Usage Analysis of Public AC Chargers in the UK

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Abstract

In the United Kingdom, approximately 56% of the total charging network, consisting of forty thousand charge points, is comprised of fast AC chargers. However, there exists a significant lack of information regarding usage patterns, which poses a challenge for making informed decisions about future infrastructure planning. This paper focuses on a statistical analysis of the usage patterns of 416 public AC chargers (7 kW) in the UK, based on a dataset comprising over ten thousand charging sessions. The data was collected from one of the UK's largest AC charging network operators over a four-month period (April to July 2022). The study specifically examines the charging demand (measured in kWh) and utilisation rates of chargers located in four different types of parking lots: multi-storey, workplace, on-street, and surface car parks. The analysis reveals that the median charging demand remains consistent across different locations, but there is a high standard deviation in locations with parking restrictions. Two different utilisation metrics, namely sojourn-based and energy-based, are employed to assess the utilisation rates. The results indicate that the overall median utilization rates are generally low, with most locations recording rates below 5%. These findings contribute valuable insights for effective planning and optimal allocation of investments aimed at expanding charging infrastructure.

1 Introduction

The United Kingdom is leading the way in the adoption of electric vehicles (EVs) on its roads, with over 1.2 million plug-in electric vehicles sold as of March 2023 [1]. Moreover, EV sales have accounted for over 30% of new car registrations by that date. To achieve the goals of net-zero emissions in road transportation and further increase EV sales, continuous efforts are being made to expand the charging infrastructure and improve access to charging stations. Currently, the UK has a robust public charging network consisting of over forty thousand charging devices operating at various speeds [2].

Public charging stations can be classified into two types: AC and DC. AC charging relies on the capacity of onboard AC/DC converters and typically offers charging rates below 22 kW. AC chargers are further categorized as fast (7 kW to 22 kW) and slow (3 kW to 6 kW). In the UK, as of 2023, 56% of the charging devices are fast AC chargers, while 25% are slow AC chargers. On the other hand, DC fast chargers utilize off-board chargers and are capable of transferring higher power volumes, ranging from 25 kW to 150 kW. Rapid DC chargers account for 19% of the chargers in the UK. In this study, we consider fast AC chargers (7 kW) in the UK and analyse the usage patterns.

In order to accommodate the growing number of EVs, the UK government has set a target to deploy 300,000-700,000 chargepoints of both types by 2030 [3]. Additionally, the ratio of EVs to chargers is considered an important metric to support the electrification of transportation. In the European Union, the goal is to have a maximum of 10 EVs per charger across member states to meet the charging needs of drivers [4]. Fig. 1 illustrates the EV to public charger ratio in the UK, which is significantly lower than the EU's target of one public charger for every ten EVs.

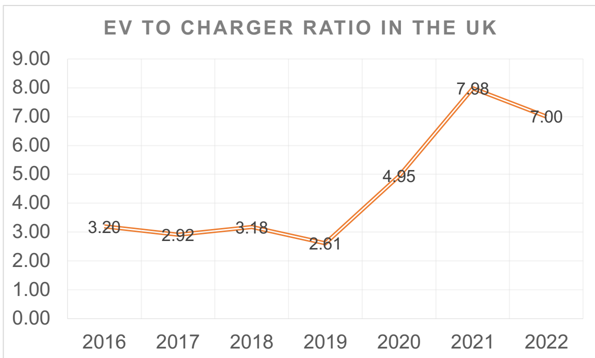

Fig. 1. EV to charger ratio in the UK (source: [5]).

Currently, the operation of most public charging stations in the UK is the responsibility of private businesses. Therefore, conducting a comprehensive investigation into the economics of charging stations is crucial. This investigation involves analysing key factors such as utilization rates, usage patterns, and potential queuing times. The economics of charging stations are also influenced by the type of charging, whether it's AC (7 kW single phase and 22 kW three-phase) or DC (50 kW and above), as well as the associated infrastructure investments. Deploying fast DC chargers incurs considerably higher costs due to complex power electronics components, protection

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Table 1 Number of charging sockets at each location.

	On-Street	Multi- Storey	Surface	Workplace
# of Chargers	202	29	215	14
# of Sessions	2556	494	5389	714

equipment, and necessary civil works to establish a three-phase electricity connection at the site [6]. As a result, fast DC chargers require higher utilization rates to generate profits [7–9]. According to [7], it is projected that fast DC charging will become profitable after 2025, primarily due to low utilization rates. On the other hand, amortizing investments for Level 2 or 7 kW AC chargers is more feasible, as the capital investments required are significantly lower than those for DC chargers, and grid reinforcements are less urgent.

In the coming decade, there will be significant investments made in expanding the charging infrastructure for electric vehicles. To ensure the success of these investments, it is important to conduct a data-driven analysis of the existing charging network. This requires statistical modelling and characterization of EV charger usage patterns to gain insights into current utilization rates and inform decision-making. In this particular study, data from nearly 10,000 charging sessions at 460 public AC chargers (7 kW) in the UK between April and July 2022 are analysed. The study includes statistical analysis to understand key charging behaviour, such as utilization rates and energy transfer characteristics, based on the charger's location.

There is only a handful of literature on the analysis of public charging networks. In [10], 390k charging session data collected from public chargers (AC and DC) in the Netherlands between 2011-15 is analysed to understand drivers' usage behaviour. In [8], data analysis for twenty-two thousand German public charging stations are analysed and driver behaviour and station profitability assessments were made. The utilisation rates of public chargers are studied in [11] for the US and in [12] for Canada. In [11], it is shown that utilisation rates (given in kWh/day) vary significantly among different locations and AC charging utilisation is lower than DC chargers. In [12], seven thousand charging events are analysed and it is shown that the median number of charges per 7 kW AC charger is 0.4 and the median energy transfer is 6.6 kWh.

2 Dataset

In this paper, data collected from one of the UK's leading charge point operators' networks compromised of 7 kW chargers are used. The data includes nearly ten thousand charging sessions completed between April 1, 2022, and July 31, 2022, in the UK. Furthermore, we filtered sessions with charging demand less than 1 kWh. Therefore, our dataset reduced to 9153 charging sessions and session distribution among different parking locations is presented in 1 along with the number of chargers. It can be seen that significant amount of chargers are located at on-street and surface car parks.

It is noteworthy that the management of the parking spaces of all parking types is handled by the owner of the parking space, who could have different parking restrictions. Moreover our dataset does not include local signage or notices, and therefore, we assume that all parking locations are accessible throughout the study period and that all car parks are operational 24 hours a day. For each charging session, the dataset includes the following parameters:

- *Charging Power* is either 7 or 22 kW as described above.
- *Session Start/Stop Date and Time* shows when the vehicle is plugged-in and leaves the charger.
- *Duration* attribute shows the total duration the vehicle spends as plugged in.
- The amount of energy data is reflected via *Total Energy* attribute (in kWh).

It is noted that the data for *Duration* are less than or equal to the total charging duration, as the vast majority of vehicles *overstay* after completion of charging. This is taken into account when calculating the utilisation rates.

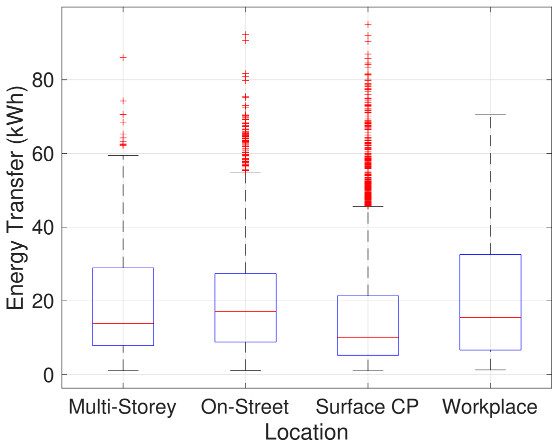

Fig. 2. Charging demand (kWh) at different parking locations.

3 Results

3.1 Energy Transfer

We start our analysis by calculating the amount of electrical energy (kWh) transferred to charge EVs. Figure 2 shows the energy transfer characteristics for each type of parking. The median values for energy transfer are 13.88 kWh, 17.15 kWh, 10.11 kWh, and 15.49 kWh for multi-storey, on-street, surface car park, and workplace parking, respectively. Assuming the average EV has an energy rating of 250 Wh/mile, these median charge rates could provide a range of 44 to 68 electric miles under ideal weather conditions (e.g., 21 degrees Celsius) [13]. Although the median charge amounts are similar across all parking types, there is considerable variability beyond the third quartiles. Surface car parks and on-street parking exhibit a higher number of outliers due to variations in parking restrictions among locations within this category, as depicted in Figure 3. Notably, the duration of stay is significantly longer at on-street and surface car parks, while it is limited at workplaces (less than 10 hours) due to work hour restrictions.

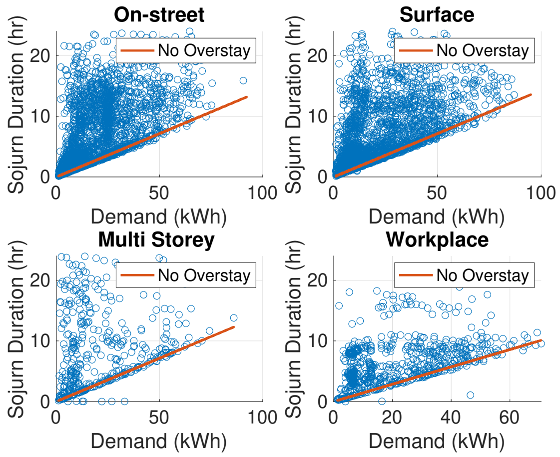

Fig. 3. Scatter plot of energy demand and sojourn durations.

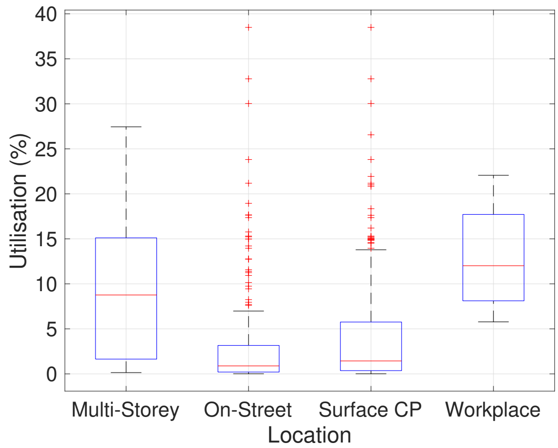

Fig. 4 Sojourn-based utilisation rates for different locations (based on (1)).

3.2 Sojourn-Based Utilisation Rates

The utilization rate of a charger is a crucial measure that indicates the profitability of chargers and serves as an indicator of the effectiveness of facility location decisions. Given the attributes of our dataset, we use two utilisation metrics. The first one is connection duration-based (sojourn duration) utilisation, which is the ratio of total amount of time a car is connected to a charger to the total amount of time (122 days (or hours equivalent)). Utilisation rate can be formulated as follows. Let $t_{\mathrm{arrival_i}}$ denote the time EV i is connected to a charger and, similarly, $t_{\mathrm{departure_i}}$ denotes the time EV i leaves the charger. Then, the sojourn time for EV i becomes $\delta^i_{\mathrm{sojourn}} = t^i_{\mathrm{departure}} - t^i_{\mathrm{arrival}}$. Suppose that there are N EVs which are connected to charger j during the course of our study T (in hours). Then, the utilisation rate of charger j becomes

$$\mathrm{U^s_j} = \frac{1}{T}\sum_{i=1}^{N} \delta^i_{\mathrm{sojourn}}. \tag{1}$$

It is critical to note that it is very unlikely for an arbitrary EV i to charge constantly during sojourn duration $\delta^i_{\mathrm{sojourn}}$ as the vast majority of EVs experience overstay, that is the duration when the charging is completed, but the vehicle is still connected to the charger. For instance, [11] shows that for most venue types, the overstay periods are longer than 35% of the sojourn times. In Fig. 3, red lines show the charging sessions with no overstay. It can be seen that the vast majority of the charging session experience overstay. Figure 4 shows the utilization rates for different locations, highlighting that workplace chargers have higher utilization rates compared to others. There are two primary reasons for this observation. Firstly, the workplace car park only has 12 chargers available in one location and have less variability. Secondly, these chargers experience high usage during work hours and EV to charger ratio is higher than other cases. In contrast, on-street and surface car parks have a significantly higher number of chargers. The median utilization rates for on-street and surface car parks are 0.88% and 1.44% respectively. These statistics indicate that a substantial number of chargers remain idle and unused for a significant portion of the time. Multi-storey car parks, on the other hand, exhibit higher charger utilization rates compared to on-street and surface car parks, primarily higher shares of overnight chargings. For instance, 43% of the charging sessions in multi-storey parking has more than 10 hours of parking. This ratio is 31% for on-street and 12% for surface car parks.

3.3 Charging Demand-based Utilisation Rates

The utilisation calculations based on sojourn durations provide useful insights into how chargers are utilised at different locations. However, equation (1) does not consider overstay periods, meaning that actual utilization rates are expected to be lower unless there is a queue. In this section, we calculate utilization rates based on the amount of transferred energy. Let ω^j_i represent the amount of electrical energy transferred to charge EV i at charge point j. Ω^j represents the total amount of energy that could be transferred if a charger were constantly occupied for a specified period T (e.g., 7 kW x T hours). Suppose there are N EVs connected to charger j during our study period T (in hours). The utilization rate of charger j can then be expressed as:

$$\mathrm{U^c_j} = \frac{1}{\Omega^j}\sum_{i=1}^{N} \omega^j_i. \tag{2}$$

One limitation of this approach is the assumption that the charging rate remains constant at 7 kW throughout any charging session, except when the battery state of charge exceeds 80%. In such cases, the charging power reduces due to the constant current constant voltage charging scheme. Nonetheless, we assumed a charging power of 7 kW, as most public charging events do not go beyond 80% of charging. This can be observed in Figure 2, where the third quartile of energy transfer for all charging locations is 35 kWh or lower, which is below the capacity of a typical EV battery pack.

Figure 5 illustrates the utilization rates calculated using the amount of energy charged. Comparing these rates to those in Figure 5, it is evident that almost all utilization rates experience a significant decrease. This discrepancy reflects the impact of

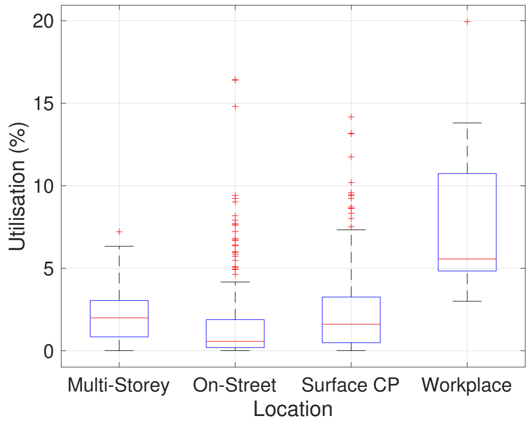

Fig. 5 Energy transfer-based utilisation rates for different locations.

overstay periods, as the energy-based utilization metric yields lower rates compared to the duration-based rates. The median utilization rates for multi-storey, on-street, and surface car parks are below 2%, whereas it reaches 5.7% for workplace chargers. Consistent with previous findings, these results highlight that a considerable number of chargers are seldom used and remain idle for most of the time.

4 Conclusions

In this paper, we presented the statistical analysis of 7 kW public AC chargers in the UK. We compared the statistical behaviour using energy demand (kWh) and charger utilisation for different parking types, namely multi-storey, on-street, surface, and workplace. We showed that energy demand across different charging types are consistent when median demand is considered. Also, EVs using on-street and surface car parks stay connected for additional durations even if the charging is completed. Due to low utilisation rates this is not an issue at the moment. However, different pricing mechanisms are needed to avoid queueing with increasing penetration rates. For the utilisation rates, we used both sojourn duration and charge demand based metrics to capture the impact of overstay periods. In both cases, the utilisation rates are less than 5%. The primary reason for the low utilisation rates is the fact that most EV owners in the UK have dedicated domestic chargers and do not need to use public chargers, or are the chargers located in the wrong place? Further work is required to match behaviour change as a result of technology changes and options offered to the driver. Opportunity AC charging with a 90 mile range car is understandable especially if it comes with guaranteed parking, but will opportunity charging take place with a 300mile range car? The next stage is to locate the correct type of infrastructure in the correct location based on modelling.

5 Acknowledgement

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6 References

[1] 'How many plug-in cars are there in the uk?'. (, . accessed May, 2023. https://www.zap-map.com/ev-stats/ev-market/

[2] 'Electric vehicle charging device statistics: April 2023'. (, . accessed May, 2023. https://www.gov.uk/government/statistics/electric-vehicle-charging-device-statistics-april-2023/electric-vehicle-charging-device-statistics-april-2023

[3] 'A full scale recovery requires a fully charged future'. (, . accessed May, 2023. https://www.smmt.co.uk/2023/01/a-full-scale-recovery-requires-a-fully-charged-future

[4] Todts, W. 'Recharge eu: How many charge points will Europe and its Member states will need in the 2020s'. (Transport & Environment, 2020.

[5] 'Electric vehicles - united kingdom'. (, . accessed April, 2023. https://www.statista.com/outlook/mmo/electric-vehicles/united-kingdom

[6] Smith, M., Castellano, J. 'Costs associated with non-residential electric vehicle supply equipment: Factors to consider in the implementation of electric vehicle charging stations'. (, 2015.

[7] Borlaug, B., Yang, F., Pritchard, E., Wood, E., Gonder, J.: 'Public electric vehicle charging station utilization in the united states', *Transportation Research Part D: Transport and Environment*, 2023, **114**, pp. 103564

[8] Hecht, C., Figgener, J., Sauer, D.U.: 'Analysis of electric vehicle charging station usage and profitability in germany based on empirical data', *Iscience*, 2022, **25**, (12), pp. 105634

[9] Gellrich, M., Block, A., Leikert.Böhm, N.: 'Spatial and temporal patterns of electric vehicle charging station utilization: a nationwide case study of switzerland', *Environmental Research: Infrastructure and Sustainability*, 2022, **2**, (2), pp. 021003

[10] Sadeghianpourhamami, N., Refa, N., Strobbe, M., Develder, C.: 'Quantitive analysis of electric vehicle flexibility: A data-driven approach', *International Journal of Electrical Power & Energy Systems*, 2018, **95**, pp. 451–462

[11] Borlaug, B., Yang, F., Pritchard, E., Wood, E., Gonder, J.: 'Public electric vehicle charging station utilization in the united states', *Transportation Research Part D: Transport and Environment*, 2023, **114**, pp. 103564

[12] Jonas, T., Daniels, N., Macht, G.: 'Electric vehicle user behavior: An analysis of charging station utilization in canada', *Energies*, 2023, **16**, (4), pp. 1592

[13] Senol, M., Bayram, I.S., Naderi, Y., Galloway, S.: 'Electric vehicles under low temperatures: A review on battery performance, charging needs, and power grid impacts', *IEEE Access*, 2023, **11**, pp. 39879–39912