Quantifying the regional imbalance in EV charging infrastructure: A UK case study

Kaitai Dong
Mindsphere Analytics Centre
Siemens Mobility
London, UK
kaitai.dong@siemens.com

Tom Aston
Central Engineering
Siemens Mobility
London, UK
tom.aston@siemens.com

***Abstract*—Electric Vehicles (EVs) are crucial to achieving the UK's ambitious target to reduce carbon emissions by at least 100 percent by 2025. Critical to the success of the EV transition is the prompt construction of sufficient EV charging infrastructure. However, the UK lags behind other European nations in the development of charging infrastructure, which hinders EV adoption. This paper aims to examine the regional EV sales and chargepoint data in the UK and provide a quantitative assessment of the charging point requirements in each region. While comparing different regions of the UK, a significant disparity in charging infrastructure was discovered, with some areas having a chargepoint deficit as high as 3.2 times the national average. Furthermore, the factors that can determine EV success in the UK are explored.**

***Index Terms*—smart mobility, EV, charging infrastructure, regional analysis, imbalance**

I. Introduction

By 2050, the UK aims to reduce its greenhouse gas (GHG) emissions by at least 100 percent compared to levels in 1990, as detailed in an ambitious plan put forth by the government. When it comes to cutting down on carbon emissions, the transportation sector may make a significant contribution. Scotland has announced its intention to completely phase out the need to purchase petrol and diesel cars or vans by 2032 [1]. This is one step further than the UK's goal of gradually ending the sales of petrol and diesel automobiles, transitioning to 50-70% of the new car market being ultra-low emission by 2030 [2]. Despite EV sales increasing dramatically each year in the past 5 years, EVs still only make up a small fraction of the UK's overall auto market. As of September 2022, 137,498 new electric vehicles had been registered in the United Kingdom, equalling a 14% share of the market for new autos [3].

A sufficient charging infrastructure is an integral part of making EVs a reality. Unfortunately, in the beginning stage of the development of the EV market, due to the low volume of EVs, investors in EV charging infrastructure inevitably encounter cold business periods. During this time revenue does not cover the up-front investments, which makes them hesitant to extend the charging network substantially. Simultaneously, promoting the uptake of EVs becomes more challenging because of the absence of adequate charging infrastructure [4] [5]. In reality, this chicken-and-egg dilemma between investors and potential buyers necessitates multi-faceted and coordinated solutions, such as charging network optimisation [6], power system management [7], and government policy [8], to mention a few. However, research suggests [8] [9] that laying the groundwork for an extensive charging network prior to the introduction of EVs is essential for boosting the confidence of potential EVs buyers, decreasing 'range anxiety,' and realising advantageous tactics like vehicle-to-grid (V2G) [4].

The UK lags behind other European countries, like Norway and the Netherlands, which are widely regarded as the most EV-friendly in Europe, when it comes to developing EV charging infrastructure. According to Falchetta and Noussan's research on the availability of charging stations for electric vehicles [8], residents of Northern and Central Europe have greater access to public charging stations than those in the rest of Europe, resulting in a more convenient charging experience and a higher percentage of EVs in these regions. As a consequence of its earlier development stage, the United Kingdom, and particularly England, has one of the largest discrepancies between its charging point-to-vehicle (C/V) and charging point-to-population (C/P) ratios. Hence, greater public and government support is needed to propel the UK into the EV growth phase. Moreover, Hardinghaus et al [9] was able to shed light on the city's charging demand and infrastructure by analysing Berlin's public charging statistics and information on carsharing vehicles. The research also shows that charging point utilisation will only increase after EV users overcome range anxiety, and that establishing infrastructure is a key prerequisite for the uptake of EVs.

In addition, supply chain disruptions, inflation, skyrocketing energy prices, and an overall bleaker economic outlook characterise the post-COVID-19 era as a result of the recent geopolitical tensions and confrontations between major economies. The British government's plans for expanding the use of electric transportation would be hampered in the short- and mid-term if these problems were compounded with the complications posed by Brexit. Furthermore, the media and political elites in the UK have been increasingly conscious in recent years of the extent to which the UK's regional inequality differs from that of other competitor EU countries [10] [11]. The UK market's characterisation of EV ownership and charging availability also reflects this imbalance. On the plus side, it has been discovered that there is still widespread support amongst the general population and government authorities to prioritise the environment economically. 62% of respondents to a study conducted by Kenward and Brick [12] supported prioritising the environment and sustainable development during the post-crisis economic reconstruction process. This makes it all the more important for the UK to advance its industrial policies and regional development and realise the 'Green Transport' goal.

In light of the preceding discussion, we present a study comparing key EV coverage metrics in leading European countries with those in the United Kingdom, displaying real-world charging infrastructure and EV registration data from around the country. The study will quantify the chasm between the actual and ideal EV charging network conditions by revealing the uneven expansion of charging infrastructure across the UK. The objective of this study is to provide insight into the work that is required by policymakers and businesses to accelerate the growth of EVs and establish the UK as a regional leader in this field.

The main content of this paper is organised as follows: Section II presents a case study to analyse the UK EV uptake and chargepoint data and quantify the imbalanced charging infrastructure demands among different regions across the UK. In Section V, uncertainties and challenges are discussed. Finally, the concluding remarks are drawn in Section VI.

II. Case study

In this section, a case study is presented to examine EV registration and charging network data across UK regions and forecast the EV demand in the next five years. It is followed by a scenario analysis to calculate the regional charging infrastructure demands using a benchmark metric from Utrecht, Netherlands.

A. Dataset description

For this study, multiple datasets from the Department for Transport's (DfT) website (https://www.gov.uk/transport) were considered. Official statistics relating to EV charging devices, grant schemes and other decarbonisation topics are released by the DfT on a quarterly basis, providing a reliable and complete data source for analysis in this work.

New plug-in-vehicle (PiV) registration data from the DfT for 2011 through to 2021 has been used to understand the EV sales increase across the UK. In this dataset, PiVs account for vehicles that require a charging point, including fully electric battery-electric-vehicles (BEVs) and hybrid-electric-vehicles (HEVs). For simplicity, we will refer to PiVs as EVs throughout the paper.

To assess the supply of infrastructure from the government against the regional demand, Electric Vehicle Home Charging Scheme (EVHS) device installation data has been utilised. The EVHS dataset from the DfT presents the number of installed charging devices each year between 2017 and 2022 in every UK region as a result of the scheme. In addition, overall growth in UK public charging infrastructure has also been considered between 2017 and 2022. DfT reports on the number of rapid and normal charging devices available to the public are included in this study to understand the gradual development in public infrastructure availability. In the reports, rapid charging devices have been defined as devices which provide >25kW of charging power, ultimately providing shorter charging periods. Alongside overall trends in UK charging infrastructure, EV charging grant data from the DfT between 2015 and 2022 has been analysed to showcase trends in government incentives relating to the expansion of charging infrastructure. All regional datasets have been normalised to represent a 'per 100k population' value in order to remove population bias in the results.

B. Data visualisation and analysis

Fig. 1 displays the total number of public charging devices in the UK in every quarter between January 2017 and January 2022, in which the device types are categorised into rapid and normal devices. A consistent increment in charging devices in the UK can be seen with respect to time. In January 2017, a total of 5111 charging devices had been installed in the UK (4208 normal, 903 rapid), compared to 28,375 devices installed by January 2022 (23,219 normal, 5156 rapid). This corresponds to an overall increase in EV charging devices of 455%. A steeper elevation in lately installed rapid devices reflects the government and businesses' push for faster charging time and better customer charging experience.

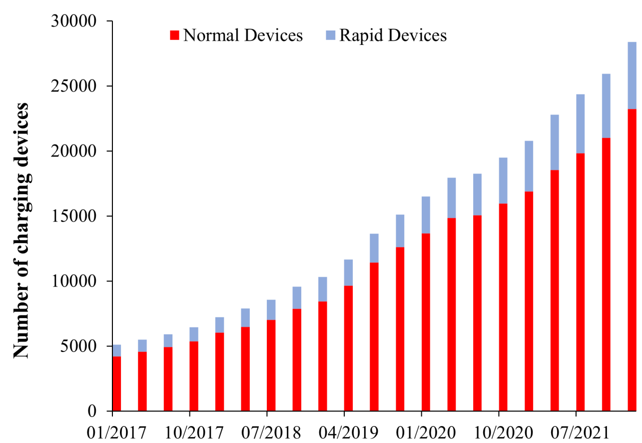

Fig. 1: Number of normal and rapid charging devices in the UK between 2017 and 2022

Looking at the demand for electric vehicles over the same period in Table I, it can be seen that across the UK, 221 EVs/100k population had been registered at the start of 2017. By the end of 2021, nearly 1200 EVs are owned by every 100k population, equating to a UK-wide 5-fold ownership growth. However, the statistics paint a different picture when looking at EV growth in different regions. By 2021, England leads the UK with 1302 new EVs/100k population, almost doubling that of Scotland, which ranks 2nd with 822 EVs/100k. Wales and Northern Ireland share a similar EV growth trajectory and lag behind other nations in EV adoption. This is mainly driven by uneven population density and household wealth across different parts of the UK [10]. Therefore, it is of vital importance to factor in regional characteristics in the latter analysis.

TABLE I: New EV Registrations/100k Population in the UK between 2017 and 2021

	registrations/100k				
	ENG	***SCO***	***NI***	***WAL***	***UK***
2017	243	128	81	84	221
2018	346	192	119	114	316
2019	477	286	165	154	437
2020	774	489	270	269	713
2021	1301	821	478	463	1199

Fig. 2 illustrates two sets of choropleth maps to display the UK regional EV ownership and charging availability changes between 2017 and 2021. The upper and lower set of plots depict the cumulative number of EV registrations and installed charging devices per 100k population in each region for 2017, 2019, and 2021, respectively. It can be observed that the South-West have the highest EV ownership with 2062 registrations per 100k population, whereas this number is only 81 in Northern Ireland. Moreover, North-West of England shows the highest percentage of growth at 744% between 2017 and 2021, going from 117 to 982 EVs/100k population. When looking at the charging infrastructure expansion, North-West enjoys a 522% increase, which is again the highest across all UK regions. This reveals the sustainable and positive correlation between EV uptake and charging network accessibility in the North-West of England. However, the charging infrastructure increase in South-West falls behind its EV sales, with 414 charging points per 100k population by 2021, representing a moderate 430% increment compared to its 2017 level. From Fig. 2, Scotland is also noticeable for having a relatively low rate of growth in charging devices despite its mission to reduce transport emissions by 75% by 2030 [1]. Moreover new charging points tend to be densely clustered around Scotland's main settlements, Glasgow and Edinburgh, where the majority of the population reside. Additionally, lack of space, high parking and rent fees, and traffic congestion are likely to contribute to the moderate EV growth in London. To some extent, Fig. 2 demonstrates the regional imbalance across the UK during the EV transitioning process. The UK government should therefore judge the effectiveness of their schemes on a regional basis and tailor the policies and support accordingly for different markets.

It is speculated that government incentives and financial schemes would encourage more people to purchase and use electric cars [15]. Both home and workplace charging subsidies provided by the UK government are included in this analysis. Fig. 3 compares the quarterly EV sales against the corresponding government subsidies between 2015 and 2022. Zooming in on the growth over the past five years, the total government EV grant has risen by 734% from £729,750, to £6,086,066 between January 2017 and January 2022. More importantly, a highly correlated exponential growth pattern

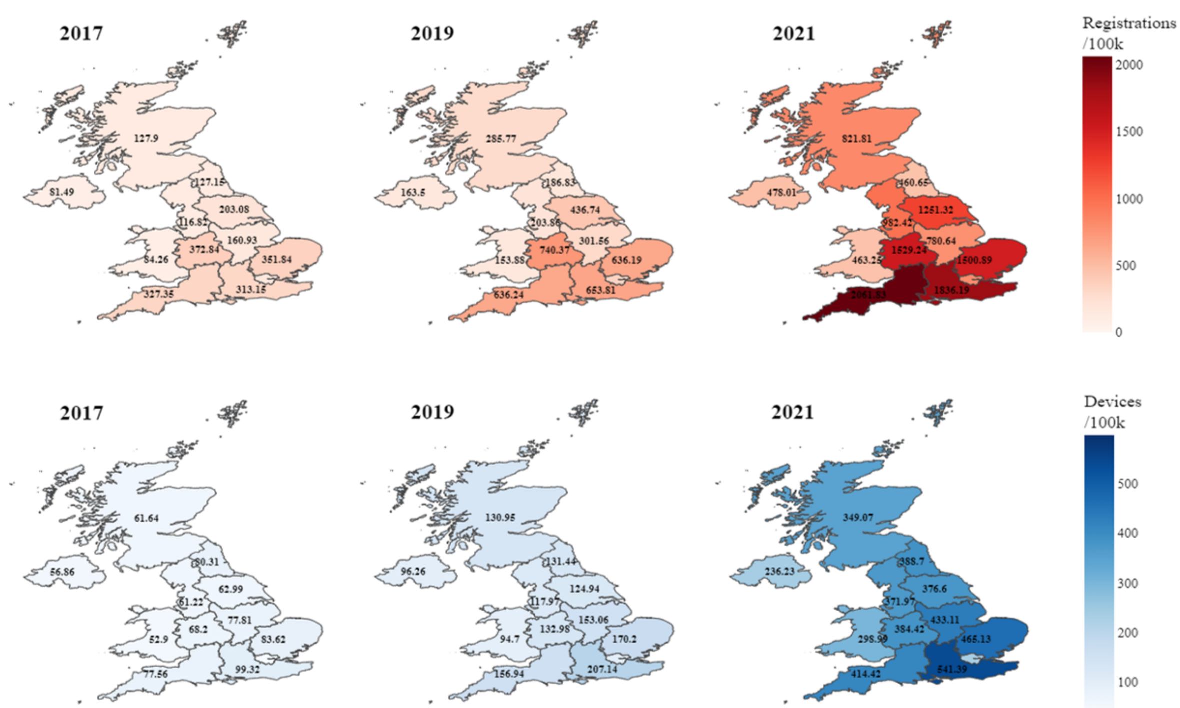

Fig. 2: Regional EV registration and charging device distribution in 2017, 2019 and 2021

can be found in Fig. 3, albeit there being a sharp grant value drop in April 2020, which marks the start of the COVID-19 pandemic. Concurrently, UK-wide EV adoption has also elevated by 714% during this period. The surging trend is particularly noticeable following the start of the pandemic in early 2020. This has clearly emphasised the key role the UK government can play in deepening EV penetration across the country.

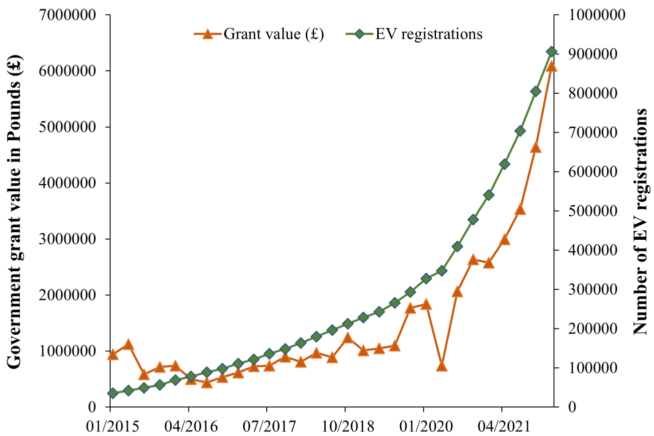

Fig. 3: Growth in EV adoption and corresponding government incentives/grants in the UK between 2015 and 2022

C. EV sales forecast using the Prophet model

In order to quantify the UK's charging infrastructure requirements for keeping up with the rising EV consumers, it is critical to understand the EV growth across the country. This paper has applied regional cumulative EV sales data within the UK from 2010 to 2022 to forecast EV ownership in four years' time. The Prophet model is chosen as the forecasting tool in this analysis. The Prophet model shines in fitting and predicting non-linear trends, with the ability to compute the effects of seasonality on future trends based on historical seasonal data [13]. In addition, predicted results in Prophet provide uncertainty intervals with distinct upper and lower result bounds. This enables the evaluation of best- and worst-case scenarios, which will be utilized in this study.

The prophet model, as expressed in (1), can be considered as a nonlinear regression model:

$$y_t = g(t) + s(t) + h(t) + \epsilon_t \tag{1}$$

where $g(t)$ describes a piecewise-linear trend that models non-periodic changes (or "growth over time"), $s(t)$ presents the periodic seasonal patterns (i.e., weekly, monthly, or yearly), $h(t)$ captures the holiday effects, and ϵ_t is a white noise error term.

Since historic EV registration data is only available on a quarterly basis from 2010, the Prophet model has been defined to predict with an annual seasonality (order=10) over the five future periods. Yearly forecasting means overall trends can be analysed and issues of overfitting related to having a relatively small dataset can be avoided. The uncertainty interval width is set as 0.95 to account for short-term unpredictability.

Moreover, this study will accommodate two different prediction scenarios relating to EV ownership based on the credible interval of the posterior predictive distribution: a worst-case and a best-case. The worst-case scenario will assume trends in EV sales meet the lower bound, $\hat{y}_{lower}$, of the forecasting results, meaning less EV purchases will be made due to various complexities and challenges ahead. A best-case will assume trends follow the upper bound, $\hat{y}_{upper}$, indicating more positive EV growth.

In this work, only regions in North East (NE), East Midlands (EM), West Midlands (WM), East (E), London (LDN), and Wales (WAL) are included owing to their relatively low EV market penetration. Table II lists the current total number of EVs (y) in each region and the corresponding forecasted values in 2027. The result indicates a continuous and strong demand for EVs over the next five years. The EV sales could see a rise as high as 145% in 2027, whereas in the worst EV uptake scenario it still forecasts at least 44% increase compared to the current level.

TABLE II: Predicated total EV ownership in 2027

Region	**Population (in mil)**	**Total EVs**		
		y	$\hat{y}_{lower}$	$\hat{y}_{upper}$
NE	2.68	15,336	23,676	34,134
EM	4.87	48,168	69,012	108,629
WM	5.96	105,663	185,385	250,788
E	6.27	111,248	185,879	255,476
LDN	8.92	89,753	157,391	220,441
WAL	3.17	18,548	29,196	46,399

D. Scenario analysis for charging infrastructure demand

In the early stages, EV charging points are often deployed to support an increase in EV sales. In order to evaluate the public charging device requirements, Electric Vehicle per Charger (V/C) metric has been widely used to determine EV charging accessibility. V/C value details how many electric vehicles there are to one available charge point. The study conducted by Monk has shown that European countries with high EV penetration have significantly higher charging point densities than others, meaning lower V/C ratios [14]. This ratio should ideally reach an optimal equilibrium value to maximise the EV adoption, however, it will likely vary depending on a number of factors, including the population density and local charging power [9].

This case study will adopt the V/C ratio of 7.3 from Utrecht, a leading European city in EV maturity, as the ideal value to calculate the number of charging devices UK regions require in order to reach the same level of maturity. Table III displays the chargepoint demands, calculated based on the best and worst UK regional EV sales scenarios in 2027, to achieve a V/C ratio of 7.3. c denotes the current number of publicly accessible charging points in the region, and c_{upper} and c_{lower} represent the required charging demand based on the best and worst EV growth scenarios. It is evident that a steep increase in public charging infrastructure is needed across all regions. More importantly, the regional imbalance of charging infrastructure is also well documented in Table III. For instance, the West Midlands and the East of England are two highly populated areas with 5.96 mil and 6.27 mil population, respectively. But these two regions have 21% and 55% fewer public charging points than that of the North-East of England, which has only 2.68 mil residents. The East of England, with the highest predicted EV sales in 2027, will require an additional 24,630 public chargers by 2027 to meet the worst-case scenario or an additional 34,164 public chargers for the best-case scenario. This represents a whopping increase of 2957% or 4104% from the current level of charging infrastructure. However, the pressure to expand the charging infrastructure drastically is much less in the North East of England, where the charging accessibility is relatively high and only requires an 82% to 162% upgrade in their network.

TABLE III: Predicated chargepoint demand in 2027

Region	c	**Chargepoint demand**			
		c_{lower}	%	c_{upper}	%
NE	1,784	3,243	+82%	4,676	+162%
EM	1,247	9,453	+658%	14,881	+1093%
WM	1,507	25,395	+1585%	34,355	+2179%
E	833	25,463	+2957%	34,997	+4101%
LDN	9,528	21,560	+126%	30,197	+217%
WAL	486	3,999	+722%	6,356	+1207%

Moreover, to achieve the same level of penetration of EV charging infrastructure, the East and West Midlands would need to construct 16 times more charging points than their London or North East counterparts. This regional imbalance of charging infrastructure necessitates targeted investment and policy support from the government and businesses in order to accomplish the UK-wide 'Green Transport' goal.

III. EV SUCCESS DETERMINANTS IN UNCERTAIN TIMES

The aforementioned study can be used to quantify the disparity between regions, pinpointing areas for improvements to EV charging infrastructure in the UK. Nonetheless, the global pandemic and the recent eruption of hostilities between Russia and Ukraine have placed the EV sector on notice. High inflation and accompanying tightening of government finance policies have resulted from the shattered supply chain and skyrocketing energy prices - the full extent of which is still unknown. The addition of these complications to the task of expanding the charging network is inevitable. As a result, we have zeroed in on technological advancements, financial resources, and regulatory support as the determinants of whether or not EVs will take off in the UK during this uncertain time.

Firstly, range anxiety is a constant factor that prevents further EV uptake in the UK. Despite being linked to a dearth of accessible charging infrastructure, technological progress can help alleviate concerns about vehicle range. An EV's range, for instance, is affected by an array of variables, such as the battery's degradation owing to age, total battery capacity, and the driving style under which the battery is made to perform [15]. Energy density of traction batteries can be increased as battery technology advances, allowing cars to travel over longer distances for a given pack mass. An upgrade in battery beginning-of-life (BoL) capacity will also reduce the effects of capacity depreciation. Improvements in battery technologies, promoted by large commercial EV companies such as Tesla, will aid in relieving public range anxiety, increasing EV buyers' confidence. Secondly, the economics of EV charging are negatively affected by the prevalent financial worries of the population. These economic issues have a significant impact on the decisions investors make and the habits consumers adopt [16]. Another potential factor hampering the UK charging market is the termination of subsidies and incentives. Given the poor utilisation rate of charging stations and the lack of charging device sales, private charging service providers will need to increase their charging fee. Higher charging rates, on the other hand, would undoubtedly deter individuals who wish to purchase EVs and would make the business of the charging provider even less sustainable and profitable [4]. As a result of supply chain disruptions and general inflation, the cost of manufacturing EVs has soared substantially, and consumers will have to foot the bill at some point. Given that most people are already battling with the rising cost of living, a significant increase in EV ownership in the coming years would necessitate a drastic reduction in the expenses associated with both EV production and maintenance. Last but not least, the tragic and ongoing war in Ukraine has spawned a raft of challenges for governments and organisations around the world. The conflict has created a humanitarian crisis throughout Europe and has prompted many countries, including the UK, to increase their military spending. Due to the need to divert resources in this direction, the UK government may cut or cease to offer subsidies or incentives for EV purchase. Government incentives for EVs, as shown in Fig. 3, are positively correlated with an increase in EV ownership. Potential buyers may be discouraged from purchasing EVs if no financial incentives are provided. Additionally, the removal of government subsidies would further dissuade private charging service providers from installing additional charging points, particularly rapid charging devices [16]. Consequently, it will be considerably more challenging to win over new EV buyers. Given the severe regional imbalance in the charging network, tailored government policy should be in place to support regional development of the charging infrastructure market. What's more, volatile shifts on many fronts, including technology, economics, and politics, might be in store in the future due to geopolitical tensions simmering between key economies. UK policymakers will need to be cognizant of these factors and coordinate in advance to steer the British EV market through the less predictable tides in the short term.

IV. Conclusion

The purpose of this study is to examine the present status of EV ownership and charging infrastructure in different parts of the UK. The authors use the Prophet model to forecast the regional adoption of EVs in 2027 under both optimistic and pessimistic growth scenarios for electric vehicles. Charging infrastructure requirements across the United Kingdom have been calculated using the Utrecht accessibility metric as a benchmark. The quantitative study uncovered a substantial regional discrepancy in charging infrastructure. To reach the required V/C ratio of 7.3, the North East of England will need to increase its chargepoints by 82% to 162% over the next five years. Yet if the East of England followed the same percentage rise, its charging infrastructure would expand by 2957–4101%. Additionally, technological advancements, financial resources, and regulatory support are identified as EV success determinants during uncertain and turbulent times.

References

[1] The Scottish government, “Climate Change Plan: Third report on proposals and policies 2018–2032 (RPP3),” Edinburgh, September 2018. [Online]. Available: https://www.gov.scot/publications/scottish-governments-climate-change-plan-third-report-proposals-policies-2018-9781788516488/

[2] HM government, “Net zero strategy: Build back greener,” London, October 2021. [Online]. Available: https://www.gov.uk/government/publications/net-zero-strategy

[3] Department for Transport and Driver and Vehicle Licensing Agency, “Vehicle licensing statistics data tables,” London, September 2022.

[4] L. Shi, Y. Hao, S. Lv, L. Cicigan and J. Liang, “A comprehensive charging network planning scheme for promoting EV charging infrastructure considering the Chicken-Eggs dilemma,” Research in Transportation Economics, vol. 88, pp. 1–10, 2021.

[5] L. Shi, T. Lv and Y. Wang, “Vehicle-to-grid service development logic and management formulation,” Journal of Modern Power Systems and Clean Energy, vol. 7, no. 4, pp. 935–947, 2019.

[6] L. Jia, Z. Hu and Y. Song, “An integrated planning of electric vehicle charging facilities for urban area considering different types of charging demands,” Power System Technology, vol. 40, no.9, pp. 2579–2587, 2016.

[7] H. Kamankesh, V. Agelidis and A. Kavousi-Fard, “Optimal scheduling of renewable micro-grids considering plug-in hybrid electric vehicle charging demand,” Energy, vol. 100, pp. 285–297, 2016.

[8] M. Hardinghaus, M. Löcher and J. E. Anderson, “Real-world insights on public charging demand and infrastructure use from electric vehicles,” Environmental Research Letters, vol. 15, pp. 1–11, 2020.

[9] G. Falchetta and M. Noussan, “Electric vehicle charging network in Europe: An accessibility and deployment trends analysis,” Transportation Research Part D, vol. 94, no. 2021, pp. 1–18, 2021.

[10] P. McCann, R. Ortega-Argilés, D. Sevinc and M. Cepeda-Zorrilla, “Rebalancing UK regional and industrial policy post-Brexit and post-Covid-19: lessons learned and priorities for the future,” Regional Studies, pp. 1–13, 2021.

[11] B. Los, P. McCann, J. Springford and M. Thissen, “The mismatch between local voting and the local economic consequences of Brexit,” Regional Studies, vol. 51, no. 5, pp. 786–799, 2017.

[12] B. Kenward and C. Brick, “Even conservative voters want the environment to be at the heart of post-COVID-19 economic reconstruction in the UK,” Journal of Social and Political Psychology, vol. 9, no. 1, pp. 321–333, 2021.

[13] S. Taylor and B. Letham, “Forecasting at Scale,” The American Statistician, vol. 72, no. 1, pp. 37–45, 2018.

[14] A. Monk, “On a charge or out of juice – can EV charging infrastructure keep up with demand?,” London, September 2021. [Online]. Available: https://www.schroders.com/en-gb/uk/intermediary/insights/on-a-charge-or-out-of-juice–can-ev-charging-infrastructure-keep-up-with-demand/

[15] Q. Zhang, H. Li, L. Zhu, P. Elia Campana, H. Lu, F. Wallin and Q. Sun, “Factors influencing the economics of public charging infrastructures for EV – A review,” Renewable and Sustainable Energy Reviews, vol. 94, pp. 500–509, 2018.

[16] H. Kim, D. Kim and M. Kim, “Economics of charging infrastructure for electric vehicles in Korea,” Energy Policy, vol. 164, pp. 1–8, 2022.