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LETTER

Sufficiency of level 1 charging to meet electric vehicle charging requirements

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Abstract

As electric vehicle (EV) deployment increases there is increasing attention to meeting charging needs. We analyze 13 months of real world driving and charging data for 129 battery electric vehicles in Calgary, Canada to evaluate the potential for home-based level 1 charging to deliver the energy needed to satisfy observed driving demand. We find that 29% of vehicles can have their energy needs met entirely with level 1 charging. A further 53% of vehicles in our sample require only occasional supplementary level 3 charges and only a small minority of vehicles require 12 or more supplementary level 3 charges across the sample period. Across all vehicles the median ratio of charge energy that can be shifted to level 1 charging is 0.99. These results challenge the assumption that level 2 charging access is required for convenient operation of EVs and offer a partial solution to enable broader EV charging access and reduce the need for near term electrical panel or distribution grid upgrades.

1. Introduction

With the growing deployment of battery electric vehicles (BEVs), there is increasing attention to the challenges and barriers related to electric vehicle (EV) charging [1–3]. In North America, the location of this study, EV chargers are classified based on the rate of charge [4, 5]. Level 1 describes EV charging at 120 V AC (standard North American household power level) and typically delivers 1.4 kW of power with the potential to deliver up to 1.9 kW. Level 2 EV charging refers to charging at 240 or 208 V AC (residential and commercial respectively) and has a wide range of charging speeds from 5–20 kW, with the lower end more common for residential chargers. For residential charging the use of faster Level 2 charging speeds, compared with Level 1, enables EVs to be recharged more quickly. Direct current fast charging, sometimes referred to as Level 3 EV charging, has charging rates of 50 kW and above and are not installed in residential settings.

Concerns have been raised related to the roll out of home-based EV charging as lack of access to residential charging infrastructure may slow or prevent wide-scale adoption, with unique challenges arising for individuals in multi-residential buildings or others without access to charging on their property [6–10]. There is the potential for increased power draw from level 2 (240 V) charging to require costly panel and service upgrades in some single-family homes[11], while the installation of multiple chargers in a single location may require local distribution infrastructure upgrades [12–14]. A residential Level 2 charger with a charging speed of 7 kW represents a larger power draw than typical home appliances in use today such as an electric dryer (typically less than 5 kW) or air conditioner (typically less than 3.5 kW), which may make it more challenging to integrate into residential distribution grids.

The majority of solutions proposed for home-based charging needs focus on increasing access to level 2 charging while using coordinated or smart charging, either at the individual charger or building/neighborhood level, to smooth demand [15–17]. Many of these discussions and proposals implicitly assume the need for regular access to level 2 charging as a minimum requirement or standard

practice for the convenient operation of EVs as personal vehicles. This norm is reflected in media stories about EV charging where level 2 charger are described as the default or preferred option[18]. In contrast, level 1 (120 V) charging could directly mitigate many of the challenges that arise from level 2 charging as the lower power draw can be integrated into existing building electrical panels and distribution infrastructure without the need for upgrades, while level 1 outlets may be already available or more cheaply and easily retrofitted into existing parking spaces. However, questions remain about the ability of level 1 charging to deliver the energy needed to satisfy vehicle drivers' demand. In this analysis, we evaluate this assumption of the need for routine access to level 2 charging access for the operation of a BEV personal vehicle using real-world driving data to determine the ability of level 1 charging, supplemented by neighborhood-based level 3 chargers, to meet driving needs.

2. Methods

2.1. Conceptual approach

Using real-world trip-level driving data over a 13 month period from December 2021–December 2022 for 129 BEVs operating in Calgary, Alberta, we evaluate the ability for routine level 1 charging access to meet energy needs for observed driving demand.

For each vehicle in our sample, we combine real-world driving data with a theoretical charging model and track the state of charge after trips and after charging. The theoretical charging model increases the state of charge at a level 1 rate (assumed to be 1.2 kW in our model, taking into account charging losses) in two situations (1) when the vehicle data shows it is parked overnight, and (2) when the charging data indicates the vehicle was charged with a level 2 charger. In the latter case, we replace the observed level 2 charging with our theoretical level 1 charging and track the state of charge accordingly, this represents the replacement of a level 2 charger in the home by a level 1 charger in the home. In some cases, the actual level 2 charging observed in the data may be happening away from home (i.e. at a commercial charger) but due to a lack of locational data for charging we substitute level 1 charging in the analysis. Overnight parking is determined to occur based on the vehicle being stationary for at least 6 h, including the hour of 5 a.m. In this case, the state of charge of the vehicle is increased at a level 1 charging rate for the full time the vehicle is stationary, representing the vehicle having been plugged in to the level 1 charger on arrival and disconnected at departure.

We maintain the state of charge of the vehicle following level 3 charging events as observed in the data, as these charging events take place outside of the home. In the case where the state of charge of a vehicle falls below 5%, we increase the state of charge of the battery to 80% and track the event as a supplementary fast-charging event. This represents the use of a neighborhood-based, or other local charger, to meet the charging gap from level 1 charging. Our empirical objective is to determine the sufficiency of level 1 home charging quantified by the frequency of supplemental level 3 charging required to fulfill observed driving needs.

2.2. Data

The data set consists of charging and trip data from 129 BEVs over 13 months, from December 2021 until December 2022 in Calgary, Alberta. The data come from a pilot run by ENMAX Power to assess the responsiveness to time-of-use rates and nudges to shift the timing of EV charging. The vehicles in the data set are listed by make and model in table 1.

Charging and driving data were collected at the vehicle level via hardware devices connected to each vehicle's on-board diagnostic port. Driving data include information on start and end times, as well as distance traveled in kilometers, of each trip. Charging data include information on the rate of charging, the type of charger, the state of charge of the battery, and the kilowatt–hours added during each charging session in 15 min increments. Table 2 summarizes the information collected during each trip (a) and charging incident (b).

Trip data for the 129 BEVs range from a minimum of 149 trips for the period to a maximum of 4684 trips. The mean number of trips was 1589 trips per vehicle, and the standard deviation was 790. Charging data was collected in 15 min intervals. If charging was longer than 15 min, the charging ID remained the same during the charge. Charging data for the 129 EVs range from a minimum of 25 charging sessions for the period to a maximum of 1909 charges. The mean number of charges was 471 per vehicle, and the standard deviation was 336.

The 129 BEVs in the sample had an annual median distance traveled of 14 649 km with the distribution of km traveled shown in figure 1. The 12 months of 2022 are used as the best representative sample of annual driving distance.

Table 1. Makes and models of BEVs in data set.

Make	Model	Vehicle Count
Chevrolet	Bolt EV	8
Ford	Mach-E	4
Hyundai	Ioniq electric	3
Hyundai	Kona electric	9
Nissan	Leaf	9
Tesla	Model 3	36
Tesla	Model S	11
Tesla	Model X	10
Tesla	Model Y	29
Volkswagen	e-Golf	4
Other		6

Table 2. List of data collected for each trip (a) and charging event (b).

A. Trip data information
User key (unique user identifier)
Vehicle key (unique vehicle identifier)
Device name
Vehicle make
Vehicle Model
Vehicle Year
Trip Key (unique trip identifier)
Start Date
End Date
Total distance travelled (km)
Total electric distance traveled (distanced traveled on electric power only, km)
Start SOC (state of charge of vehicle at start of trip)
End SOC (state of charge of vehicle at end of trip)
Fuel consumption (*L*) (total gasoline used for trip, n/a for BEV)
Energy consumed (kWh)
Auxiliary load (kWh)
Ambient temperature (C)
B. Charging data information
User key (unique user identifier)
Vehicle key (unique vehicle identifier)
Device name
Vehicle make
Vehicle model
Vehicle year
Start date (date of start of charge)
End date (date of end of charge)
Charge ID (unique charge session identifier)
Charge session interval key
Geofence name (binary as either 'ENMAX territory' or 'Out of territory')
Max charge power (kW)
Charge energy (total energy supplied to vehicle, kWh)
Charge energy Loss (energy supplied to vehicle that does not increase state of charge, estimated, kWh)
Start SOC (state of charge of vehicle at start of the charging session)
End SOC (state of charge of vehicle at the end of the charging session)
Charging location (binary as either home or away)

We calculate the average observed range for the vehicles across the 13 month period based on the data for distance traveled and change in state of charge from each trip. The distribution of vehicle ranges is shown in figure 2.

A portion of the energy delivered to a BEV during charging does not directly charge the battery as it is needed to run the battery management system or other vehicle systems. This charge energy loss has a more significant impact on the rate of actual battery charging for level 1 charging given the relatively slow rate of

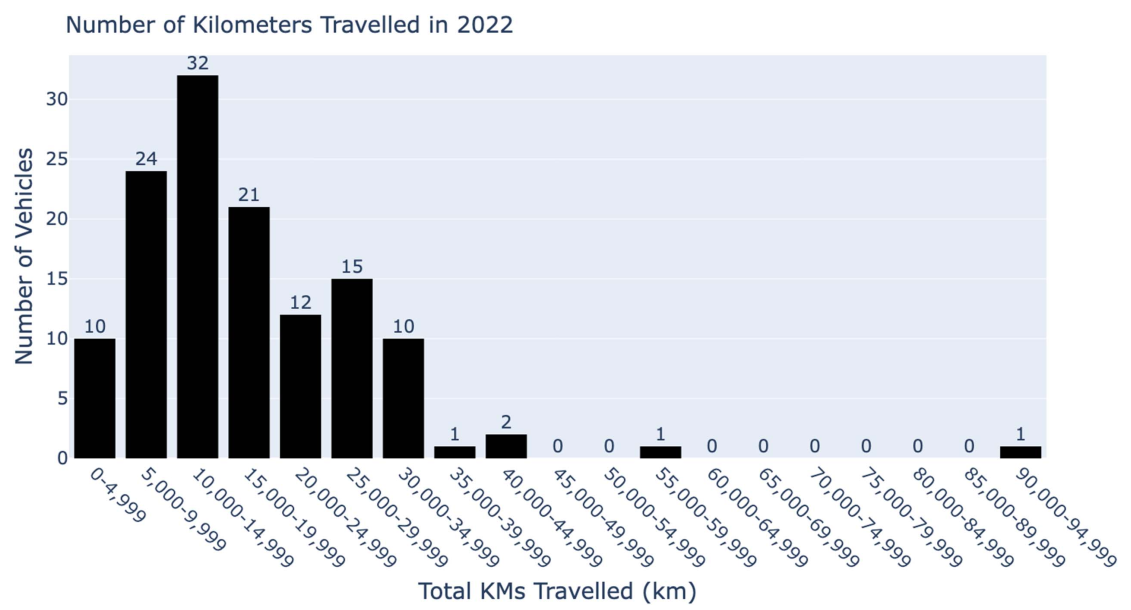

Figure 1. Histogram of total kilometers travelled by vehicles in the data set in 2022.

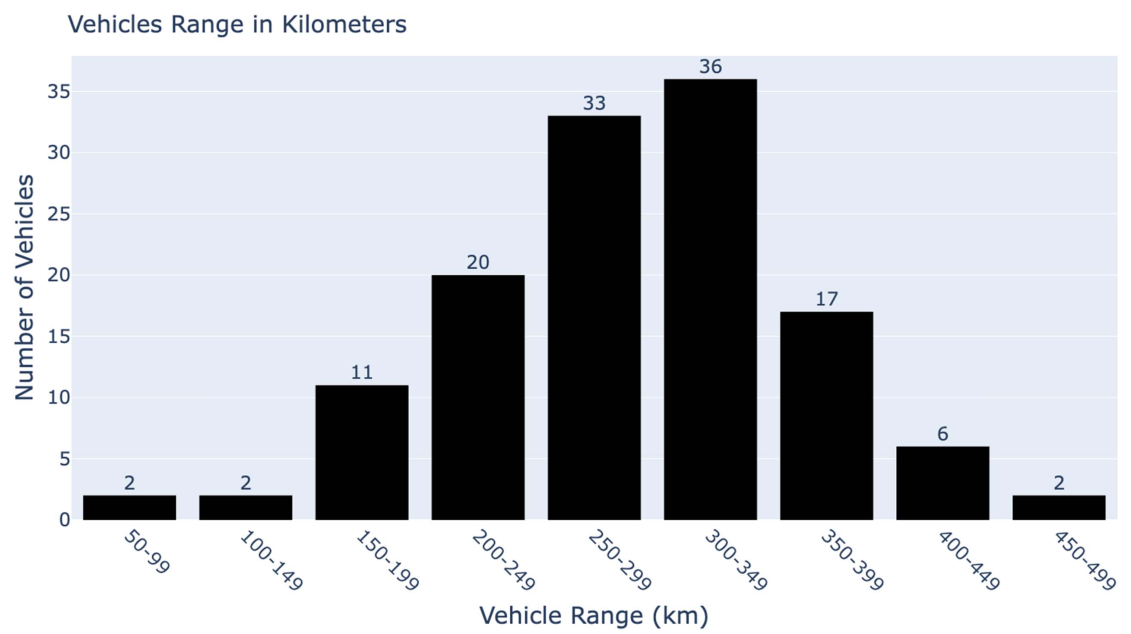

Figure 2. Histogram of average observed vehicle range across the 13 month period for all vehicles in the data set.

charge. This charge energy loss can be observed via the rate of increase in battery charge during charging events in the data, and we calculate an average battery charging rate of 1.2 kW for observed level 1 charging at full power.

2.3. Overnight charging analysis

Our primary analysis consists of replacing actual (observed) level 2 charging with simulated level 1 charging and augmenting this charging with additional level 1 charging time when the vehicle is parked overnight. This analysis is done to model the case where there is no level 2 charger installed in the home and instead home-based charging is done exclusively at level 1. To do so involves the following steps:

We identify all times where the vehicle is observed to be charging at level 2. We track as a potential level 1 charge time the entire time period a vehicle is parked that includes this level 2 charging as a Parked Time. To

these potential level 1 charging times we identify additional overnight Parked Time based on the time between observed trips in the driving data where parked time is longer than six hours including the hour of 5 a.m. which we assume is overnight parking. Each of these Parked Time are treated as a charging event where a vehicle is assumed to have access to a level 1 charger at home. We assume a Level 1 charging rate of 1.2 kW, based on the average observed charging rate of the battery for all charging events in the data set with max charge power of 1.4 kW or less that are a full 15 min long and where the final state of charge of less than 75%. These parameters are chosen to exclude the cases where a vehicle has reached its maximum charge setpoint and charging sessions are only trickle charges. This would be equivalent for example to a 1.4 kW Level 1 charger rate reduced by the average 0.15 kW observed charging energy loss and an estimated 0.05 kW power factor loss. The energy gained using a Level 1 charger during each event was calculated as Parked Time (in hours) multiplied by 1.2 kW, as given in equation (1)

$$\text{Charge energy} = \text{Parked Time} * 1.2\ \text{kW}. \tag{1}$$

We make two assumptions in this analysis because we do not have specific location information in the data if the vehicle is not charging. The first is that when a vehicle is parked overnight we assume it is parked at home or in a location with access to level 1 charging. This could overestimate the time available for level 1 charging in the case where a vehicle is parked overnight somewhere other than the home where it has no access to charging. We expect the impact of this assumption on the conclusion of the suitability of home-based level 1 charging is limited as vehicles will typically require non home-based charging access on multi-day trips.

The second is that we replace all level 2 charging events by level 1 charging, but this could include cases of level 2 charging that takes place outside of the home (for example level 2 charging overnight at a hotel on a trip) that would remain even in the absence of home-based level 2 charging. This assumption could lead to an overestimate of the number of supplementary charging events required, making our results a lower bound for the suitability of level 1 home based charging.

In order to evaluate the potential for home-based level 1 charging to deliver the energy needed to satisfy observed driving demand, and determine the number of supplementary charging events required, we track the state of charge of each vehicle over the 13 month study period, setting the initial state of charge of each vehicle to 100%. We track the state of charge after charging and before and after each trip as follows:

First, we calculate a total energy capacity for each vehicle from the data on charging events. We use all charging events n where an actual charge took place and determine the total energy added to the vehicle in each event n as shown in equation (2)

$$\text{Energy}_{\text{in}\ n} = \text{Charge Energy (kWh)}_n - \text{Charge Energy Loss (kWh)}_n. \tag{2}$$

Similarly, the change in state of charge of the vehicle during the actual charging event n is calculated as shown in equation (3)

$$\text{State of charge}\ \Delta_n = \text{End SOC}_n - \text{Start SOC}_n. \tag{3}$$

And finally, the total energy capacity for each vehicle is calculated from these n charging events for each vehicle as:

$$\text{Total energy capacity} = \frac{1}{n}\sum_{1}^{n}\frac{\text{Energy}_{\text{in}\ n}}{\text{State of charge}\ \Delta_n}. \tag{4}$$

We track the state of charge after each trip and after charging sessions by increasing and decreasing the state of charge for each vehicle as follows:

We use the simulated level 1 charging calculated in analysis 1.1 and 1.2 to increase the state of charge for each charging event by a charging state of charge change as given in equation (5)

$$\text{State of Charge}\ \Delta_C = \frac{\text{Charge energy}}{\text{Total energy capacity}}. \tag{5}$$

We limit the state of charge of the vehicle to a maximum of 100%.

We use the observed change in the state of charge during the driving events to decrease the state of charge by a driving state of charge change as given in equation (6)

$$\text{State of Charge } \Delta_D = \text{End SOC} - \text{Start SOC}. \tag{6}$$

We maintain the observed level 3 charging events in the data set as follows. When a vehicle has a level 3 charge event, we set the state of charge tracking equal to the observed state of charge of the vehicle following the level 3 charge event. This represents an assumption that drivers will use a level 3 charger to achieve a desired state of charge rather than spend a specific amount of time at the charger. It may overestimate the level 3 charge energy if our state of charge tracking is below the observed and if a driver is time limited, while in other cases it will underestimate the level 3 charge energy if our state of charge tracking is above the observed and the driver uses the same time at the charger.

If the state of charge of the vehicle drops below 5% in our simulated state of charge tracking we increase the state of charge to 80% and record the event as a supplementary charge. This represents the case where a driver visits a level 3 charger prior to dropping below 5%.

Building on the first analysis, we add level 1 charging during the daytime for longer park times, similar to the case of overnight parking. In the first analysis, we assume vehicles have access to level 1 charging only when they are parked overnight, or when they were already charging at level 2 in the data set. However, vehicles in the dataset are also parked for long periods of time during the day. In some cases, these vehicles may be parked at home, in which case our analysis underestimates the level 1 charging potential. In other cases, the vehicles may be parked at a work location where level 1 charging could be provided.

In order to quantify the potential for additional level 1 charging to meet charging needs, we model the case where vehicles have access to level 1 chargers while parked during the day. Similar to the overnight level 1 charging case we identify additional times when vehicles are stationary during the day for at least 4 h between 5am and 8pm, chosen to represent half a working day. Periods that are already captured in the overnight charging modeling are excluded, for example if a vehicle is parked for 2 days the daytime charging is already assumed to take place and does not represent additional charging in this analysis.

The energy gained during daytime park time is modeled at a rate of 1.2 kW as described above in equation (1) and the state of charge is tracked as described in the analysis above.

3. Results

We perform the state of charge tracking analysis for all vehicles and record the number of supplementary charges needed for each vehicle over the 13 month period. Figure 3 shows the resulting histogram of required supplemental level 3 charge events per vehicle as a percent of all vehicles for overnight charging only. We find that 29% of vehicles in our sample require no supplementary level 3 charge events. A further 53% of vehicles require occasional supplementary level 3 charges, with the majority of those requiring 3 or fewer supplementary charges. Only 18% of vehicles require 12 or more supplementary level 3 charges across the sample period.

In addition to quantifying the sufficiency of level 1 charging as measured by the count of supplementary charges required, we consider the fraction of the required energy that can be shifted to level 1 charging, excluding the $L3$ charging. This shifted energy is calculated as given in equation (7) where $L1_{\text{simulated}}$ is the total $L1$ energy in our tracking simulation, and $L1_{\text{actual}}$ and $L2_{\text{actual}}$ are the total $L1$ and $L2$ energy observed, respectively

$$\text{Shifted energy} = \frac{L1_{\text{simulated}}}{L2_{\text{actual}} + L1_{\text{actual}}}. \tag{7}$$

The ability to shift charging to the lower level 1 rate depends both on the total amount of energy required, which is limited by the rate of charge, as well as the way the energy use is distributed across the time period, i.e. if energy is used evenly throughout the week versus clustered on two days where overnight level 1 charging may be insufficient. The histogram of this measure of level 1 charge sufficiency is shown in figure 4. Across the sample the median ratio of energy that can be shifted to level 1 charging is 0.99. A ratio below 1 is the case where the level 2 charging cannot be fully shifted and some supplementary level 3 charging is required. A ratio above 1 represents the case when some observed level 3 charging is shifted to level 1 charging. This is possible in in our analysis because we maintain the final state of charge following observed level 3 charging events. If a vehicle receives more charge in our simulated level 1 charging it can start a level 3 charging event with a higher state of charge level in our tracking. In practice this corresponds to a reduction in time and expense at level 3 chargers and represents the real world practice of targeting a desired end state charge at a level 3 charger.

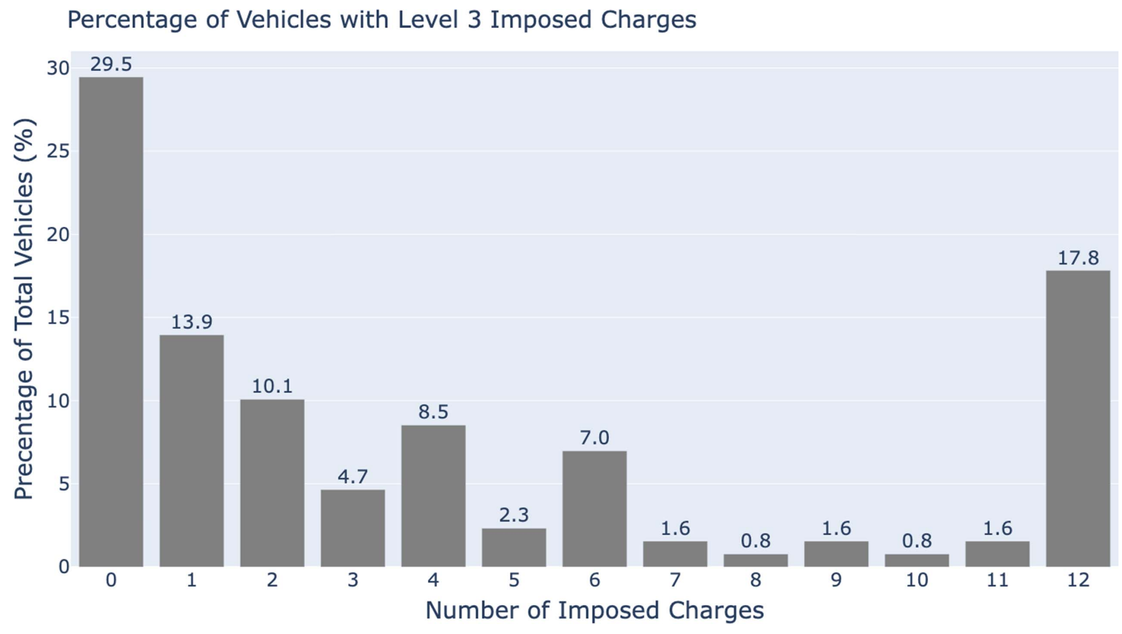

Figure 3. Number of supplementary level 3 charging events required for each vehicle over the 13 month modeling period.

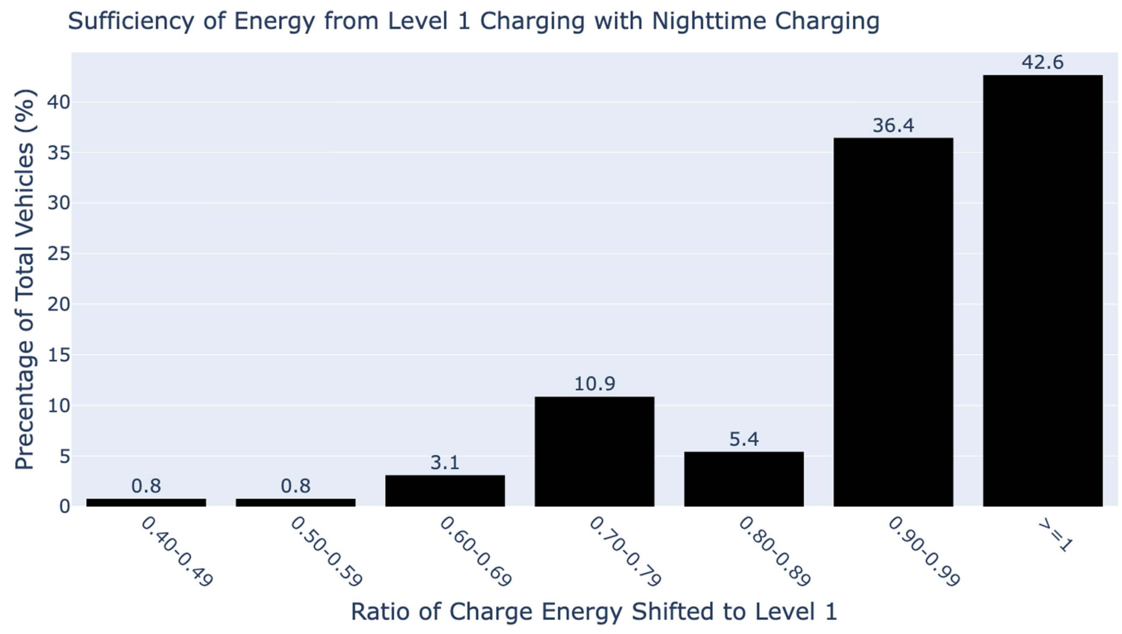

Figure 4. Histogram of sufficiency of level 1 charging as measured by the ratio of energy shifted to level 1 charging for all vehicles.

We examine the correlation between the sufficiency of level 1 charging and both the total distance driven, as well as the vehicle range and the results are plotted in figure 5.

The data and simple linear regression suggests a negative correlation between the total distance traveled and sufficiency of level 1 charging. Vehicles driven shorter distances are more likely to be fully served by level 1 charging. In contrast the sufficiency of level 1 charging does not appear to differ based on vehicle range.

In order to test the potential for access to daytime charging as a solution to enable level 1 charging sufficiency we repeat the state of charging analysis with the additional daytime charging and we find that access to daytime charging increases the percentage of vehicles in our sample that require no supplementary

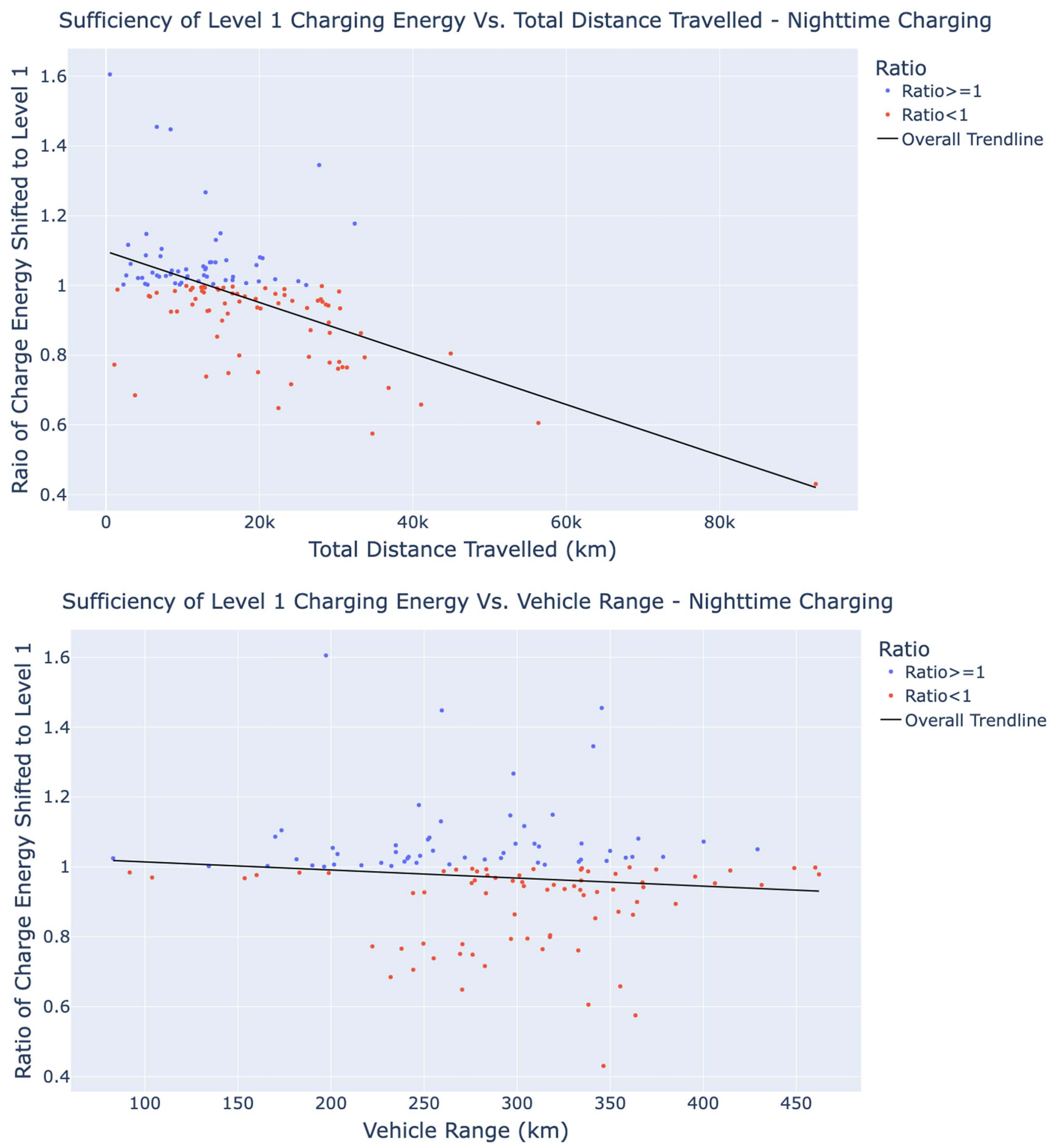

Figure 5. (A) Correlation between total distance traveled across the 13 month period and ratio of charge energy shifted to level 1 for all vehicles in the sample. (B) Correlation between vehicle range and ratio of charge energy shifted to level 1 for all vehicles in the sample. In both cases ratios ⩾1 represent level 1 charge sufficiency and are shown in blue and the line is a simple linear regression.

level 3 charge events from 29% to 38%. The resulting histogram of required imposed charges is shown in figure 6.

As in the analysis of night only level 1 charging we calculate the ratio of energy from the observed level 1 and level 2 charges that can be shifted to level 1 charging only for each vehicle. The resulting histogram of charge energy shifting is shown in figure 7 and the median ratio of energy that can be shifted to level 1 charging across the sample is 1.00.

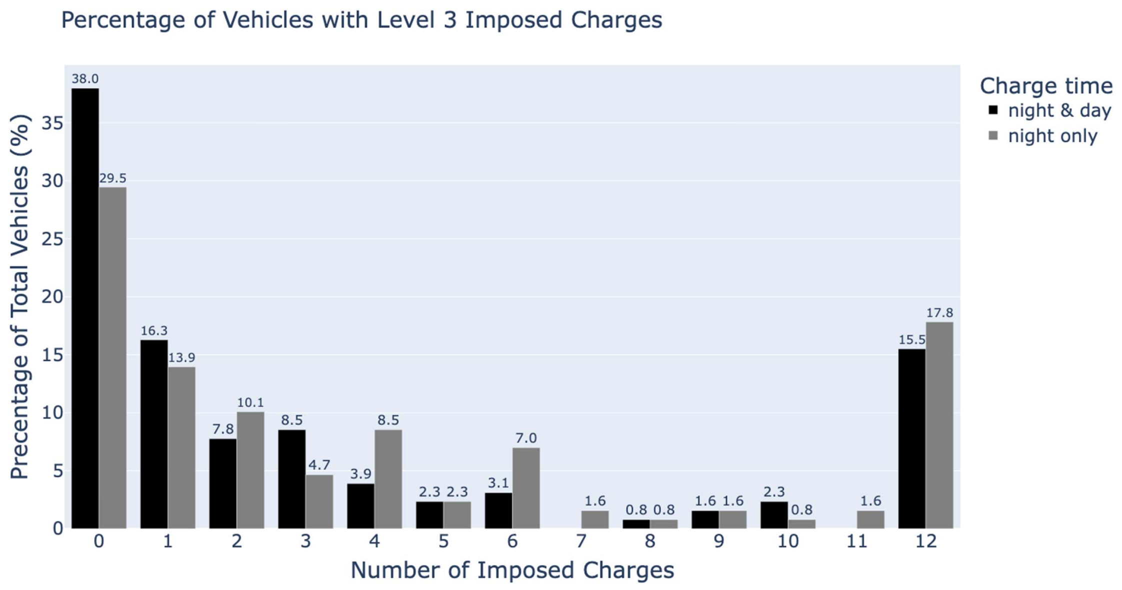

Figure 6. Comparison of the number of supplementary level 3 charging events required for each vehicle over the over the 13 month modeling period with night only and night and day level 1 charging.

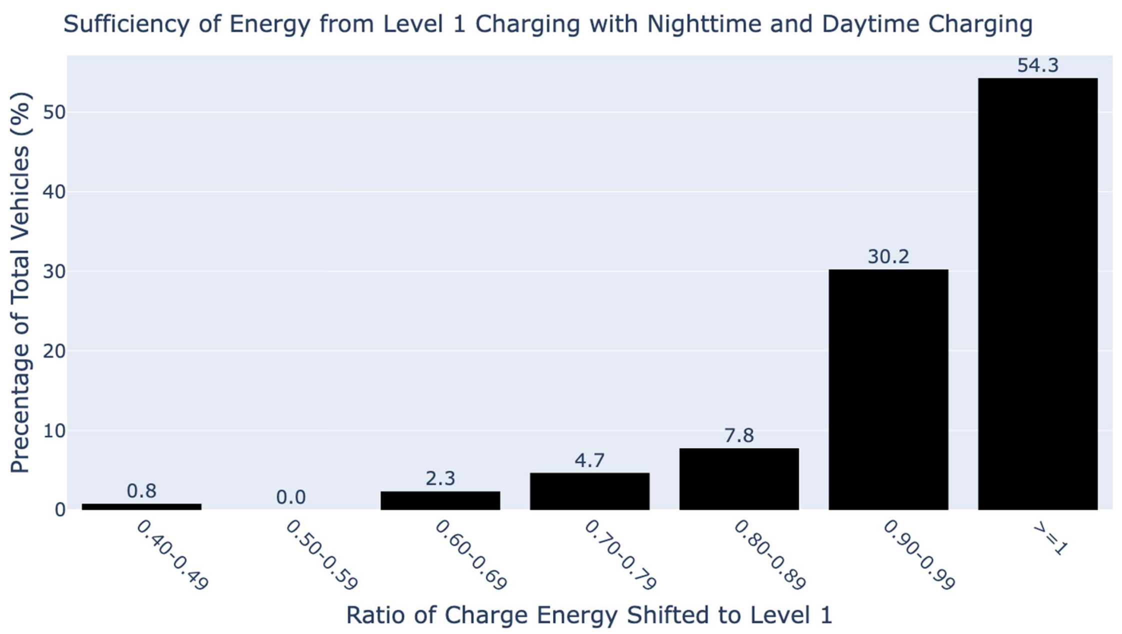

Figure 7. Histogram of sufficiency of level 1 charging with additional daytime supplementary charging, as measured by the ratio of energy shifted to level 1 charging for all vehicles.

4. Discussion and conclusion

A significant percentage of the vehicles in our sample, 29%, can fully meet their observed energy needs with the modeled level 1 charging only. That is, they require no supplementary level 3 charging during the experiment period. This result challenges the norm that all EV owners need access to level 2 charging. Instead, the vehicles in this category are examples of a significant share of vehicles that can be well served by level 1 charging only. The sufficiency of level 1 charging as measured by ratio of charge energy that can be shifted to level 1 appears to be highly correlated with the total kms driven but not the range of the vehicle. Across the sample the median ratio for required energy, excluding level 3 charging, that can be met through level 1 charging is 0.99.

Many of the remaining 71% of vehicles in our sample could also be served by alternative solutions to deliver the energy needed to satisfy their observed driving demand without requiring regular access to a level

2 charger. Two potential alternative solutions are increased access to level 1 charging infrastructure outside the home and/or access to 'neighborhood' level 3 chargers.

Increasing access to level 1 charging outside the home is one option to supplement at-home charging. Providing access to daytime charging in the second analysis increases the percentage of vehicles that require no supplementary level 3 charges from 29% to 38%. The impact is smaller for the percentage of vehicles that require 12 or more supplementary charges, which declines only slightly from 18% to 15%. These results suggest that for vehicle owners with access to overnight level 1 charging additional daytime level 1 charging access may be helpful in some cases to avoid or reduce the need for level 3 charging.

As an alternative to, or in addition to supplementary level 1 charging, our results suggest widely available level 3 neighborhood chargers could also reduce the need for level 2 home charging by allowing for a rapid 80% supplementary charge for the times additional charging beyond the rate of level 1 charging is needed to meet the observed driving need. While this represents additional infrastructure requirements, level 3 chargers placement could be chosen to reduce distribution grid upgrades, and would address unequal access to home-based level 2 charging.

The need to visit a level 3 charger places an additional constraint on EV drivers, however there are a significant number of EVs in our sample for which only a small number of supplementary charges are required. 34% of vehicles that require supplementary charges only require 1 or 2 such charges per year. Across the whole sample 58% of vehicles require 3 or fewer supplementary charges over the 13 month period analyzed. The ability to access level 3 chargers may also be important for drivers who had their charging needs fully met by level 1 chargers. While these drivers may never need to visit a level 3 neighborhood charger, the ability to conveniently do so could be important in their comfort level or willingness to not install a level 2 charger at home. A minority of the vehicles in our sample would clearly benefit from regular access to level 2 charging. For example, 18% of vehicles require 12 or more supplementary charges.

There are three key limitations in our analysis: the use of EV specific driving data, the relatively small sample size (129 vehicles), and the assumption around level 1 charging rates. In the case of EV specific driving data, driving patterns for early adopters of EVs may differ from the general population which could lead to over or underestimates of the sufficiency of level 1 charging. However, the use of actual EV driving data as opposed to simulated general population data allows for a more accurate inclusion of factors that impact real world EV performance such as the impact of temperature on range and charging, and driving behavior (e.g. acceleration, regenerative breaking). We also find the observed annual median driving distance per vehicle of 14,649 km is comparable to the annual km driven per vehicle in Alberta of 15,600 km. In addition, the result depend on the actual charging rate of battery charging at level 1, which we assume here to be 1.2 kW after losses. Lower rates due to higher losses would lower level 1 sufficiency, while higher rates of charging that could be achieved with higher amperage outlets would increase level 1 sufficiency.

As a result of these three limitations caution should be taken in interpreting the percentage of vehicles that we determine can use level 1 charging to meet their energy needs as a detailed estimate of the percentage of vehicles in a future with significant EV adoption. Instead, it is intended to test the implicit assumption that level 1 charging is universally insufficient. Future work could apply the real-world EV performance observed to a broader dataset of general driving patterns to address these limitations and estimate population wide viability of level 1 charging, but this is beyond the scope of this paper.

Despite these limitations the results are still highly relevant for the current discussion of EV charging access and the concerns around the potential need for electrical panel or distribution grid upgrades which often implicitly assume level 1 charging is insufficient for all vehicles rather than a subset. Our findings suggest this implicit assumption should be further studied and may not be valid in all cases. In the case of multi-residential buildings or properties without charging access it may be easier and less costly to retrofit level 1 charging infrastructure. Residents of single-family homes could in some cases avoid the need for costly panel and service upgrades by instead using level 1 charging. This could also reduce the need for local distribution infrastructure upgrades, especially in the near to mid-term. These benefits would need to be measured against the increase in overall demand for electricity that would arise from charging system losses such as those arising from battery management system energy requirement during longer level 1 charge times.

A better understanding of why people choose to install level 2 chargers in cases where level 1 chargers are sufficient would be helpful in unlocking these opportunities. There could be many different reasons individuals chose to install level 2 chargers when they are not strictly necessary, including but not limited to a need for additional charging capacity for a second vehicle, concerns about the ability of level 1 charging to meet their needs which would be exacerbated by a lack of access or concern about access to level 3 charging as a backup, lack of information or misinformation regarding the sufficiency of level 1 charging, social pressure, or future proofing. These factors could be tested through surveys in future work. In addition, future work could evaluate the key factors in sufficiency of level 1 charging where our results suggest total distance

travelled is an important factor, whereas vehicle range—which can depend on both typical driving distance but also consumer preferences—appears less important.

Efforts, including education, incentives, and build out of the level 3 charging infrastructure, are likely required to take advantage of the potential to serve EV charging demand in this way. Educational campaigns could help to make potential EV owners aware of the potential to rely on level 1 charging depending on their driving patterns and total driving distance. Where level 1 charging could avoid distribution grid upgrades, policymakers could consider incentives for EV owners that choose to use level 1, or managed level 2, charging in homes. All of these solutions could be supported by increased efforts to develop level 3 charging infrastructure that could in some cases be designed to serve both the needs of supplementary charging for local EVs as well as supplement the build out of the level 3 EV charging network for longer distance travel that is also critical to support widespread EV adoption.

While the focus of this study was on the ability of level 1 charging to meet charging needs, for EV owners that already have level 2 charging infrastructure these results demonstrate a significant amount of flexibility to throttle or shift charging times to address issues of capacity on the distribution grid/in multi residential building installations, or to optimize charging for use of electricity generated from variable renewable energy sources.

While the focus of this analysis is the sufficiency of level 1 charging, there may be additional ways to serve EV charging needs without home-based level 2 charging. For example, non-residential level 2 charging to supplement home based level 1 charging and the faster charging rate could reduce the need for supplementary charges for some vehicles in our sample. Future work could evaluate the feasibility of options such as level 2 charging at businesses to expand the percentage of EVs that could have their energy needs met without level 2 charging at home.

Data availability statement

The data cannot be made publicly available upon publication because they are owned by a third party and the terms of use prevent public distribution. The data that support the findings of this study are available upon reasonable request from the authors.

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Ethics statement

Approval was given by the University of Calgary Conjoint Faculties Ethic Review REB 22-0080. All participants gave written informed consent to participate in the study.

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