share of 100% before 2020 due to the slow fleet turnover. Therefore, we do not develop an EV sales curve and instead assume that the entire projected LDV stock is electric in 2030 and report 2030 values only. Although zip code level EV shares differ across Seattle through 2019, all zip codes are assumed to reach the same EV shares in the 2025-2030 timeframe. Relative differences in vehicle ownership per capita by zip code remain identical to 2018 across all years, reflecting general density, housing, and parking patterns across the city.

Charging energy demand projection

Charging energy demand for each charger type is calculated based on the number of EVs applicable for the given charger, the applicable charging events per vehicle per

3 More detailed method description of the EV sales curve and vehicle survival rate can be found in Appendix A.

4 We include the complete zip code boundaries for the analysis even if they are partially outside of the City of Seattle.

5 Seattle Department of Transportation, "New mobility playbook" (2017), https://www.seattle.gov/Documents/Departments/SDOT/NewMobilityProgram/NewMobility_Playbook_9.2017.pdf

day based on a California charging behavior survey,[6] and the energy consumption per charging event.[7] Charging behavior is determined based on three main factors: (1) EV technology (i.e., battery electric or plug-in hybrid electric); (2) housing characteristics, which determine the likelihood of having home charging access; and (3) whether the driver uses the EV to commute. Public charging energy demand and demand for home chargers increase with the growth in EV registrations. The overall housing characteristics of EV drivers shift over time, as the market moves beyond early adopters (i.e., primarily in detached homes) to universal uptake, ultimately resembling each zip code's housing characteristics. The analysis of housing characteristics and home charging access incorporates Seattle's EV ready building code, such that 20% of parking in new apartments are assumed to be EV charger ready, as mandated in the recent city measure.[8] Each residential charger in apartments is assumed to serve two EVs.

Workplace charging demand is a function of the number of commuter EVs going into each zip code,[9] including both intra-city commuters and those commuting into the city from elsewhere. For the EV owners living in the city, we assume that 80% commute with their EVs in 2020. The percentage of EV drivers that commute to work gradually declines to 45% by 2050, which represents the percentage of all drivers that commuted with their vehicles—including both internal combustion engine and electric vehicles—in 2017.[10] We estimate approximately 13% of Seattle EV commuters leave the city for work; we do not include their workplace charging demand in the city's charging need analysis. We estimate about 284,000 LDVs commute into Seattle daily from outside of the city.[11] We assume 10% (in 2020) to 12% (2035) of all EV commuters, both intra-city and from outside the city, have access to workplace chargers. Lastly, for the intra-city commuters, the unfulfilled workplace charging demand is allocated to be supplied by public and home chargers.[12] And for the commuters from outside the city, their unfulfilled workplace charging demand is assumed to be supplied outside of the city, thus it does not impact the public and home charging demand in the city.

6 Gil Tal, Jae Hyun Lee, Michael Nicholas, *Observed charging rates in California,* (Institute of Transportation Studies: Davis, CA, 2018), https://escholarship.org/uc/item/2038613r

7 See Appendix A for the EV driver topology, their associated daily charging events, and the energy supplied per charging event.

8 *"Statement by Mayor Jenny Durkan on City Council's Vote to Approve Her Legislation That Ensures More New Seattle Buildings Are Ready for Electric Vehicles",* Office of the Mayor, accessed August 17, 2020, https://durkan.seattle.gov/2019/04/statement-by-mayor-jenny-durkan-on-city-councils-vote-to-approve-her-legislation-that-ensures-more-new-seattle-buildings-are-ready-for-electric-vehicles/. We assumed the average annual change of apartment units is 1.1%, as informed by pg. 16 in U.S. Department of Housing and Urban Development Office of Policy Development and Research, "Comprehensive Housing Market Analysis" (2017). https://www.huduser.gov/portal/publications/pdf/SeattleWA-comp-17.pdf.

9 Workplace charging demand at the zip code level is assessed based on the job distribution in Seattle; data provided by the City of Seattle.

10 Calculated using commute mode reported in the 2017 American Community Survey data and the vehicle sales data provided by city staff. The change of the percentage of EV owners that commute with EVs year-to-year is related to the EV adoption rate (i.e., percentage of EVs in the overall LDV fleet). It is calculated by assuming that as EV adoption rate reaches 100%, the EV drivers commute with EV reach 45%—the percentage of current vehicle owners that commute with their vehicles. The percentage of EV owners commuting with EVs each year is interpolated based on the initial year's EV adoption rate.

11 EV commuters commute in and out of the city for work is informed by the trips origins and destinations using the LEHD origin-Destination Employment Statistics (LODES) data (accessed August 17, 2020), https://lehd.ces.census.gov/data/. To account for only the trips made by vehicles but not other modes of transportation (e.g., bus, carpool), the commute trips were converted to vehicles using the commuter to vehicle ratio calculated using the American Community Survey data (accessed August 17, 2020), https://www2.census.gov/geo/tiger/TIGER2017/ZCTA5/.

12 The allocation of the unfulfilled workplace charging demand can be found Table A4 in Appendix A.

Charging infrastructure projection: Public, home, and workplace chargers

The number of home chargers needed in detached and attached homes is estimated based on the number of EV owners with access to home charging divided by the average number of vehicles in a household, accounting for the shared use of a single charger within a household.[13] For apartments, the analysis assumes each residential charger can serve two EVs. The ratio of home Level 1 to home Level 2 charger are determined based on the home charger availability suggested by the same Institute of Transportation Studies survey.[14] For workplace chargers, we assume that 10% of EV commuters have access to a charger at work, and the projections are estimated by dividing the total workplace charging events per day required by commuters by the assumption that each workplace charger supports 1.5 charging events a day.

For public Level 2 and DC fast chargers, we estimate charger needs by dividing the daily energy demand projections by the daily average amount of energy supplied by the chargers. The energy supplied is derived from the chargers' average daily plugged-in time and the average power supplied. The average power supplied is estimated at 4.6 kW for Level 2 chargers and 26.4 kW for DC fast chargers in 2020, increasing to 8 kW for Level 2 chargers and 130 kW for DC fast chargers by 2035, due to the improvement of vehicle and charger technology. Based on charger utilization data in similar markets, the analysis assumes that the utilization of public Level 2 and DC fast chargers in 2020 is 4.6 hours per day and 2.4 hours per day, respectively. Beyond 2020, charger utilization increases in the manner identical to the observed changes in the EV-to-charger ratio as a function of EV adoption.[15] Table 2 shows the assumed public charger utilization in 2025, 2030, and 2035. The utilization capacity is dependent on the EV adoption rate, such that higher EV adoption leads to higher charger utilization.

Table 2. Assumed public charger utilization in Seattle from 2025 to 2035.

Charger	Utilization	30% EV stock goal			50% EV stock goal			100% EV stock goal
		2025	2030	2035	2025	2030	2035	2030
Public Level 2	Time (hour/day)	6.0	7.0	7.4	6.7	7.4	7.7	8.1
	Energy (kWh/day)	40.7	52.6	59.5	45.6	56.1	61.6	61.0
DC fast	Time (hour/day)	3.3	4.0	4.3	3.8	4.3	4.4	4.7
	Energy (kWh/day)	312	462	556	355	496	577	542

In addition to the central analysis of charger needs presented above, we investigate how meeting Seattle's goal of shifting mobility toward more sustainable trips effects EV charging infrastructure needs. Specifically, we analyze Seattle's goal of shifting mobility to modes other than driving alone to 65%–75% by 2035. This sustainable trip case is compared to the central case which does not consider a broader mobility shift. To do so, we estimate the annual decline in private vehicle trips based on the current sustainable trip rate of each zip informed by the American Community Survey to meet Seattle's

13 2017 TIGER. (accessed August 17, 2020), https://www2.census.gov/geo/tiger/TIGER2017/ZCTA5/.

14 Gil Tal, Jae Hyun Lee, Michael Nicholas, *Observed charging rates in California*

15 See the trends and descriptions of the method on page 14 in Michael Nicholas, Dale Hall, Nic Lutsey, *Quantifying the electric vehicle charging infrastructure gap across U.S. markets,* (ICCT: Washington, DC, 2019), https://theicct.org/sites/default/files/publications/US_charging_Gap_20190124.pdf.

goals as outlined in its 2035 Comprehensive Plan.[16] The vehicle travel demand decrease applies to both the commuters in the city and the commuters coming from elsewhere.

Equity analysis

To complement the demand-based charger need analysis, we complete a sociodemographic-based equity analysis highlighting the communities that may need additional government assistance in near-term charger deployment. We follow the similar spatial multicriteria approach used in Portland's EV charging location study and Seattle's own EVSE (electric vehicle supply equipment) Dynamic Siting Tool to investigate the opportunities for more equitable and inclusive EV infrastructure planning and deployment.[17] This is achieved by overlaying seven selected factors that have implications for either charger utilization or equitable access.

We divide the city into hexagons with 0.14 miles radius spaced 0.25 miles apart. For each hexagon and the area it represents we tally the following factors:

1. Lack of access to current public chargers, impacting the utilization of the new chargers
2. Close proximity to major freeways, indicating the potential utilization from corridor traffic
3. High density of multi-unit dwellings, increasing the potential public charger utilization due to lower home charger access in the area
4. Close proximity to selected points-of-interest where visitors tend to stay for a longer period of time, also impacting the potential utilization[18]
5. Low median household income, reflecting the economic disadvantage of the area
6. High concentration of the person-of-color residents, emphasizing charger access for the historically underserved
7. Health disadvantage, focusing on areas with higher health burden

The hexagons where all seven factors apply are considered high-priority communities with socioeconomic disadvantages (based on factors 5 through 7) where public chargers may experience high utilization (based on factors 1 through 4). Steering infrastructure deployment and associated complementary outreach and engagement efforts toward these communities can potentially help to fill gaps in the charging network and provide more equitable and inclusive access. Table 3 further summarizes the seven factors and how they are measured.

16 Seattle Office of Planning & Community Development, "Seattle 2035 Comprehensive Plan" (2019), http://www.seattle.gov/opcd/ongoing-initiatives/comprehensive-plan.

17 "Electric Vehicle Composite Analysis", City of Portland, updated July 31, 2020, https://www.arcgis.com/home/item.html?id=ffae460eaec94a7a8c3504a139e0c89a; "Seattle EVSE siting model", City of Seattle, updated October 10, 2019, http://evsharedmobility.org/resource/seattle-evse-siting-model/.

18 See Appendix B for the list of points-of-interest considered

Table 3. Factors considered in the spatial overlay charger need analysis.

	Factor		How it is measured	Analysis unit
Charger utilization factors		No immediate access to existing EV chargers[a]	More than 0.25 miles away from the nearest charger	Actual location
		Close proximity to primary and secondary roads[b]	Within 0.25 miles from interstate highways and state freeways, i.e., Hwy 5, 90, 99, 509, 520, 522, and 523	Actual location
		High multi-unit dwelling concentration[c]	Higher than the city's third quartile (i.e., 2266 units per square mile)	Block group
		Close proximity to selected points-of-interest (POIs)[d]	Within 0.1 miles from the nearest selected POIs	Actual location
Equity implication factors		Lower median household income[c]	Lower than the city's first quartile (i.e., $69,265 per year)	Block group
		Demographic makeup[c]	More than 50% of residents are persons of color	Block group
		Health disadvantage priority[e]	Of the highest and second highest priority as determined in the City's Racial and Social Equity Index	Tract

[a] Data from "Electric Vehicle Charging Station Locations", Alternative Fuels Data Center at U.S. Department of Energy, accessed on August 17, 2020, https://afdc.energy.gov/fuels/electricity_locations.html#/find/nearest?fuel=ELEC

[b] 2017 TIGER/Line Shapefiles: Roads (accessed on August 17, 2020), https://www.census.gov/cgi-bin/geo/shapefiles/index.php?year=2017&layergroup=Roads.

[c] 2017 TIGER. (accessed August 17, 2020), https://www2.census.gov/geo/tiger/TIGER2017/ZCTA5/

[d] King County tax parcel centroids with select City of Seattle geographic overlays (accessed on August 17, 2020), https://data-seattlecitygis.opendata.arcgis.com/datasets/king-county-tax-parcel-centroids-with-select-city-of-seattle-geographic-overlays

[e] Racial and social equity composite index (access on August 17, 2020), https://data-seattlecitygis.opendata.arcgis.com/datasets/225a4c2c50e94f2cb548a046217f49f7_0

Results

The charger need analysis results are summarized on a citywide level to convey the scale of increasing infrastructure needs, followed by zip code-level results to illustrate the variation between zip codes. The results are shown for the central case as well as the sustainable trip case that could reduce charging needs. The charger equity analysis follows the charger need analysis and shows the charger equity implications at a higher spatial resolution, and the results of the two analyses are compared.

Electric vehicle charging infrastructure needs

Meeting the city's EV goals requires significant charger deployment. Figure 2 shows the citywide EV stock and associated number of public chargers needed in 2025 and 2030 in the central case, where sustainable trip increase is not considered. The charging infrastructure results are shown for the three 2030 EV stock scenarios: 30% (solid bars), 50% (thicker hashed bars), and 100% (thinner hashed bars). The different color bars represent the number of chargers needed, where blue is public Level 2 and red is DC fast. Home and workplace chargers are not shown. Figure 2 shows how the number of public chargers will need to increase significantly, from about 700 in 2020 to about 1,700 in 2025 and 3,700 in 2030, based on the 30% EV stock by 2030 scenario. About 25% of the public chargers needed in 2030 are DC fast. Compared to the 30% EV stock by 2030 scenario, achieving 50% EV stock by 2030 requires about 50% more public chargers.

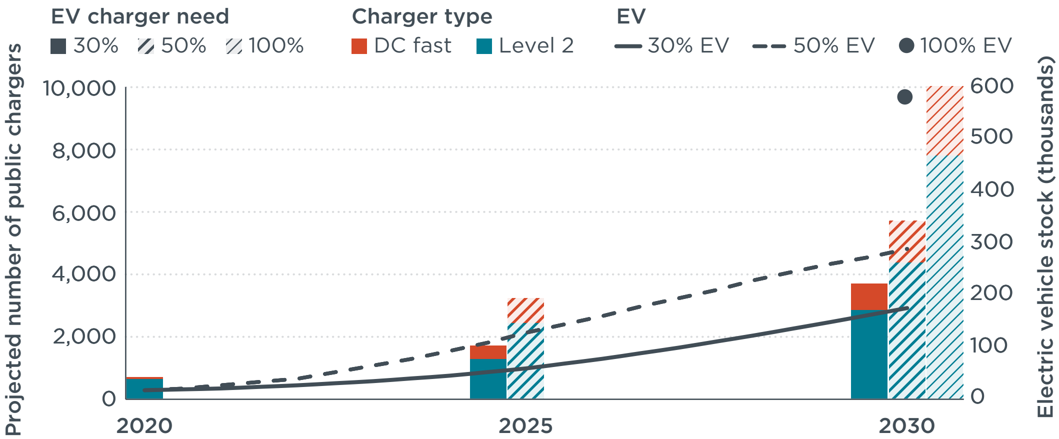

Figure 2. Seattle public charging infrastructure needed to support 30%, 50%, and 100% EV stock by 2030.

Several other points provide context to the results shown in Figure 2. By the end of 2019, Seattle had about 19%, 12%, and 7% of the public chargers needed in 2030 for the 30%, 50%, and 100% EV stock scenarios, respectively. Under the 30% EV stock scenario, an annual charger growth rate of 19% is needed in the first half of the 2020 decade to reach 2.4 times the 2020 charger count for 2025. And for the 2026 to 2030 period, a 17% annual charger growth rate is needed to reach 5.3 times the 2020 charger count for 2030.[19] A higher charger growth is needed in the first half of the decade; corresponding with relatively faster growth in EV uptake. Relatively slower growth in later years is also due to faster average charging speeds (kW) and greater average charger utilization (hours per day).

Based on Seattle's goals to reach 30%, 50%, and 100% EV stock, about 174,000, 289,000, and 578,000 EVs, respectively, could be on the road in 2030. The EV sales and stock projection curves based on the 30% and 50% EV goals are shown in Figure 1. In order to achieve 30% EV stock by 2030, EV sales need to reach approximately 40% of all LDV sales by 2025 and 87% by 2030. For the 50% EV stock by 2030 scenario, EV sales needs to reach 93% by 2025 and 100% by 2027. As discussed in the method section, even if the city sustains 100% EV sales starting in 2020, it falls short of 100% EV stock by 2030. Based on the stock turnover model, EVs reach approximately 68% of the LDV stock in 2030.

Figure 3 shows a more detailed breakdown of charging infrastructure needs across Seattle. It shows the home, public, and workplace charger needs in 2025, 2030, and 2035 for the central case and sustainable trip case under the three 2030 EV stock scenarios. The projections of home chargers are shown along the top of the figure, disaggregated by detached, attached, and apartment housing types. Public and workplace chargers are shown along the bottom of the figure. Results for the central case are shown by the hashed bars while the sustainable trip case results are shown by the solid bars.

19 See Appendix C for the summary table of the citywide charger projections and growth.

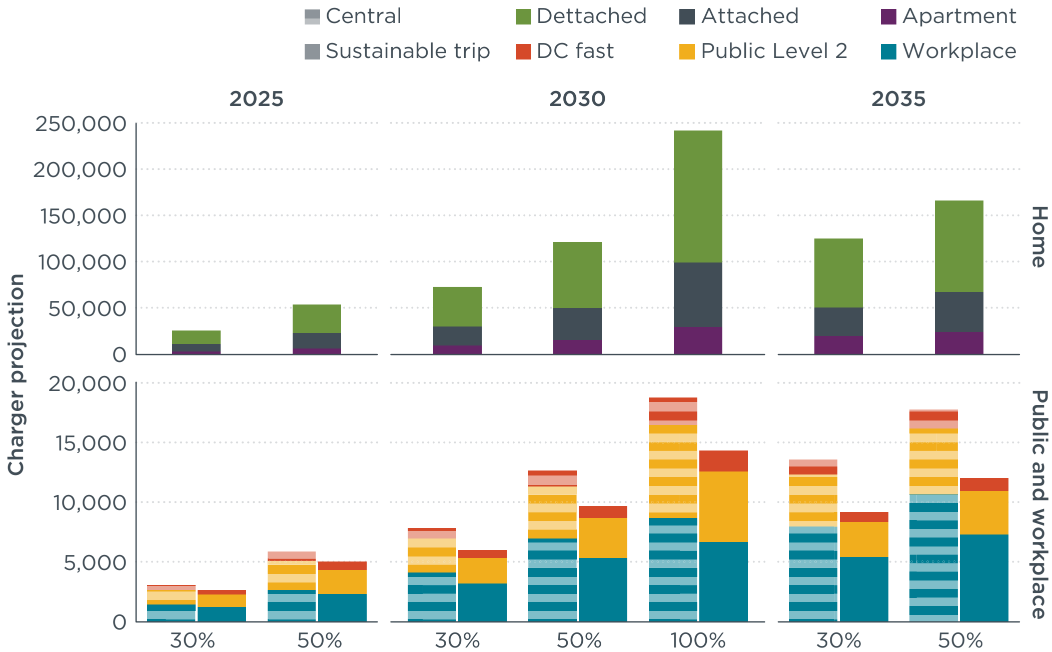

Figure 3. Citywide charger projection in 2025, 2030, and 2035 based on the EV stock goals to reach 30%, 50%, and 100% by 2030. Hashed bars represent the central case and solid bars represent the sustainable trip case. Home charger projections are identical between two cases.

The key results for 2030 are shown in the middle pane. Home chargers are expected to fulfill the majority of charging needs. About 72,000 home chargers are needed in 2030 based on the 30% EV stock by 2030 scenario, which is about 90% of all chargers needed that year. We estimate that about 13% of the home chargers needed in 2030 are in apartments. Under the central case, we estimate 2,900 public Level 2 chargers, 860 DC fast chargers, and 4,100 workplace chargers are needed. The number of public and workplace chargers needed by 2030 is reduced by about 25% under the sustainable trip case. A more detailed summary of public charging infrastructure needs in Seattle is included in Appendix C.

The 50% and 100% EV stock by 2030 scenarios require more home, public, and workplace chargers. The 100% EV stock scenario charger projections can be considered the high-end of needed infrastructure. Our model includes a 2% reduction in annual new LDV sales, so the total number of LDVs on the road plateaus in late 2020s and declines thereafter. If city efforts to reduce total LDV sales and shift mobility away from private car trips are sustained, the 100% EV stock scenario can serve as a reference point for the maximum number of chargers needed, which is about 14,000 public and workplace chargers combined by 2030.

Seattle's EV-ready building code, which requires new buildings with off-street parking to provide electrical outlets for EV charging,[20] can expand home charger access and alleviate some public charging demand. With our estimate, in the 30% EV stock scenario in 2030, the EV-ready building code reduces the projected need of public Level 2 chargers by 92 and DC fast chargers by 35. This is achieved through providing home charger access to approximately 3,800 apartment dwelling EV owners. We model the apartment stock growth with a 1.1% compounded growth rate, which is the historic

20 Seattle City Council. Ordinance 12585, http://seattle.legistar.com/View.ashx?M=F&ID=7226916&GUID=734F02DC-0CF2-419F-8378-02F124F52644.

housing stock growth rate from 2010 to 2017. We also explored a hypothetical doubling of the apartment stock growth rate to 2.2% per year and found that EV-ready building codes bring home charging access to an additional 3,400 EV drivers, reducing public Level 2 charger needs by 81 and DC fast charger needs by 31.

At the zip code level, the zip codes in and surrounding downtown Seattle are projected to need more public chargers relative to other areas. Figure 4 shows the 2030 public charger projection by zip code for the 30% EV stock by 2030 scenario. For each zip code, the numbers in black represent the public Level 2 charger projection, the numbers in blue represent the DC fast charger projection, and the size of the plug icon provides the relative scale of the total public chargers need. Although fewer EVs are registered in the downtown zip codes (98101, 98104, and 9812), these zip codes account for about a third of the jobs in the city and one-third of the destinations of the commuting trips originated anywhere in the city. Therefore, a lot of the commuter EV charging demand that is not accommodated by the workplace chargers would need to be fulfilled by nearby public chargers. In practice, if space or other constraints occur, some of the public chargers projected for downtown zip codes can likely be deployed in the surrounding nearby zip codes to fulfill charging demand. While not shown here, the relative distribution of public chargers needed across the city under the 50% and 100% EV stock by 2030 scenarios follows a similar pattern.

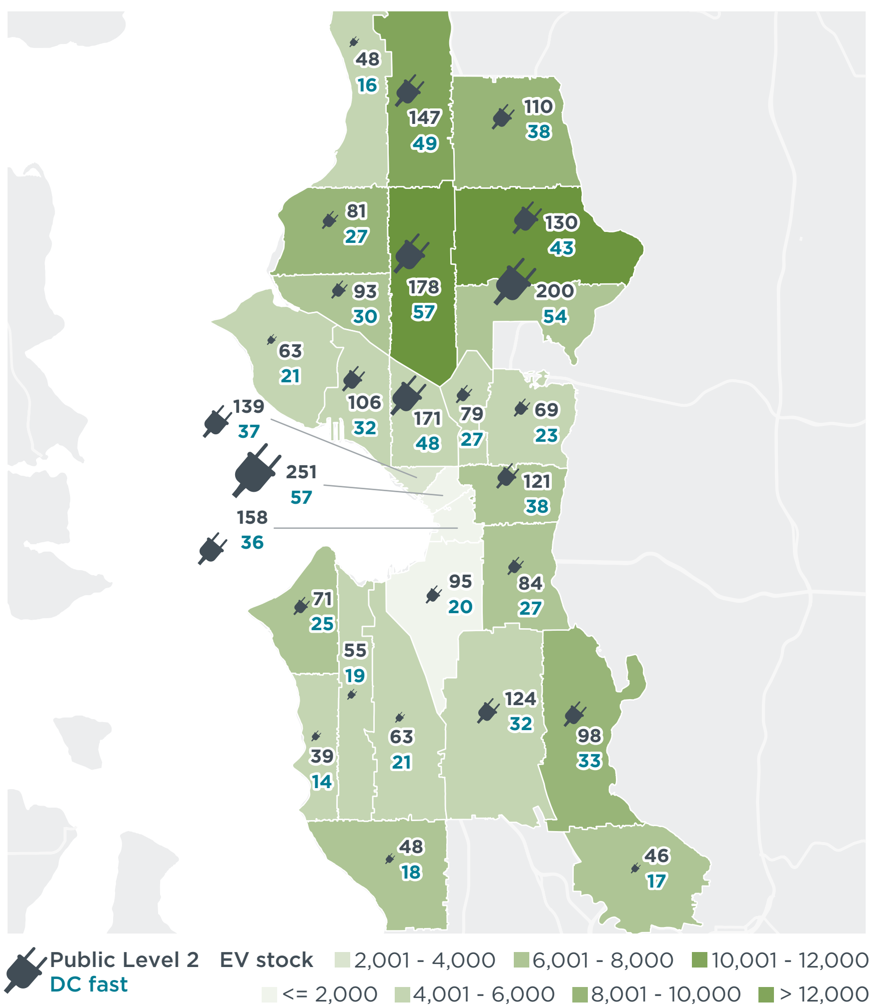

Figure 4. Projected public charger needs in 2030 in the 30% EV stock by 2030 scenario.

The public charger projections are sensitive to inputs regarding charger utilization rates and power capacity, in addition to the local factors such as EV stock, housing characteristics, and commute patterns. The assumed rates of charger utilization in this analysis (Table 2) are informed by observed trends in similar leading but early EV markets. These values are aligned with limited real world charging data in markets with similar characteristics and other analysis of high-uptake markets.[21] Increasing the utilization rates results in a decrease in the public chargers by the same factor, and vice versa. Reaching higher utilization rates becomes increasingly likely as the EV market matures and evolves—shifting from deploying infrastructure for geographic coverage toward reaching higher utilization capacity. Compared to similar analysis for San Francisco,[22] where the land area is roughly half and the population is more than double that of Seattle, the utilization used here is about 10% to 50% lower in 2030, depending on the type of public charger (Level 2 or DC fast) and EV stock scenario.

Electric vehicle charging energy demand

The total daily energy demand of EV charging, measured as megawatt-hours (MWh), is significant. About 520 MWh will be needed daily to power 58,000 EVs by 2025, 1,530 MWh will be needed for 174,000 EVs by 2030, and 2,650 MWh will be needed for 300,000 EVs by 2035 for the 30% EV stock scenario. These respectively represent 4%, 10%, and 18% of Seattle City Light's average daily energy generation in 2019.[23] Table 4 shows the EV charging energy demand for each type of charger for the three 2030 EV stock scenarios in 2025, 2030, and 2035. The table shows daily energy demand for the central case and the sustainable trip case, where mobility shifts from personal vehicles to transit and pedestrian modes. Compared to the central case, energy demand is reduced by 15% in 2025, 24% in 2030, and 33% in 2035 under the sustainable trip case.

Table 4. Projected energy demand from EV charging in 2025, 2030, and 2035 based on 30%, 50%, and 100% EV stock goals, in MWh.

	30% EV stock by 2030			50% EV stock by 2030			100% EV stock by 2030
	2025	2030	2035	2025	2030	2035	2030
Central case, energy demand (MWh)							
Public Level 2	51	151	260	110	247	341	477
Public DC Fast	130	397	692	285	646	900	1,226
Workplace	30	93	185	59	158	248	197
Home	310	890	1,513	654	1,450	1,962	2,720
Total	522	1,531	2,650	1,108	2,501	3,450	4,618
kWh / EV / day	8.8	8.8	8.8	8.7	8.6	8.6	8.0
Sustainable trip case, energy demand (MWh)							
Public Level 2	44	115	175	94	188	229	363
Public DC Fast	111	303	465	243	493	606	936
Workplace	26	71	125	50	121	169	151
Home	264	675	1,006	557	1,099	1,035	2,062
Total	445	1,164	1,772	945	1,902	2,308	3,512
kWh / EV / day	7.5	6.7	5.9	7.4	6.6	5.8	6.1

21 Michael Nicholas, Dale Hall, Nic Lutsey, *Quantifying the electric vehicle charging infrastructure gap across U.S. markets,* (ICCT: Washington, DC, 2019), https://theicct.org/publications/charging-gap-US

22 Chih-Wei Hsu, Peter Slowik, Nic Lutsey, *City charging infrastructure needs to reach 100% electric vehicles: The case of San Francisco,* (ICCT: Washington, DC, 2020), https://theicct.org/publications/sf-ev-charging-infra-oct2020

23 Average daily energy generation in 2019 was 14,800 MWh calculated using Hourly Electric Grid Monitor (accessed on August 17, 2020), https://www.eia.gov/beta/electricity/gridmonitor/dashboard/electric_overview/balancing_authority/SCL.

About 58% of Seattle's 2030 EV charging energy demand is projected to be provided by home chargers, followed by DC fast chargers (26%), public Level 2 chargers (10%), and workplace chargers (6%). Most zip codes follow a similar pattern of proportional demand. Figure 5 shows the EV charging energy demand by charger type for each zip code in 2025, 2030, and 2035. The dots represent the total energy demand under the sustainable trip case. Zip codes that do not follow the citywide pattern of proportional demand are those with predominantly apartment buildings where residents are less likely to have home charger access and thus are more reliant on public charging. In these zip codes (98101, 98104, 98121, and 98134), the energy demand from public charging is similar and sometimes greater than energy demand from home charging.

Figure 5. Daily EV charging energy demand by charger type and zip codes in 2025, 2030, and 2035. The dots represent the total energy demand in the case where the city is on track to achieve the sustainable trip goal.

The proportion of the total charging demand by each charger type is based on assumptions regarding the energy consumption per event and charging events per day. These are derived from the observed behaviors of the early EV adopters in California. Public charging infrastructure is not fully developed in the early market, and early adopters in California typically live in detached homes and have the greatest potential to access home charging. This suggests that the charging behavior of early adopters may be more skewed toward home charging than the majority market.[24] Home charging

24 EV Consumer Survey Dashboard (accessed on August 17, 2020), https://cleanvehiclerebate.org/eng/survey-dashboard/ev.

provides many benefits. It is typically the easiest to install, is the most cost-effective in terms of both energy and installation costs, and it provides demand management flexibility for the electric grid due to EVs' long dwell times. Home charging is a fundamental piece of the EV charging ecosystem but not everyone has access to it. It therefore poses an infrastructure equity challenge and opportunity as examined in more detail below.

Transitioning to EVs provides significant greenhouse gas emission reduction benefits relative to combustion cars. These benefits are especially significant in areas like Seattle where the carbon intensity of electricity generation is very low, about 14 kg CO_2/MWh in 2009;[25] which is about 2% of the U.S. national average.[26] By 2030, in the 30% EV stock scenario, we estimate 0.7 million metric tonnes (MMT) of CO_2 equivalent can be avoided annually. In the 2020 to 2030 period, the 30% EV stock scenario leads to a cumulative 3.4 MMT of CO_2 equivalent abatement. For the 50% EV stock scenario, 1.1 MMT is abated in 2030 and a total of 6.2 MMT is abated in the time period of 2020 to 2030. In the 100% EV stock scenario, the CO_2 equivalent avoided is roughly double that of the 50% EV scenario. Because Seattle City Light purchases carbon offsets to mitigate the emissions from electricity generation, the overall emission abatement from the EV transition are further increased.

Charger equity analysis

The spatial multicriteria charger equity analysis—as a snapshot of 2020—shows locations where, in the near term, targeted and intentional deployment could fill gaps in the public charging network and have positive equity implications by broadening access. We equally weight the factors regarding a location's (1) current access to public chargers, (2) proximity to major freeways and highways, (3) density of multi-unit dwellings, (4) proximity to selected points-of-interest, (5) level of household income, (6) concentration of the person-of-color residents, and (7) health disadvantage. As shown in Figure 6, the following listed neighborhoods and areas are those where six or all seven factors apply:

» Lake City (98125)

» North gate-Haller Park-Broadway region (98133)

» University District (98105)

» Chinatown-Central District-Judkin Park Station region (98104 and 98144)

» New Holly and along Rainier Ave (98118)

» East of and along Freeway 509-Freeway 99 junction south of the Duwamish Waterway (98106 and 98108)

These areas stand to benefit significantly from near-term charger deployment in terms of encouraging and improving ease of EV operation for the residents and attracting commercial activity to the local businesses and communities through their proximity to charging infrastructure. Public charging infrastructure policies and programs would ideally be steered toward these neighborhoods and individuals to advance EV equity and inclusion.

25 Seattle Office of Sustainability & Environment, "City of Seattle Municipal Greenhouse Gas Emission Inventory" (2010), https://www.seattle.gov/Documents/Departments/OSE/Muni-GHGInventory_2010.pdf

26 "Greenhouse Gases Equivalencies Calculator - Calculations and References", United States Environmental Protection Agency, accessed on November 18, 2020, https://www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculations-and-references.

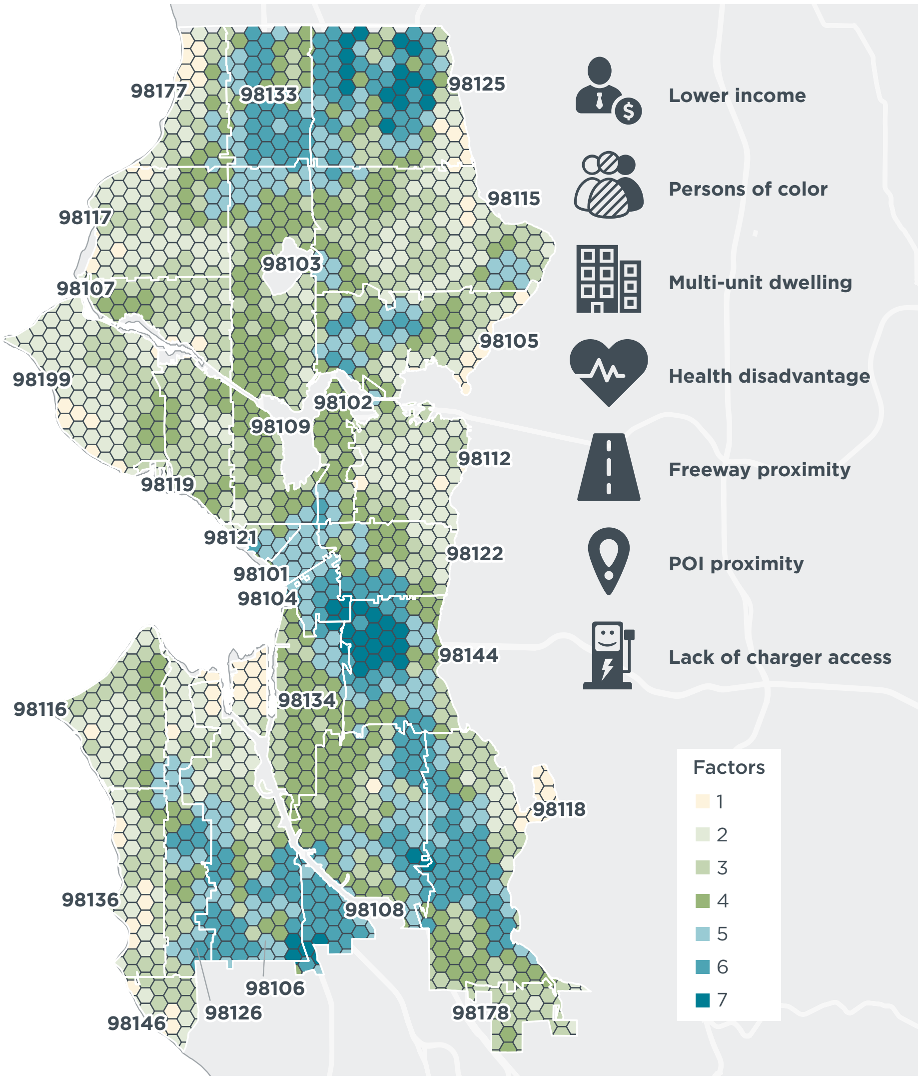

Figure 6. Sum of factors concerning a location's potential charger utilization and equity implication.

The equity analysis highlights important sociodemographic and other factors that would ideally be considered when guiding near-term charger deployment. We acknowledge there are other relevant factors that may impact EV charger utilization, equity, and access. For example, current EV ownership is not one of the factors we use for the equity analysis, as that is already the main input for the demand-based charger need analysis. Furthermore, although not assessed here, other electric mobility options such as electric carsharing, ride-hailing, and other modes of shared mobility play an important role in expanding zero-emission mobility equity and access and would benefit from public charging infrastructure. Factors such as traffic pollution and transit access, which are used in Seattle's charger siting tool, can also influence a charger's utilization and equity implications. Although the seven factors assessed here are weighted equally, the analysis can be further enhanced in the future through a stakeholder feedback and evaluation process to adjust the weighting of the factors accordingly—as was done in Seattle's own charger siting tool during its development process.[27] An iterative feedback

27 See page 13-17 in Seattle Department of Transportation, "EVSE roadmap for electric shared mobility" (2020), http://evsharedmobility.org/wp-content/uploads/2020/05/EVSE-Roadmap.pdf.

and evaluation process with strong emphasis on community engagement can lead to more equitable and inclusive planning and outcomes.

The results from the two approaches—one based on private vehicle induced demand and the other based on a mix of charger utilization and equity factors—can guide the charger deployment and investment differently. The left side of Figure 7 is the private vehicle demand-based infrastructure projection in 2030 using the same underlying result as Figure 4. But instead of reporting the charger counts, it shows the public chargers per capita for each zip code. On the right is the equity and utilization-based approach using the same result as Figure 6, but shown in the same color gradient as the charger density map on the left for comparison.

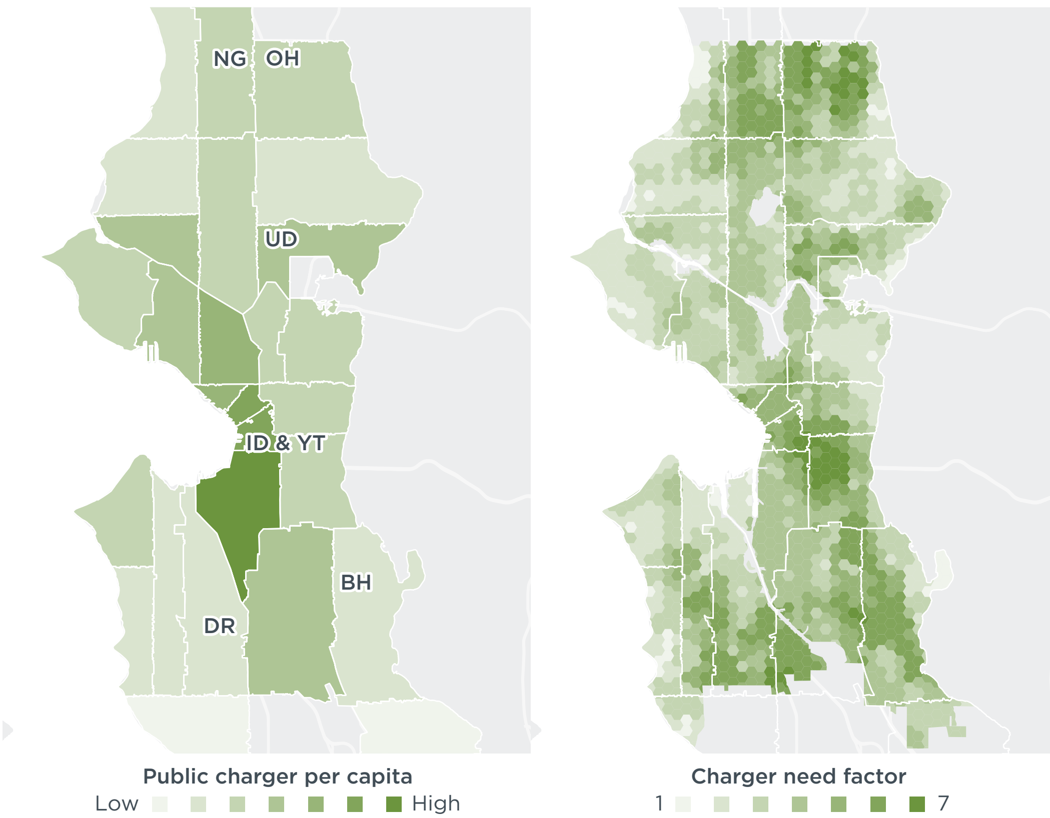

Figure 7. Private-vehicle demand-based charger need analysis and multicriteria equity analysis result comparison.

The demand-based result (left) emphasizes charger deployment in the downtown core in terms of chargers per capita. Factors such as commuting patterns and housing characteristics contribute to this outcome. Contrarily, the equity-focused result (right) suggests focusing near-term deployment in priority communities around Seattle, which is mainly driven by sociodemographic and health disadvantage. This is especially relevant for public funding given that charger investments from the private sector tend to aggregate at locations with a better EV charger business case, e.g., where there is more local EV traffic like shown on the left in Figure 7. Government's involvement in priority communities not only encourages the local EV adoption and enhances the ease of EV operation, it also brings additional benefits. For instance, when a charger is installed at these locations with their proximity to the freeways—one of the factors used in the equity analysis—local businesses in these communities can benefit from more visits from EV drivers.

Figure 7 shows areas in Seattle that both have higher charger needs suggests by the demand-based analysis (left) and stand to benefit most from near-term deployment based on the multicriteria equity analysis (right). These areas are the Downtown Core, University District (UD), International District and Yesler Terrace (ID&YT). But the demand analysis, with limited spatial resolution and reliance on private vehicle ownership and current commuting patterns, does not fully highlight the needs of neighborhoods such as Northgate (NG), Olympic Hills (OH), Delridge (DR) and Beacon Hill (BH) where there are predominantly lower-income persons of color. These gaps are better illustrated in the multicriteria equity analysis.

Equitable infrastructure planning: Opportunities and exemplary examples

Community engagement in the planning and implementation process of charger deployment is an inextricable part of planning for equitable outcomes. In addition to those with technical expertise, inputs from diverse voices will ensure the planning is done with all the residents in mind. To this end, Seattle's initiatives such as the Community Partners Steering Committee, Environmental Justice Committee,[28] and human-centered design can and have been used to equitably deploy infrastructure.[29] Greenlining Institute's three-step mobility equity framework can be put in practice to amplify "the ability of the marginalized communities to influence decisions in a way that addresses their needs and concerns."[30] The steps of the framework are: (1) identify the mobility needs of the underserved communities, (2) conduct the mobility equity analysis prioritizing transportation modes best meeting the needs of the communities with maximum benefits and minimum burdens, and (3) leave the decision making power to the local communities. For example, participatory budgeting can be used to allocate the funding for charger projects deemed desirable and suitable for and by the local communities.

A series of mobility access and equity workshops convened by the Zero-Emission Vehicle Alliance with equity practitioners offers a few more recommendations.[31] Some highlights include: (1) funding community-led outreach and engagement and making sure the information is appropriate to the targeted audience, (2) intentionally planning infrastructure to provide benefits centering on targeted communities, and (3) incorporating workforce training into transportation electrification programs.

Community engagement to better understanding private vehicle reliance in each neighborhood and the receptiveness and effectiveness of other mobility options is critical. Early engagement with shared-mobility companies to explore public-private partnerships can help to craft a shared mobility vision. This vision can jointly identify locations where shared mobility can both be economically feasible for the investors with government support and bring the appropriate mobility options to the underserved communities. As Seattle has acknowledged, accessible, affordable, and appropriate electrified mobility options are needed where EV ownership is not the best option for

28 "Environmental Justice Committee", Seattle Office of Sustainability & Environment, accessed on August 17, 2020, https://www.seattle.gov/environment/equity-and-environment/environmental-justice-committee.

29 Seattle Department of Transportation, "Human-centered design study on equitably expanding the EV charging network" (2019), http://evsharedmobility.org/resource/human-centered-design-study-on-equitably-expanding-the-ev-charging-network/.

30 The Greenlining Institute, "Mobility equity framework: how to make transportation work for people" (2018), https://greenlining.org/wp-content/uploads/2018/03/Mobility-Equity-Framework-Final.pdf.

31 ZEV Alliance, "Expanding zero-emission mobility equity and access" (2019), http://www.zevalliance.org/wp-content/uploads/2019/12/ZEV_access_workshop_report-_fv.pdf.

individuals or communities. By utilizing studies similar to Seattle's travel survey, the community-identified priorities, and the community's mobility vision, the charging demand of private vehicles *and* other electrified mobility options can both be accounted and planned for.

Additionally, cities can pursue pre-approving preferred and suitable sites for charger development.[32] Cities can prioritize preapproving sites in underserved communities to incentivize charger investment accordingly. To address the cost barrier associated with electrical upgrade in existing building stocks, cities or local municipal utilities can provide income-based financial assistance through rebates and waived permit fees.[33] To address limited access to garage or dedicated off-street parking for apartment residents, cities can consider providing application-based residential curbside Level 2 chargers such as Amsterdam's residential charger request program.[34] Alternatively, cities and utilities can assess the feasibility of retrofitting light and utility poles with EV chargers, such as been done in Los Angeles, as a way to increase charger access in these areas.[35]

Technological advancements and increased production volumes are lowering the hardware costs of charging infrastructure, and the business case for private sector operation is improving. However, soft costs, such as permitting, easement, and code compliance, remain high and have the most potential for further reduction.[36] Government agencies play a key role in reducing soft costs by means of simplifying and streamlining codes and permitting, facilitating easement processes, and providing informational materials for residential and charging provider stakeholders. Yet additional public efforts are needed to ensure equitable infrastructure access in areas with lower EV uptake, low-income communities, and less populated areas, where the business case for private-sector investments can be more challenging. This includes intentional and focused public-sector direct deployment in key areas and steering of private-sector investments by means of incentives or requirements. Outreach and engagement are important, particularly for segments such as low-income and migrant communities. To raise community awareness and interest, cities and partner organizations would ideally demonstrate that EVs and their infrastructure bring economic and environmental benefits to community members as well as charging operators, property owners, and landowners.

Conclusions

This working paper demonstrates different approaches for cities to estimate charging infrastructure needs, both in terms of charger counts and city assistance priorities, while taking equity in access into account. The EV charger projection analysis presents the case of Seattle based on data inputs for EV growth, vehicle ownership patterns, commuting and housing patterns, and EV charging behavior, among others. Meanwhile, the equity analysis presents locations with opportunities for government actions based

32 "Ansök om att etablera nya laddplatser för elbil", Stockholms stad., accessed on August 17, 2020, https://tillstand.stockholm/tillstand-regler-och-tillsyn/parkering/ansok-om-att-etablera-nya-laddplatser-for-elbil/.

33 Example of waived permit fee and charger rebate: "Personal Use EV Charger Rebates", Anaheim Public Utilities, accessed on August 17, 2020, https://www.anaheim.net/593/Personal-EV-Charger-Rebate.

34 "Een openbare laadpaal in Amsterdam", Vattenfall, accessed on August 17, 2020, https://www.vattenfall.nl/producten/elektrisch-rijden/openbare-laadpaal/laadpaal-amsterdam/.

35 "EV charging stations", Los Angeles Bureau of Street Lighting, accessed on August 17, 2020, https://bsl.lacity.org/smartcity-ev-charging.html.

36 Rocky Mountain Institute, "Reducing EV charging infrastructure costs" (2019), https://rmi.org/wp-content/uploads/2020/01/RMI-EV-Charging-Infrastructure-Costs.pdf.

on a mix of charger utilization and sociodemographic factors. This work leads us to the following conclusions and policy recommendations.

Cities with aggressive EV goals, like Seattle, need to rapidly deploy their charger infrastructure. Although local factors like rates of vehicle ownership, commuting and housing patterns, population density, and land use impact the specific charging infrastructure composition, cities with EV goals require substantial charging infrastructure deployment. For Seattle, the vehicle demand-based charger need projection finds that meeting its 30% EV stock by 2030 goal requires approximately 2,900 public Level 2 chargers and 860 DC fast chargers to support 174,000 EVs on the city's road in 2030, which is over five-times more than the number of public chargers installed through 2019. In 2030, these EVs and the approximately 63,000 EV commuters from out of the city would consume approximately 1,530 MWh daily, or 10% of Seattle City Light's average daily generation. In 2020, there are about 17 EVs for each public charger, and this ratio increases to about 47 EVs per public charger by 2030 as capacity increases in a maturing market.

Home charging is a fundamental component of EV charging infrastructure, but not everyone has access to it. In our analysis based on early adopters' charging behavior, home chargers account for close to 90% of all chargers and they provide over half of the energy to the EVs in the city. While home charging is a key pillar in the charging ecosystem, the need for more public charging options becomes more prominent as the market matures and EV adoption becomes more widespread. Home charging typically offers the lowest installation and energy cost which maximizes the economic benefits of EVs, but EV owners without access to private garages or dedicated off-street parking who rely more on charging elsewhere face greater barriers to adoption, both perceived and real. To overcome this barrier, alternative residential charging options, including curbside or streetlight chargers, that is accessible to all residents, would ideally be deployed where possible.

The distribution of charging infrastructure is important to EV adoption equity. This analysis considers two approaches to infrastructure planning: a private vehicle demand-based charger projection and a geospatial multicriteria equity analysis. Comparing the two approaches reveals relative gaps and opportunities for more equitable and inclusive near-term deployment of infrastructure by focusing on the communities and individuals that stand to benefit most. For example, targeted deployment in neighborhoods like Northgate, Olympic Hills, Delridge, and Beacon Hill will be important to expand infrastructure access and the associated economic benefits in priority communities across the city. This comparison underscores the need for a multi-pronged charging infrastructure planning approach for more effective, efficient, and equitable use of public assistance.

Cities have many tools to remove or reduce the infrastructure deployment barriers. Cities play an important role in supporting EV adoption and charging infrastructure deployment. City policies and programs can lower the EV charger deployment barriers and, when appropriate, fill the access gap and the market gap to prevent disparities from widening. For example, cities can create preferential and preapproved charger sites to promote investments in priority communities. Cities can also consider funding application-based residential curbside chargers for families meeting certain sociodemographic criteria in at locations with a greater opportunity for charger sharing, such as areas with predominately apartments without off-street parking. City policies ideally would be guided by its determined role in charger deployment; whether through owning, operating, supporting, or a combination of them. All city policies would ideally be viewed through the lens of community development and equitable access. The key findings and recommendations for policy based on the analysis are summarized in Table 5.

Table 5. Summary of key findings and policy recommendations.

Key findings	Policy recommendations
Seattle's aggressive EV goal means rapid charger deployment is needed	Develop strategy to deploy 72,000 home chargers, 2,900 public Level 2 chargers, 860 DC fast chargers, and 4,100 workplace chargers by 2030 to support 174,000 EVs Bolster and steer private sector and utility investment toward priority communities
Home charging is fundamental to EV charging infrastructure, but not everyone has access to it	Pursue alternative residential options including curbside or streetlight chargers Prioritize deployment in underserved areas by preapproving and streamlining Work with drivers and residents to identify key locations for residential style charging, including application-based programs
The distribution of charging infrastructure is important to EV adoption equity	A comprehensive multi-pronged approach to infrastructure planning is needed Leverage equity frameworks and community networks to guide the charging strategy Provide income-based financial assistance for public and residential chargers
Cities have many tools to remove or reduce the infrastructure deployment barriers	Spur private investment through EV-ready codes, permitting, zoning, priority access Create preferential and preapproved charging locations in priority communities Identify and fill gaps in the public and residential charging network with public funds

As plans for meeting EV and charger deployment goals are implemented, cities can reexamine the infrastructure strategy and adapt to underlying and current trends, local factors, and limitations. Cities will also benefit from having a holistic mobility view which considers other mobility options as integral part of a mobility future, especially those also served by public chargers such as ride-hailing and carsharing services. The non-private vehicle options will undoubtedly be integral for an equitable transportation future. Not only do carsharing programs increase mobility options of those cannot afford or does not prefer private vehicles, they also helps to strengthen the business case at charging hubs—such as the city's vision of shared mobility hubs. Further, these hubs can serve locations where the business case for public charging is less robust, such as the priority communities identified in the equity analysis.

Appendix A. Key analysis method, assumptions, and inputs

Analysis of EV sales shares, stock, and fleet stock turnover model

For the 30% EV stock by 2030 goal, we develop a logistic growth curve by forcing the curve through the EV sales percentage in 2019 and the estimated percentage in 2030 needed to achieve the stock goal. We then replace the 2020 to 2025 segment of the logistic curve with an exponential curve. The exponential growth rate for 2020 to 2025 is determined based on the recorded EV sales percentage in 2019 and the projected percentage in 2026 based on the logistic growth. This hybrid growth curve then provides the annual EV sales to the vehicle stock turnover model that calculates the annual EV stocks base on the vehicle survival rate at different vehicle ages (Table A1). Base on the calculated EV stock percentage in 2030, we then modify the input estimated sales percentage in 2030. The process is repeated until the 2030 EV stock matches the city's goal. The same general approach is done for the 50% EV stock by 2030 scenario with some modifications. The exponential growth rate is used only from 2020 to 2022. And the logistic growth rate is determined by the 2019 EV sales percentage and an estimated EV sales in 2025, instead of 2030, needed to achieve the 50% EV stock goal.

Table A1. Vehicle survival rate based on the vehicle age.

Age	Survival rate	Age	Survival rate
1	100%	21	14%
2	100%	22	13%
3	100%	23	12%
4	100%	24	12%
5	100%	25	11%
6	100%	26	10%
7	100%	27	9%
8	99%	28	8%
9	94%	29	7%
10	89%	30	6%
11	82%	31	6%
12	73%	32	5%
13	64%	33	4%
14	55%	34	4%
15	47%	35	3%
16	40%	36	3%
17	34%	>37	0%
18	29%		
19	24%		
20	16%		

EV charging energy demand

The EV charging energy demand is determined based on the daily charging events at different types of chargers and the energy supplied per charging event. Table A2 shows the daily charging events by the EV technology types, the EV owners' home charger access, and whether the owners commute with the EVs. Table A3 shows the energy supplied per charging event at different types of chargers.

Table A2. The number of daily charging events based on the EV driver topology.

EV technology	Home charger access	Commuter	Home	Workplace	Public Level 2	DC fast
PHEV	No	Yes	0.00	0.59	0.10	0.00
BEV	No	Yes	0.00	0.38	0.03	0.13
PHEV	Level 1	Yes	0.70	0.48	0.05	0.00
BEV	Level 1	Yes	0.38	0.32	0.05	0.09
PHEV	Level 2	Yes	0.76	0.44	0.06	0.00
BEV	Level 2	Yes	0.50	0.27	0.04	0.04
PHEV	No	No	0.00	0.00	0.52	0.00
BEV	No	No	0.00	0.00	0.23	0.32
PHEV	Level 1	No	0.70	0.00	0.26	0.00
BEV	Level 1	No	0.48	0.00	0.10	0.06
PHEV	Level 2	No	0.74	0.00	0.14	0.00
BEV	Level 2	No	0.46	0.00	0.09	0.03

Table A3. Energy consumption per charging event, in kWh.

EV technology	Home	Workplace	Public L2	DCFC
PHEV	6.50	7.50	3.25	0.00
BEV	11.50	15.50	5.50	16.00

Unfulfilled workplace charging demand allocation

Table A4 shows the allocation of unfulfilled workplace charging demand to home and public chargers based on the EV technology and EV owners' home charger access.

Table A4. The percentage of the unfulfilled workplace charging demand to be allocated to public and home chargers.

EV technology	Home charger access	Public Level 2	DCFC	Home
PHEV	Yes	14.4%	0.0%	85.6%
PHEV	No	100.0%	0.0%	0.0%
BEV	Yes	8.7%	17.2%	74.1%
BEV	No	35.2%	64.8%	0.0%

Appendix B. List of selected points-of-interest used for equity analysis

The following points-of-interest are used to identify locations where a charger may experience higher utilization due to higher plugged-in time:

Art gallery/museum/social service
Bank
Bowling alley
Car wash
Church/welfare/religious service
Condominium (office)
Convenience store with gas
Convenience store without gas
Driving range
Golf course
Governmental service
Grocery store
Health club
Hospital
Hotel/motel
Medical/dental office
Mortuary/cemetery/crematory
Movie theater
Office building
Office park
Park, private (amuse center)
Park, public (zoo/arboretum)
Parking (associate)
Parking (commercial lot)
Parking (garage)
Post office/post service
Restaurant (fast food)
Restaurant/lounge
Retail store
Retail (big box)
Retail (discount)
Retail (line/strip)
School (private)
School (public)
Shopping center (community)
Shopping center (maj retail)
Shopping center (neighborhood)
Shopping center (regional)
Sport facility
Tavern/lounge

Appendix C. Seattle citywide public charging infrastructure projection summary

Table C1 and Table C2 show the Seattle citywide public charging infrastructure projection summary. Table C1 highlights the infrastructure growth rate needed from 2020 to 2025 and from 2025 to 2030. Table C2 provides a breakdown of the charger projections by charger types.

Table C1. Seattle public charging infrastructure to reach 30%, 50%, and 100% EV stock by 2030.

	Year	30% EV stock	50% EV stock	100% EV stock
Total public chargers (Level 2, DC fast)	2020[a]	699	699	699
	2025	1,675	3,220	N/A
	2030	3,729	5,704	10,073
Electric vehicle stock	2020 (estimate)	16,383	16,383	16,383
	2025	58,140	126,056	N/A[b]
	2030	173,634	289,211	578,414
Projected future charging compared to 2020	2025	2.4	4.6	N/A
	2030	5.3	8.2	14.4
Annual charger growth needed	2020-2025	19%	36%	31%[c]
	2025-2030	17%	12%	

[a] As of September 2020

[b] Values are not available for the 100% EV stock goal in 2025 due to the lack of a full EV sales curve that can achieve such goal using our method.

[c] 2020 to 2030 annual increase in chargers to meet future needs for the 100% EV stock

Table C2. Citywide charger projection from 2025 to 2035 based on the EV stock goals.

	30% EV stock by 2030			50% EV stock by 2030			100% EV stock by 2030
	2025	**2030**	**2035**	**2025**	**2030**	**2035**	**2030**
EV stock percentage	10%	30%	56%	21%	50%	74%	100%
Central case, charger counts							
Public Level 2	1,259	2,869	4,374	2,419	4,400	5,531	7,812
Public DC fast	416	860	1,243	801	1,303	1,559	2,261
Workplace	1,388	4,101	7,934	2,651	6,927	10,650	8,650
Home (detached)	14,231	42,946	74,641	30,491	71,510	99,055	143,026
Home (attached)	8,136	20,558	31,175	16,982	34,840	43,425	69,728
Home (apartments)	2,620	9,009	19,036	5,761	14,630	23,437	28,964
Home (total)[a]	24,986	72,513	124,853	53,233	120,981	165,917	241,718
EV:public Level 2 ratio	47	61	69	53	66	72	74
BEV:public DC fast ratio	131	196	238	149	215	252	247
Sustainable trip case, charger counts							
Public Level 2	1,075	2,186	2,932	2,065	3,353	3,709	5,954
Public DC fast	356	656	836	685	995	1,049	1,727
Workplace	1,190	3,146	5,394	2,271	5,321	7,253	6,634
EV:public Level 2 ratio	55	79	103	62	86	108	97
BEV:public DC fast ratio	153	256	354	174	281	374	323

[a] Home charger projections are identical between the two scenarios; thus it is only shown under the central scenario section.