Evidence of Unmet Demand for Public Charging Points for Electric Vehicle Users in the United Kingdom

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Abstract—The widespread adoption of electric vehicles is necessary for the United Kingdom to achieve its net zero target by 2050, but barriers exist if the electric vehicle charging infrastructure is not well-established. This study aimed to characterise the distribution of public electric vehicle charging points as compared to the distribution of electric vehicles in areas across the Scottish region of the United Kingdom served by 2 energy networks, and investigate any evidence of unmet demand for public charging points. Publicly available data on charging points (n = 2,810) and charging sessions (n = 579,294) were obtained and analysed. The region studied contained so-called blackspot areas where 100 or more electric vehicles were owned, but there were less than 10 public charging points available (termed "high demand" areas). Charging sessions in these areas, when compared to sessions lasting less than 30 minutes, had over twice the odds of lasting 30 minutes to 1 hour, almost 3 times the odds of lasting between 1 and 2 hours, and over 5 times the odds of lasting 2 or more hours compared to charging sessions outside high demand areas. Also, compared to work day times, in high demand areas, charging sessions had over 3 times the odds of starting in evening hours, almost 3 times the odds of starting during sleep times, and about 2 and a half times the odds of starting in early morning, compared to other areas. In conclusion, the findings suggest that the number of public charging points available to serve electric vehicle owners in this area appears to be inadequate.

Keywords—*Electric vehicles; United Kingdom; charging point infrastructure; net zero; charging sessions; charging point demand; smart charging.*

I. INTRODUCTION

As of 2021, the United Kingdom (UK) government set a target to reduce carbon dioxide emissions by 68% from 1990 levels by 2030, and to achieve net zero emissions by 2050 [1–3]. Consequently, the UK Climate Change Committee (CCC) established strategies to promote improved sustainable energy use to meet net zero targets, with a specific focus on promoting the adoption of Electric Vehicles (EVs) [1–4]. The widespread adoption of EVs is seen as a necessary condition to enable the UK to achieve net zero, as passenger cars have been documented as the largest source of road transport emissions [2][5]. To that end, in 2022, 17% of the new cars purchased in the UK were EVs, and one million EVs were registered in the UK in 2021, exceeding expectations [6][7].

However, the absence of a coordinated rollout of an EV public charging infrastructure that complements the enthusiastic uptake of EVs in the UK has been identified as a significant barrier to overall EV adoption in the UK [6–8]. Currently, charging facilities are not evenly spread across the UK, leaving areas with a low prevalence of public Charging Points (CPs) [7][9]. Although it is known that some regions in the UK lack public CP access, research into how well the public EV charging infrastructure is meeting the demand of EV users in the UK is lacking. Research addressing this point is necessary to inform UK leaders as to whether EV adoption is outpacing the development of the public EV charging infrastructure.

In October 2022, the UK had nearly 35,000 CPs, and over the first nine months of that year, more than 1,200 new public rapid chargers and over 5,000 new public standard chargers were installed [7]. Over the same period, there were 250,000 new EV registrations in the UK, which means there was on average 1 new public standard charger for every 50 new vehicles [7]. The UK government has termed some regions "blackspots" due to the lack of public CPs, forcing EV owners to drive long distances to charge their vehicles, which is inconvenient and offsets the savings anticipated from owning an EV compared to a car that uses fossil fuels [7][9]. As an example, 31% of the UK's public CPs are in London, compared to only 3% being in the North East region [7]. This analysis helps bring insight into whether the public CP infrastructure in a region of the UK is able to meet the demand of EVs users in that region. The results can provide guidance on how to further develop the public CP infrastructure.

Energy networks in the UK are organised into regional collections of primary energy stations and substations. The two networks that serve Scotland are Scottish Power Energy Networks (abbreviated SP Energy) and Scottish and Southern Energy Networks (abbreviated SSEN) [10][11]. In networks in the UK such as SP Energy and SSEN, Primary Substations (PSs) directly feed from high voltage networks, and serve to step down energy transmitted through these high voltage networks from 33 to 11 kilovolts (kV) in order to enable energy to be distributed to homes and businesses [12]. SP Energy serves the areas of central and southern Scotland, North Wales, Merseyside, Cheshire and North Shropshire [11]. SSEN serves the north of Scotland and central southern England, and claims 3.9 million homes and businesses as customers [10]. Our analysis focuses on PS service areas in Scotland served by SP Energy and SSEN, and the prevalence of both EVs and public CPs in those service areas.

The aim of this research was to 1) characterise the distribution of public CPs and EVs in PS service areas across the

regions served by SP Energy and SSEN, and 2) investigate if there is evidence of unmet demand for public CPs in PS service areas in these networks with a high prevalence of EVs coupled with a low density of public CPs. The structure of this paper proceeds with Section II, which describes our materials and methods, including the sources of the data we used and our analytic approach. In Section III, the results are presented, including a comparison of EV ownership and public CPs in PS service areas, an examination of densities of public CPs and EV ownership, and an analysis of charging session patterns in high demand PS service areas. This is followed by Section IV, where we discuss our findings and their implications, and Section V, which presents a conclusion and recommended future research.

II. METHODOLOGY

A. Data Sources

The data used for this analysis came from public repositories. The data about public CPs and charging sessions for both SP Energy and SSEN came from the ChargePlace Scotland's online data repository [13]. Data about number of EVs in PS service areas for SP Energy came from the SP Energy Distribution Future Energy Scenario (DFES) forecasts posted online [14], and for SSEN, they came from data used for the DFES forecasts available on the SSEN Distribution Data Portal [15].

Data about PS service areas for SP Energy for 2023 were obtained from SP Energy Networks, and for PS service areas for SSEN, 2023 data were obtained from the SSEN data portal [14][15]. Each dataset included number of EVs in each PS service area, and we connected these data to the CP data to determine the number of public CPs in each PS service area.

B. Analytic Approach

First, public CP data from December 2024 for both SP Energy and SSEN were obtained from ChargePlace Scotland, which included 2,848 CPs in total [13]. CP monthly variables that were analysed included number of charging sessions, power drawn (kWh), number of faults (outages), and percentage of uptime (see Table 1 for categories). A bivariate analysis was conducted on public CP usage for both SP Energy and SSEN in December 2024 on the basis of these variables. Based on available data, we established 5 EVs per public CP in each PS service area as an acceptable public CP density.

To identify areas of potentially high demand for public CPs, we compared maps of both SP Energy and SSEN PS service areas in terms of EV prevalence and CP density. An interactive geospatial map was developed to visualise the distribution of EV counts and associated public CPs across PS service areas. This analysis used Python to integrate postcode-level geolocation data to enable aggregation and enumeration of CP density and EV prevalence by PS service areas. CP locations were spatially joined with PS polygons using a Geographic Information System (GIS) method to determine PS service area inclusion. Distinct colour schemes were applied to PS service areas based on thresholds for both CP density and

TABLE I
CATEGORIES.

Category	Level
Number of Sessions	0 to 5
	6 to 19
	20 to 49
	50 or more
Power Drawn (kilowatt hours)	0 to < 75
	75 to <400
	400 to <1,000
	1,000 or more
Number of Faults	0
	1
	2 or more
Uptime	100%
	<100%
Number of Connectors	1
	2
	3 or more
	Unknown
Session Start Time of Day	Work Day (8:00 to 18:00)
	Evening (18:00 to 22:00)
	Sleep Time (22:00 to 6:00)
	Early AM (6:00 to 8:00)
Duration of Session	<30 minutes
	30 minutes up to 1 hour
	1 hour up to 2 hours
	2 or more hours

EV prevalence. The final map was rendered using the Folium Python library, which allows an intuitive, zoomable web-based exploration [16].

It was determined that PS service areas in the SP Energy network likely suffered from high demand, as many PS service areas contained 100 or more EVs, but less than 10 public CPs. As described in Global EV Outlook 2024, a ratio of 100:1 to 10:1 with respect to EVs in a region to public CPs in the region would indicate very low access to public CPs, as this entire ratio range is much higher than most country averages [17]. We classified these areas as "high demand" PS service areas. We also used session data to characterise public CPs as having 1, 2, or 3 or more connectors. We classified public CPs as to whether or not they fell in high demand PS service areas, and conducted a bivariate analysis. To explore this potential for unmet demand for public CPs, we analysed sessions from public CPs in SP Energy PS service areas from July 2024 through December 2024, using session data from ChargePlace Scotland [13] (see Table 1 for categories).

We hypothesised that sessions from public CPs in high demand PS service areas served by SP Energy would be more likely to start outside of work day times. We also hypothesized that sessions from public CPs in high demand PS service areas would show a different duration pattern than those from public CPs in other PS service areas. After conducting a bivariate analysis, to derive a profile including month of session, time of day of session start, and duration of session, for sessions occurring at public CPs in high demand PS service areas, we developed a logistic regression model, including these factors as independent variables predicting whether or not the session occurred at a public CP in a high demand PS service area.

TABLE II
BIVARIATE ANALYSIS OF PUBLIC ELECTRIC VEHICLE CHARGING POINTS IN SCOTTISH POWER ENERGY, HIGH DEMAND VS. OTHER PRIMARY SUBSTATION SERVICE AREAS, DECEMBER 2024.

Category	Level	All	High Demand*	All Others
		n, %	n, %	n, %
All	All	1,877, 100%	528, 28%	1,349, 72%
Number of Sessions	0 to 5	469, 25%	106, 20%	363, 27%
	6 to 19	410, 22%	107, 20%	303, 22%
	20 to 49	521, 28%	151, 29%	370, 27%
	50 or more	477, 25%	164, 31%	313, 23%
Power Drawn (kilowatt hours)	0 to < 75	435, 23%	102, 19%	333, 25%
	75 to <400	440, 23%	96, 18%	344, 26%
	400 to <1,000	476, 25%	148, 28%	328, 24%
	1,000 or more	526, 28%	182, 34%	344, 26%
Number of Faults	0	1,317, 70%	354, 67%	963, 71%
	1	318, 17%	103, 20%	215, 16%
	2 or more	242, 13%	71, 13%	171, 13%
Uptime	100%	1,407, 75%	393, 74%	1014, 75%
	<100%	470, 25%	135, 26%	335, 25%
Number of Connectors	1	65, 3%	11, 2%	54, 4%
	2	1,377, 73%	395, 75%	982, 73%
	3 or more	284, 15%	77, 15%	207, 15%
	Unknown	151, 8%	45, 9%	106, 8%

Note: First row has row percentages, and the rest are column percentages. *High demand refers to charging points in primary substation service areas where there are 100 or more electric vehicles but < 10 charging points.

Independent variables were coded as indicator variables, and entered into one model. All statistical analysis was done in R GUI [18] using packages *broom* [19], *dplyr* [20], *ggplot2* [21], *lubridate* [22], *readr* [23], and *scales* [24].

III. RESULTS

Data were available from 2,848 public CPs in SP Energy and SSEN PS service areas. The data that were complete and usable represented 2,810 public CPs which were included in the dataset. Data on 820 PS service areas from both networks were also included in the analysis. For monthly sessions from SP Energy, data from 833,691 sessions available for analysis. From these, 323 were removed due to missing or nonsensical duration values, and 254,074 were removed because they could not be matched to a public CP in a known PS service area, leaving 579,294 sessions that were included in the analysis.
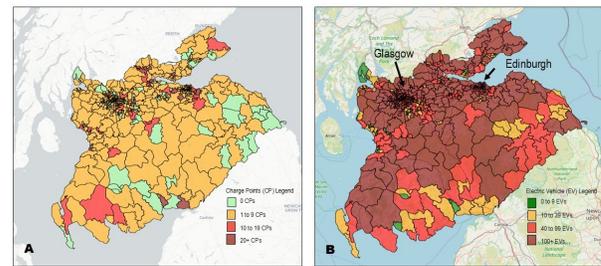

Figure 1. Scottish Power Energy Public Charging Points and Electric Vehicles per Primary Substation Service Areas. Figure 1A indicates public charging point (CP) density, and Figure 1B indicates electric vehicle (EV) density. Major cities are indicated on Figure 1B.

A. Primary Substation Service Areas: EV Ownership and Public CPs

Descriptive statistics were developed with respect to the 820 PS service areas included in the SP Energy and SSEN networks (data not shown). Of the 820 PS service areas analysed, almost half (48%, n = 393) were in the SP Energy network, and the other half (52%, n = 427) were in SSEN. Approximately one third of these PS service areas (34%, n = 279) included 0 public CPs. With respect to number of EVs owned in each PS service area, approximately one fourth (24%, n = 196) contained 0 to 9 EVs, while 27% (n = 223) contained 100 or more EVs. With respect to network, high EV ownership per PS service area was more prevalent in the SP Energy network, compared to SSEN, where 41% (n = 162) of SP Energy PS service areas contained 100 or more EVs, with only 14% (n = 61) of SSEN PS service areas including 100 or more EVs. The distribution of EVs per PS service area was also highly left skewed (median = 36 EVs per PS service area). However, of the 12 PS service areas with 20 or more public CPs, most (n = 10) were in the SP Energy network, with only 2 in the SSEN network.

Approximately two thirds of the 2,810 public CPs analysed in each network fell in the SP Energy network (67%, n = 1,877), with the remainder in SSEN (33%, n = 933). The distribution of number of monthly sessions per public CP was left skewed (median = 21 sessions), but distributions were similar across both networks. A similar distribution pattern was seen in terms of power drawn from public CPs in across networks (median = 484.81 kWh). Overall, most public CPs (70%, n = 1,958) had 0 faults (outages) and maintained 100% uptime (73%, n = 2,045), with a similar distribution for both networks analysed.

B. Comparison of Densities of Public CPs and EV Ownership

Figure 1 shows a comparison of public CP density with EV ownership patterns in SP Energy, and Figure 2 shows the same comparison for SSEN. As depicted in Figure 1, most PS service areas within the SP Energy network contained 100 or more EVs, yet most PS service areas included less than 10 public CPs, implying that there is much higher demand for public CPs than available. In Figure 2, a high prevalence
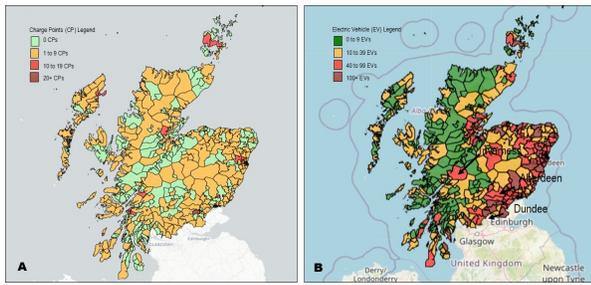
Figure 2. Scottish and Southern Energy Network Public Charging Points and Electric Vehicles per Primary Substation Service Areas. Figure 2A indicates public charging point (CP) density, and Figure 2B indicates electric vehicle (EV) density. Major cities are indicated on Figure 2B.
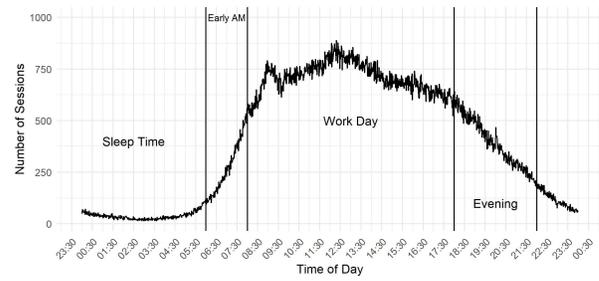

Figure 3. Time Series Plot of Start Time of Day for Sessions from Scottish and Southern Energy Network Public Charging Points, July through December 2024

of EVs in SSEN PS service areas is only evident around the eastern coastal areas, which contain large cities. However, public CP density is not high in these areas, which also may lead to unmet public CP demand. Further, throughout the SSEN network, there were many PS service areas that contain a low prevalence of EVs but 0 public CPs, forcing EV owners to travel to another PS service area to take advantage of public charging services. This implies that while the density of public CPs may be adequate to serve PS service areas in much of the SSEN network, there is also a high probability of unmet demand for public CPs throughout the rest of the network.

C. Charging Session Patterns in High Demand Primary Substation Service Areas

Table 2 presents a bivariate analysis of public CPs in the SP Energy network categorised by those occurring in high demand PS service areas compared to all others. As shown in Table 2, in December 2024, public CPs in high demand PS service areas were more likely to have 50 more sessions than those in other PS service areas (31%, n = 164, compared to 23%, n = 313), with a similar pattern seen in amount of power drawn (1,000 kWh or more, 34%, n = 182 vs. 26%, n = 344). On the other hand, distribution of number of faults, uptime, and number of connectors was similar between high demand PS service areas compared to other service areas.

Figure 3 shows the distribution of all 579,294 charging sessions at public CPs in the SP Energy network over the period of July through December, 2024 by time of day the session started. As displayed in Figure 3, charging sessions were most likely to start during the work day (8:00 to 18:00), reaching peak frequency near 800 sessions, while dropping off during evening hours (18:00 to 22:00) to a frequency of less than 250 sessions. Frequencies of charging session start time were lowest during sleep time (22:00 to 6:00), at times approaching a frequency of 0 charging sessions. During early morning times (6:00 to 8:00), frequencies of charging sessions rose from less than 250 at the beginning of the interval to over 500 at the end of the interval.

Table 3 presents a bivariate analysis of these charging sessions classified by those that took place in high demand PS service areas compared to all others. As shown in Table 3,

while most of the sessions (81%, n = 469,681) took place at public CPs outside of high demand PS service areas, monthly distribution of sessions was similar, with the greatest share taking place in August (21%, n = 120,805) compared to the other months analysed. However, a greater percentage of sessions started in evening hours at public CPs in high demand PS service areas compared to others (18%, n = 20,064 compared to 16%, n = 73,339), with a lower percentage starting during the work day (71%, n = 77,975 vs. 74%, n = 347,567). Also, while 37% (n = 40,986) of sessions at public CPs in high demand PS service areas had a duration of 2 or more hours, only 25% (n = 119,533) at public CPs in other PS service areas were 2 or more hours.

Next, a multivariate logistic regression analysis was conducted to develop of a profile of factors associated with sessions taking place at public CPs in the SP Energy network located in high demand PS service areas compared to other PS service areas. The resulting equation was the following:

$$
\begin{aligned}
\log\left(\frac{p(\text{HD})}{1 - p(\text{HD})}\right) = {} & 0.19110 + 0.8399_{\text{30MIN-1HR}} \\
& + 1.0675_{\text{1-2HRS}} + 1.6598_{\text{2+HRS}} + 1.1667_{\text{EVE}} \\
& + 1.0893_{\text{SLEEP}} + 0.9262_{\text{EARLYAM}} + 1.0235_{\text{AUG}} \\
& + 1.0712_{\text{SEP}} + 1.1040_{\text{OCT}} + 1.0512_{\text{NOV}} \\
& + 1.0532_{\text{DEC}}
\end{aligned}
\tag{1}
$$

where $p(\text{HD})$ is the probability of the session taking place at a public CP falling in a high demand PS service area (compared to other PS service areas). As indicator variables were used, each level entered into the model had a reference level ($<$30 minutes for duration, work day for time of day of session start, and July for month of session). In terms of the equation, compared to charging sessions with a duration of less than 30 minutes, sessions had over twice the odds of lasting 30 minutes to 1 hour, almost 3 times the odds of lasting between 1 and 2 hours, and over 5 times the odds of lasting 2 or more hours if they took place at public CPs in high demand PS service areas compared to all other PS service areas. Also, compared to work day times, charging sessions had over 3 times the odds of starting in evening hours, almost 3 times the odds of starting during sleep times, and about 2 and a half

TABLE III
BIVARIATE ANALYSIS OF CHARGING SESSIONS AT PUBLIC ELECTRIC VEHICLE CHARGING POINTS IN SCOTTISH POWER ENERGY, HIGH DEMAND VS. OTHER PRIMARY SUBSTATION SERVICE AREAS, JULY THROUGH DECEMBER 2024.

Category	Level	All n, %	High Demand* n, %	All Others n, %
All	All Sessions	579,294, 100%	109,613, 19%	469,681, 81%
Month of Session in 2024	July	82,359, 14%	14,930, 14%	67,429, 14%
	August	120,805, 21%	22,519, 21%	98,286, 21%
	September	108,818, 19%	21,146, 19%	87,672, 19%
	October	87,530, 15%	16,647, 15%	70,883, 15%
	November	91,095, 16%	17,407, 16%	73,688, 16%
	December	88,687, 15%	16,964, 15%	71,723, 15%
Session Start Time of Day**	Work Day	425,542, 73%	77,975, 71%	347,567, 74%
	Evening	93,403, 16%	20,064, 18%	73,339, 16%
	Sleep Time	27,599, 5%	5,642, 5%	21,957, 5%
	Early AM	32,750, 6%	5,932, 5%	26,818, 6%
Duration of Session	<30 minutes	170,164, 29%	29,183, 27%	140,981, 30%
	30 minutes up to 1 hour	157,674, 27%	23,141, 21%	134,533, 29%
	1 hour up to 2 hours	90,937, 16%	16,303, 15%	74,634, 16%
	2 or more hours	160,519, 28%	40,986, 37%	119,533, 25%

Note: First row has row percentages, and the rest are column percentages. *High demand refers to charging points in primary substation service areas where there are 100 or more electric vehicles but < 10 charging points. **See Table 1 for exact times.

times the odds of starting in early morning, if they took place at public CPs in high demand PS service areas compared to all other PS service areas. Finally, compared to July, charging sessions from each of the other months analysed had around 3 times the odds of taking place at a public CP in a high demand PS service area compared to all other PS service areas.

IV. DISCUSSION

The findings from the current EV analysis suggest that for the regions served by SP Energy and SSEN, EV uptake has been high, indicating significant progress toward net zero [2]. However, the number of public CPs available to serve EV owners appears to be inadequate, especially in PS service areas served by the SP Energy network. Among the charging sessions taking place in PS service areas in SP Energy, those in areas designated as high demand showed evidence of unmet demand for public CP charging services. Sessions were more likely to start at less convenient times (evening hours, sleep time, and early morning, compared to the work day), and were much more likely to be of extremely long duration (2 or more hours). This was likely because EV owners were competing for use of the few public CPs available in the area, and therefore, were more willing to charge their vehicle at inconvenient times, and were more likely to have their EV stay connected to the charger for a long enough duration to fully charge their vehicle.

This lack of public CPs in the regions served by SP Energy greatly limits the utility of EVs for long trips, and greatly increases range anxiety [9][25–27]. This situation can defeat the purpose of promoting the uptake of EVs, because it can cause EV owners to feel as if they need access to a "back-up" fossil fuel vehicle [25][26]. Expanding the selection of en-route public CPs is a key step in improving charging efficiency for EV owners, and is necessary to alleviate both grid and traffic congestion [28]. A robust strategy for determining the optimal placement and capacity of public CPs is possible to develop through integrating location modelling, with demand forecasting and market penetration analysis [29][30].

The main strength of this analysis is that it uses real-world data to assess the potential for unmet demand for public CPs served by 2 energy networks that contain rural areas thought to be underserved. However, there are also many limitations. Much data had to be removed from the analysis because of missing or nonsensical values, and many assumptions had to be applied to facilitate interpretation.

V. CONCLUSION AND FUTURE WORK

Our research aimed to characterise the distribution of public CPs and EVs in Scotland in the regions served by SP Energy and SSEN, and estimate whether there was unmet demand for public CPs in certain PS service areas. We compared the level of EV ownership with the density of public CPs, and characterised high demand PS service areas as having a high level of EV ownership coupled with a low density of public CPs. We found that the regions served by SP Energy and SSEN had several blackspots which were more prevalent in the SP Energy network, with evidence of unmet demand for access to the public EV charging infrastructure. Sessions in high demand areas were more likely to start at inconvenient times and last a longer duration. Policymakers should focus on ensuring CPs in areas with a high density of EVs have good coverage, and offer more and faster charging connectors. While this analysis has strengths, the results apply specifically to the region analysed. Additionally, the analysis was limited to the use of the variables in public data available, where reliable information about the efficiency of connectors was not available.

In terms of future research, a helpful step for the UK to take to address these blackspots would be to conduct an updated survey of EV owners to better understand their need for public CPs, and set an optimal target for public CP density. These efforts could involve input from Charging Point Network Operators (CPNOs) and Distribution Network

Operators (DNOs), with results reported by PS service areas. Through this collaboration, informed goals could be set for optimal public CP density for each PS service area. In this way, working with existing CPNOs and DNOs, the UK government could ensure that increasing EV ownership across the various energy networks continues to be supported, and effectively facilitate further progression toward their stated net zero goals.

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