Exploring the Spatial Diffusion of Electric Vehicles in Scotland

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1. ABSTRACT

The widespread diffusion of Electric Vehicles (EVs) represents a cornerstone of the Scottish Government's strategy to transition to a sustainable transport system. This diffusion is often discussed in temporal terms which relate to the time required to attain specified sales targets. A somewhat overlooked aspect of this diffusion concerns its spatial distribution. With EVs having been available to purchase in the mainstream market for the past four years, enough data now exists to begin to examine the spatial characteristics of EV adoption. This paper presents an initial analysis of the spatial diffusion of EVs throughout Scotland at the Unitary Authority (UA) level in order to approach two research objectives. Firstly, the analysis considers the relative performance of different UAs in reference to EV adoption to determine if any uptake hotspots are present. Additionally, the analysis investigates if the level of EV adoption across UAs is related to other area characteristics of the UAs inclusive of: the socio-demographic and built environment profiles of the UAs; the fleet characteristics of the UAs; the characteristics of the transport system present in the UAs; the environmental attitudes and social behaviours of the UA populace. Findings of the analysis indicate that the level of EV adoption across UAs is significantly positively related to the proportion of a UAs populace that: hold a university degree; consider climate change to be an immediate and urgent problem; commute to work by foot; and the presence of rapid charge points in a UA. The research presented in this paper is likely to be of interest to national, regional and local transport planners by expanding the knowledge base concerning how new innovations spread through the transport system.

2. INTRODUCTION

Electric Vehicles (EVs) represent a significant innovation in vehicle powertrain technology whereby the internal combustion engine of a conventional car is wholly or partly replaced by an electric motor driven by electricity stored in an on-board battery. EVs as a vehicle category can be further delineated by the degree to which their locomotion is provided by electricity with two common classifications of EVs being Plug-in Hybrid Electric Vehicles (PHEVs) and pure Battery Electric Vehicles (BEVs). The novel powertrain features of EVs have the potential to provide a number of distinct benefits to society inclusive of improvements to:

- local air quality as a result of EVs having zero tailpipe emissions;
- energy efficiency with EVs being on average four times more efficient than a conventional car;
- energy security through their ability to diversify the energy input to the transport system which is currently dominated by oil-based fuels;
- and greenhouse gas emissions originating in the transport sector if electricity generation shifts towards low carbon sources.

The Scottish Government has stated an objective to facilitate a widespread diffusion of EVs throughout the national vehicle fleet in order to realise these benefits and move towards a sustainable transport future (Transport Scotland, 2013a). This desire is partly motivated by the legislative requirement to achieve substantial reductions in greenhouse gas emissions (Climate Change (Scotland) Act, 2009) with few alternative low-carbon technologies other than EVs being on the horizon in the transport sector. Indeed, a transition towards EVs in the transport sector is one which is being pursued in most industrialised nations due to the relatively limited carbon abatement potential of alternative strategies.

This transition is often discussed in temporal terms relating to how quickly the market for EVs will expand (Eggers and Eggers, 2010; Musti and Kockelman, 2011; Al-Alawi and Bradley, 2013). Discussions of this nature are complemented by research which concentrates on understanding which individuals are likely to adopt an EV (Lieven et al., 2011; Peters and Dütschke, 2014), the pace at which EV technology will develop (Offer et al., 2010; Speirs et al., 2014), how the rate of EV uptake can be influenced by Government policy (Diamond, 2009; Harrison and Shepherd, 2013; Helveston et al., 2015) and the experiences early EV adopters are having with both vehicle and supportive infrastructure technologies (Caperello and Kurani, 2012; Graham-Rowe et al., 2012; Franke and Krems, 2013). However, little research has examined the manner in which the demand for EVs is manifesting spatially. With EVs having been available to purchase in the mainstream automotive market since 2011, enough data now exists to begin to examine the geographic distribution of EV registrations. An examination of this variety has the potential to provide a number of contributions towards understanding the features of the emerging market for EVs. Understanding any variations in the level of EV adoption between different geographical areas would allow for policies to be developed which are tailored to local circumstances. Moreover, the processes which are at play in the diffusion of EVs might be further clarified through a spatial analysis of the variance in adoption levels. Indeed, an analysis of this nature may also allow for contributions towards the theoretical understanding of how technology diffusion through the transport system is achieved.

The research presented in this paper provides an initial examination of the spatial adoption of EVs in Scotland in an effort to determine the degree of variation present in the emerging market and to investigate the factors potentially related to this variation. This analysis covers the presentation of spatial data in order to illustrate the quantity of EV registrations across Scottish Unitary Authorities (UAs) alongside a series of bivariate correlations between EV registrations and other characteristics of the UAs. The paper continues with an overview of the existing literature which examines EV demand followed by a description of the methodology employed in order to conduct the spatial analysis. The paper then proceeds by presenting the results of the analysis and concludes with a discussion of the findings.

3. PAST RESEARCH IN THE DIFFUSION OF ELECTRIC VEHICLES

Research investigating the potential demand for EVs has been an active area of inquiry for the past thirty years. The oil supply crisis of the early and mid-1970s (Akins, 1973) provided the first spark to EV interests through a desire to diversify the energy input to the transport sector. Initial research in EV demand examined consumer evaluations of the unique attributes of EVs finding that the limited range and substantial price premiums of EVs are likely to significantly restrict their demand (Calfee, 1985) leading to subdued growth prospects for the EV market (Train, 1980).

Interest in EV demand was rekindled in the mid-1990s as a result of growing awareness of the possibility of peak oil alongside mounting concerns relating to the contribution of the transport sector to the problems of local pollution (Collantes and Sperling, 2008). This interest has been sustained by the increasing awareness of global climate change and the contribution which the transport sector makes towards greenhouse gas emissions in industrialised societies. This renewed interest coincided with a broadening of the approaches utilised by researchers in their investigation of EV demand. Specific attention has been focused on identifying both lead markets for EVs and which consumer types are most likely to adopt EVs in early market phases (Sangkapichai and Saphores, 2009; Jansson et al., 2011; Campbell et al., 2012; Zubaryeva et al., 2012). The importance of EV functional attributes has been complemented through an improved understanding regarding how cars are perceived as emotive and symbolic artefacts and the effect these types of perceptions may have for how EVs are being interpreted in the mainstream automotive market (Heffner et al., 2007; Schuitema et al., 2013).

With EVs entering the mainstream automotive market at the start of 2011, research attention has shifted towards exploring how government policy can be utilised in order to accelerate EV demand. The effectiveness of fiscal policies covering financial incentives to promote EV adoption in terms of direct purchase grants and alterations to the vehicle taxation system have been assessed (Diamond, 2009; Harrison and Shepherd, 2013). Taking a multi-level perspective, research has also investigated how market regimes change over time and the influence of stabilising and destabilising factors in the transition towards EVs (Struben and Sterman, 2008; Van Bree et al., 2010; Köhler et al., 2013; Steinhilber et al., 2013).

Whilst considering the geographical issues of EV demand has so far been an underexplored area of inquiry, some preliminary research has been conducted in and around the topic. Mau et al. (2008) explored the dynamic nature of the demand for EVs by investigating if different levels of stated EV market penetration affected the willingness of consumers to adopt the technology. Results of the analysis suggest that a *neighbour effect* is present with preferences towards EVs being significantly influenced by the level of adoption within the immediate geographical area. Further investigating the influence of geographical characteristics over EV adoption, Saarenpää et al. (2013) conducted an analysis in which the spatial adoption of Hybrid Electric Vehicles (HEVs) was compared with demographic data. The analysis found that HEVs have a higher propensity to be registered in areas which have populations with a high degree of formal education, household income and proportion of owner-occupied homes.

In an effort to identify lead markets for EV adoption, Campbell et al. (2012) examined census data of a large metropolitan area in the UK using cluster analysis and found that likely early adopters of EVs tend to be concentrated in sub-urban areas. These results have been supported by the findings of Namdeo et al. (2014) who considered the spatial location of potential EV adopters through an examination of journey profiles and socio-economic characteristics with their analysis suggesting that a citizen cohort labelled *Corporate Chieftains,* which are primarily located in suburban areas, represent the consumer group most likely to adopt an EV.

With local and national governments employing an array of different policy mixes in an effort to accelerate the adoption of EVs, understanding the relative efficacy of these strategies can assist in identifying best practice. Diamond (2009) explored the level of HEV registrations across the different states of the USA and identified a strong relationship between HEV adoption and the prevailing price of gasoline but a much weaker relationship between adoption and financial purchase incentives. In a similar piece of research, Sierzchula et al. (2014) investigated the level of EV registrations across a sample of 30 countries with the analysis suggesting that the level of financial purchase incentive, the quantity of charging infrastructure installed and the presence of automotive manufacturing facilities all significantly explain EV adoption.

4. METHODS

This methods section covers two specific issues related to the analysis conducted in this paper by firstly discussing the type and source of the data utilised followed by an overview of how the data has been prepared for analysis.

4.1 Data Sources

The data necessary to conduct the analysis has been collected from a number of different sources which are summarised in Table 1. Transport Scotland provided access to a dataset which contains EV registration data at the UA level. Whilst the analysis outlined here only considers the cumulative total of EVs which have so far been registered in Scotland, this dataset holds supplementary information covering the EV registrations by year and the specific makes and models of EVs which have been registered. The additional characteristics of the UAs have been grouped into 4 broad categories covering [1] the socio-demographic and built environment, [2] transport system, [3] current vehicle fleet and [4] environmental attitudes and social behaviours.

Table 1: Types of spatial data utilised in the analysis alongside sources of the data

Spatial Category	Spatial Variable	Data Source
EV registrations	Quantity of EVs registered	Transport Scotland[1]
Socio-demographic and built environment characteristics	Age structure Degree attainment Population density Housing stock Household income structure Population location (rural, urban etc.)	Scottish Household Survey[2] NRS[A] – Scotland's Census[3] ONS[B] – Key Statistics Scotland[4] Scottish Household Survey[5] Scottish Household Survey[5] Scottish Household Survey[5]
Transport system characteristics	Modal split (journey to work) Journey to work distance Road types Installed charging points	NRS – Scotland's Census[6] NRS – Scotland's Census[7] Department for Transport[8] Office of Low Emission Vehicles[9]
Current fleet characteristics	Vehicle kilometres travelled by car Household fleet size Driving license attainment	Transport Scotland[10] Scottish Household Survey[11] Scottish Household Survey[11]
Environmental attitudes and social behaviours	Attitudes towards climate change Participation in volunteering	Scottish Household Survey[12] Scottish Household Survey[13]

[A]: ONS – Office of National Statistics
[B]: NRS – National Records of Scotland
[1] – Transport Scotland (2014); [2] – SHS (2013a); [3] – NRS (2012a); [4] – ONS (2012); [5] – SHS (2013b); [6] – NRS (2012b); [7] – NRS (2012c); [8] – DfT (2014); [9] – OLEV (2014); [10] – Transport Scotland (2013b); [11] – SHS (2013c); [12] – SHS (2013d); [13] – SHS (2013e)

4.2 Data Preparation

A number of the variables included in the analysis have undergone a standardisation procedure in order to mitigate the influence of varying sizes (both in terms of area and population) of the different UAs of Scotland.

Quantity of EVs registered: the cumulative total of EVs so far registered in a UA has been divided by the total quantity of cars registered in a UA.

Road types: the quantity of miles of different road types (such as Trunk Road, A Road, Minor Road etc.) in a UA has been divided by the total quantity of all road miles in a UA in order to determine what proportion of UA roads are assigned to specific road types (for example, what proportion of a UA's roads is classified as Trunk Road).

Installed charge points: the quantity of charge points installed in a UA has been divided by the quantity of miles of road classified as Principal Road. This is to link the variable to Transport Scotland's policy of having a charge point located at least every 50 miles along Scotland's primary road network (Transport Scotland, 2013a).

Each variable included in the correlation analysis has been assessed to determine if outliers (observations in excess of two standard deviations from the mean of the distribution) are present in terms of the observed values. Wherever outliers are present, the most extreme observations have been removed from the correlation analysis. The rationale for this removal is to limit the bias potentially introduced by the presence of outliers. As the sample size for UAs is already low (n = 32), this removal of outliers has been limited to the 4 most extreme observations. In terms of the variable quantity of EVs registered, the UAs of Dundee City and Orkney Islands have observed values substantially removed from the values observed in the remaining UAs (see Table 2). These two extreme observations lead to the variable returning a significant result for the Shapiro-Wilk test of normality indicting the presence of a non-normal distribution and thus restricting the analysis to the application of non-parametric statistics. As a result of the removal of these two extreme observations, the Shapiro-Wilk test of normality returns an insignificant result with the distribution of values better reflecting a normal structure. This procedure of removing outliers and testing for normality has been repeated for all of the variables included in the correlation analysis with the appropriate parametric (Pearson's product moment) or non-parametric (Spearman's rank-order) correlation analysis applied where appropriate.

5. RESULTS

The results of the research are presented in two stages. To begin, the spatial variance of EV adoption across the different UAs of Scotland is evaluated. Following this, a series of correlation analyses between the quantity of EVs adopted and other characteristics of a UA is conducted.

5.1 Spatial Analysis of Electric Vehicle Adoption

In Figure 1 the data detailing registrations of EVs in Scotland has been considered in three different ways. Firstly, graph Figure 1[B] illustrates the quantity of annual registrations of EVs with an upward trend being clearly apparent. To put these EV registrations into perspective, 205,216 cars were registered in Scotland in 2013 meaning that EVs represent around 0.1% of new car registrations. In addition, this graph demonstrates how the registrations of EVs are partitioning between PHEVs and BEVs. The chart Figure 1[C] further exhibits this partitioning with the cumulative registrations of BEVs in Scotland currently exceeding PHEVs by a ratio just under 3:1. Investigating how these EV registrations have spread across the UAs of Scotland, map Figure 1[A] demonstrates the spatial variance in EV adoption in terms of the total quantity of EVs registered per thousand cars.

From a visual inspection of the map, it is evident that a substantial degree of spatial variance is present in reference to the registrations of EVs in Scotland. Indeed, the range of EV adoption among UAs spans 0.079 EVs per thousand registered cars in Eileanan Siar to 1.762 EVs per thousand registered cars in Dundee. From this observation it is possible to infer that spatial heterogeneity is present in the adoption of EVs across Scotland with certain UAs having experienced a greater degree of adoption than others.

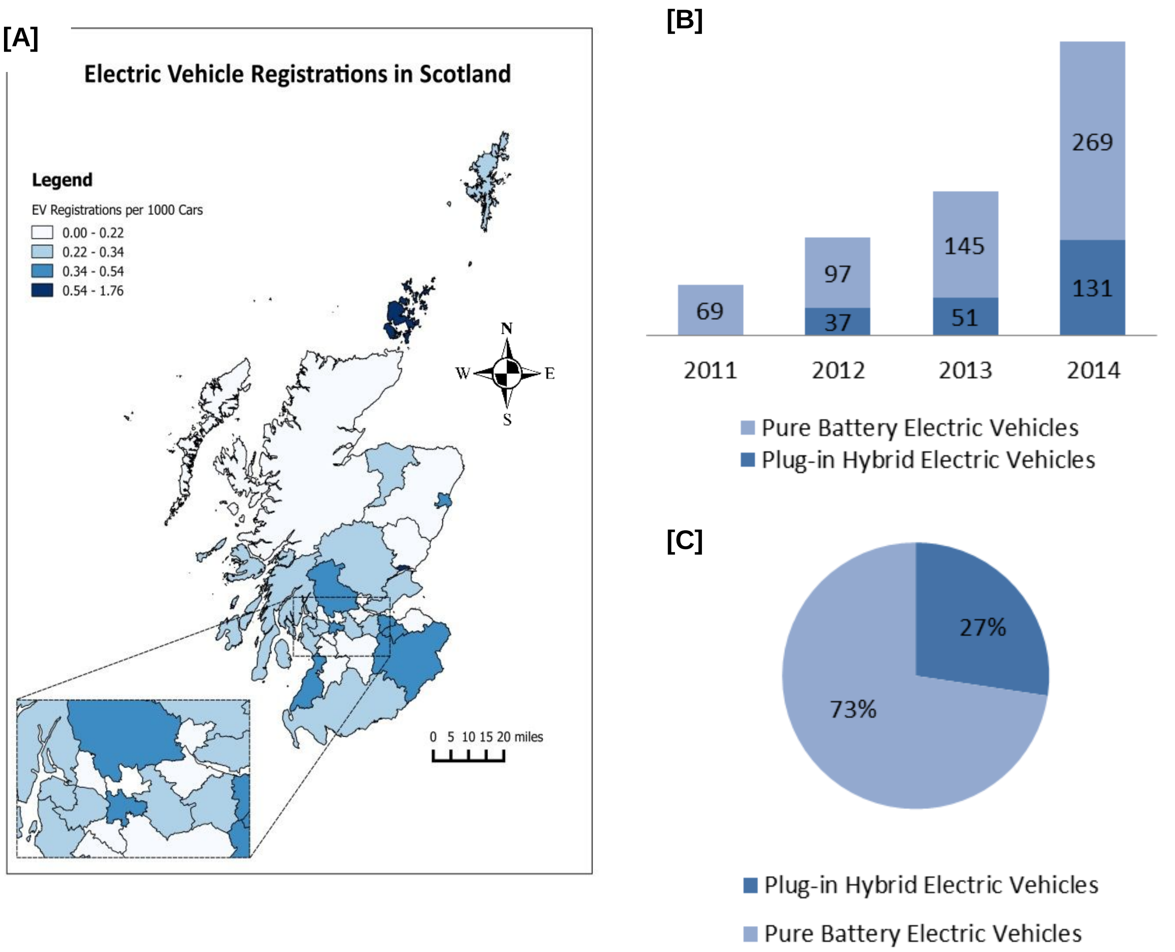

Figure 1: [A] cumulative registrations of EVs in Scotland per 1000 cars [B] quantity of BEVs and PHEVs registered annually in Scotland between 2011-2014 [C] EV market split between BEVs and PHEVs in Scotland[1]

Exploring this spatial heterogeneity in more detail, Table 2 presents the five UAs with the highest and lowest adoption rates of EVs alongside a number of descriptive statistics regarding other characteristics of the UAs. From an inspection of these descriptive statistics, a few potential patterns are visible. Firstly, it appears as if the UAs with the highest level of EV adoption seem to have a greater level of installed charge point provision compared to the UAs with the lowest EV adoption. Similarly, the UAs with relatively high EV adoption have a higher likelihood of being populated by citizens who have attained a university degree and have household incomes in excess of £40,000 per annum compared to the populations of UAs with low levels of EV adoption. Moreover, the bottom five UAs for EV adoption seem have a larger proportion of their populace who consider climate change not to be happening compared to the top five.

[1] The quantity of EVs registered in Scotland in 2014 represents registrations up to August 2014

Table 2: Characteristics of the top and bottom five unitary authorities based on quantity of EVs registered

Unitary Authority	EVs	Charge Points	VKT[A] per Car	Multi Car	Bungalow or House[B]	Over £40k	Degree Attainment	CC[C] not Happening
Top Five								
Dundee City	**1.762**	12	17058.03	13%	51.2%	10.2%	24.8%	8%
Orkney Islands	**1.368**	10	12806.73	30%	90.5%	15.7%	26.5%	14%
Stirling	**0.538**	2	23436.72	34%	72.9%	26.0%	33.3%	13%
City of Edinburgh	**0.491**	5	17687.32	16%	35.5%	21.0%	41.4%	10%
Midlothian	**0.482**	7	17254.31	28%	80.0%	21.0%	21.1%	16%
Bottom Five								
Eileanan Siar	**0.079**	2	16093.23	34%	95.6%	13.0%	26.5%	17%
Clackmannanshire	**0.083**	6	13442.65	31%	74.9%	15.3%	21.9%	15%
E. Ayrshire	**0.113**	4	18872.20	29%	79.9%	11.6%	17.9%	11%
W. Dunbartonshire	**0.144**	1	18451.68	20%	53.5%	11.9%	16.5%	11%
E. Lothian	**0.150**	18	17952.59	34%	70.4%	18.2%	27.0%	13%

[A]: VKT – vehicle kilometres travelled
[B]: as opposed to flat or apartment
[C]: CC – climate change

5.2 Correlation Analysis

In order to assess if the quantity of EVs so far registered in a UA holds statistically significant relationships with other characteristics of the UA, a series of correlation analyses have been conducted. These correlation analyses are summarised in Table 3 through 6 with a series of significant and non-significant relationships having been identified.

Table 3: Summary of the correlation analyses between the quantity of EVs registered in unitary authorities (per thousand cars) and the socio-demographic and built environment characteristics of unitary authorities

Unitary Authority Characteristics	Variable Description	Correlation Coefficient
Age structure	UA population aged 0-15 (%)	**-.414*** P
	UA population aged 16-24 (%)	N.S. S
	UA population aged 25-34 (%)	N.S. S
	UA population aged 35-44 (%)	N.S. S
	UA population aged 45-59 (%)	**-.395*** S
	UA population aged 60-74 (%)	N.S. P
	UA population aged over 75 (%)	N.S. S
Population density	Total population of UA divided by total area of UA	N.S. S
Degree attainment	UA population with a university degree (%)	**.367*** P
Housing stock	UA housing stock classified as house/bungalow (%)	N.S. S
	UA housing stock classified as flat/apartment (%)	N.S. S
Wage structure	UA population with household incomes £0-£6000 (%)	N.S. P
	UA population with household incomes £6001-£10000 (%)	N.S. P
	UA population with household incomes £10001-£15000 (%)	N.S. P
	UA population with household incomes £15001-£20000 (%)	N.S. P
	UA population with household incomes £20001-£25000 (%)	N.S. P
	UA population with household incomes £25001-£30000(%)	N.S. P
	UA population with household incomes £30001-40000 (%)	N.S. P
	UA population with household incomes over £40000 (%)	N.S. P
Deprivation	UA population classified in bottom 20% of the Scottish Index of Multiple Deprivation (%)	N.S. S
Population location	UA population living in a large urban area (%)	N.S. S
	UA population living in a other urban area (%)	N.S. S
	UA population living in an accessible small town (%)	N.S. P
	UA population living in a remote small town (%)	N.S. S
	UA population living in an accessible rural area (%)	N.S. S
	UA population living in a remote rural area (%)	N.S. S

* - correlation coefficient significant at the 0.05 level
** - correlation coefficient significant at the 0.01 level
N.S. – correlation coefficient not significant
P – Pearson's product moment correlation analysis used
S – Spearman's rank-order correlation analysis used

In terms of the socio-demographic and built environment characteristics of the UAs (Table 3), the age structure and level of degree attainment of the UAs are significantly related to the quantity of EVs registered in the UAs. A relatively high proportion of a UA's population aged 0-15 and 45-59 tends to be associated with relatively low levels of EV adoption. These findings may suggest that UAs with a high prevalence of young families or middle-aged citizens may not be among the forerunners of EV adoption. Conversely, UAs which have a relatively high proportion of university graduates have a propensity for higher levels of EV adoption, supporting the view that interest in EVs is linked with level of formal education (Anable and Schuitema, 2010). No statistically significant relationships are observed between the quantity of EVs adopted in a UA and the type of housing stock present, stratification of wages, level of deprivation or the locations of the population present in a UA.

Table 4: Summary of the correlation analyses between the quantity of EVs registered in unitary authorities (per thousand cars) and the transport system characteristics of unitary authorities

Unitary Authority Characteristics	Variable Description	Correlation Coefficient
Modal split	UA population who work mainly from home (%)	N.S. S
	UA population who travel to work by light rail or tram (%)	N.S. S
	UA population who travel to work by train (%)	N.S. S
	UA population who travel to work by bus or coach (%)	N.S. S
	UA population who travel to work by taxi (%)	N.S. S
	UA population who travel to work by car/van (driver) (%)	**-.391* S**
	UA population who travel to work by car/van (passenger) (%)	**-.406* P**
	UA population who travel to work by motorcycle or scooter (%)	N.S. P
	UA population who travel to work by bicycle (%)	N.S. S
	UA population who travel to work on foot (%)	**.463** P**
Journey to work distance	UA population who travel less than 2 km to work (%)	N.S. P
	UA population who travel 2-5 km to work (%)	N.S. S
	UA population who travel 5-10 km to work (%)	N.S. S
	UA population who travel 10-20 km to work (%)	N.S. P
	UA population who travel 20-30 km to work (%)	**-.427* P**
	UA population who travel 30-40 km to work (%)	N.S. P
	UA population who travel 40-60 km to work (%)	N.S. S
	UA population who travel over 60 km to work (%)	N.S. S
Road types	Proportion of UA roads categorised as Major Trunk (%)	N.S. P
	Proportion of UA roads categorised as Major Principal (%)	N.S. S
	Proportion of UA roads categorised as A Roads (%)	N.S. P
	Proportion of UA roads categorised as Minor Roads (%)	N.S. S
Installed charge points	Number of rapid charge points installed in a UA per mile of principal road	**.495** S**
	Number of slow charge points installed in a UA per mile of principal road	N.S. S
	Number of fast charge points installed in a UA per mile of principal road	N.S. S
	Total number of charging points installed in a UA per mile of principal road	N.S. S

* - correlation coefficient significant at the 0.05 level
** - correlation coefficient significant at the 0.01 level
N.S. – correlation coefficient not significant
P – Pearson's product moment correlation analysis used
S – Spearman's rank-order correlation analysis used

Shifting the focus on to the characteristics of the transport system (Table 4), the analysis identifies significant relationships between the quantity of EVs registered in a UA and the UA modal split, distance to work and installed charging infrastructures. Specifically, the higher the proportion of UA citizens that travel to work either as a driver or passenger of a car or van, the lower the quantity of EVs registered. This suggests that, perhaps counterintuitively, UAs in which the population is more car dependent are less likely to be sites of early EV adoption. This interpretation is further supported by the significant positive relationship which exists between quantity of EVs registered and the proportion of journeys to work conducted on foot, which indicates that built environments which support active travel tend to be associated with relatively high levels of EV adoption. Indeed, UAs where a relatively large proportion of the population travel between 20 and 30 kilometres to work have a propensity for low quantities of EV registrations. In terms of the specialist infrastructure required to support the operation of EVs, the analysis finds that the quantity of EVs registered in a UA is significantly positively related to the quantity of rapid charge points installed in a UA. With no significant relationship having been identified between EV adoption and fast or slow charge point installation, the analysis indicates that it is the presence or rapid charge points in particular which is potentially supporting the adoption of EVs.

Table 5: Summary of the correlation analyses between the quantity of EVs registered in unitary authorities (per thousand cars) and the current fleet characteristics of unitary authorities

Unitary Authority Characteristics	Variable Description	Correlation Coefficient
Vehicle kilometres travelled	The average number of vehicles kilometres travelled by car in a UA	N.S. P
Household fleet size	Proportion of households in a UA without a car (%)	N.S. S
	Proportion of households in a UA with 1 car (%)	N.S. P
	Proportion of households in a UA with 2 cars (%)	**-.409** P**
	Proportion of households in a UA with more than 2 cars (%)	N.S. P
Driving license attainment	UA population who hold a full driving license (%)	N.S. P

* - correlation coefficient significant at the 0.05 level
** - correlation coefficient significant at the 0.01 level
N.S. – correlation coefficient not significant
P – Pearson's product moment correlation analysis used
S – Spearman's rank-order correlation analysis used

Exploring how the characteristics of the current fleet registered in a UA is related to the level of EV adoption (Table 5), the analysis finds that a higher proportion of two car households present in a UA tends to be associated with a lower degree of EV registrations. This finding is somewhat unusual, as multi-car households are often viewed as being more likely to be early adopters of EVs due to their ability to manage EV limited range (Kurani et al., 1994). A possible explanation of this finding is the UAs with the highest proportion of two car households have a tendency to have a relatively large proportion of their populations being resident in rural areas. With this point in mind, the negative correlation observed between quantity of EV registrations and proportion of two car households might be influenced by the location of the population resident in a UA.

Table 6: Summary of the correlation analyses between the quantity of EVs registered in unitary authorities (per thousand cars) and the environmental attitudes and social behaviours of unitary authorities

Unitary Authority Characteristics	Variable Description	Correlation Coefficient
Attitudes towards climate change	UA population who think climate change is an immediate and urgent problem (%)	**.374* P**
	UA population who think climate change is more of a problem for the future (%)	N.S. P
	UA population who think climate change is not really a problem (%)	N.S. P
	UA population who think climate change is not happening (%)	N.S. P
Participation in volunteering	UA population who have participated in volunteering in the past 12 months	N.S. P

* - correlation coefficient significant at the 0.05 level
** - correlation coefficient significant at the 0.01 level
N.S. – correlation coefficient not significant
P – Pearson's product moment correlation analysis used
S – Spearman's rank-order correlation analysis used

To conclude the analysis, the relationship between the environmental attitudes and social behaviours of a UA and the level of EV adoption has been explored (Table 6). A significant positive relationship is observed between the quantity of EVs registered and the proportion of a UA's population that consider climate change to be an immediate and urgent problem. This result provides support to the idea that EVs are being interpreted as a form of *green technology* with a tendency for EVs to be adopted in areas which have a relatively high concern for climate change. However, the adoption of EVs may not be closely linked to wider social concerns with no significant correlation being observed between the quantity of EVs registered and the proportion of the UA's population which engage in voluntary work.

6. DISCUSSION AND CONCLUSIONS

The research presented in this paper provides an initial assessment of the spatial variance in EV adoption across the UAs of Scotland. A significant degree of variance is observed indicating that the diffusion of EVs is occurring in a spatially heterogeneous manner. Moreover, a number of hotspots of early EV adoption appear to be present with the UAs of Dundee City and Orkney having substantially higher levels of EV registrations as a proportion of their car fleets compared to other UAs.

Exploring the spatial variance of EV adoption in more detail, the research outlined in this paper investigates if the quantity of EVs registered in a UA is statistically related to other characteristics of the UA. Whilst a number of significant relationships have been identified and are described in detail in the results section, there are also a number of insignificant results which may be counter to expectations. With EVs requiring access to dedicated charging infrastructure to refuel, expectations are that EVs will be adopted more readily in areas which have a higher prevalence of off-street parking. However, the analysis presented here indicates the proportion of household type classified as house or bungalow in a UA is not significantly related to levels of EV adoption. Similarly, with the current generation of EVs tending to have achievable ranges of around 100 miles, expectations are that they would be less suitable in areas with a high proportion of the population resident in rural settings. This expectation is not reflected in the results of the analysis with a UA's population location not being significantly correlated to the quantity of EVs registered.

From the results presented in this paper a series of more general recommendations can be put forward. Firstly, setting a strategy to manage the transition towards EVs at the national level may have its effectiveness restricted if it does not appreciate the presence and potential effects of regional and local conditions. The strategy so far adopted by Transport Scotland (2013a) in an effort to promote the widespread adoption of EVs currently discusses the importance of engaging local stakeholders and the production of local incentive frameworks. It is hoped that the results outlined in this paper can provide additional support to this mixture between national, regional and local policies to accelerate the transition towards EVs by highlighting where relationships might be present between early EV registrations and area characteristics. At a more general level, this analysis demonstrates the benefits of linking multiple datasets in order to attain a more holistic and integrated perspective on issues of importance. The increasing quantity of diverse datasets which are becoming publicly available represents a valuable opportunity for researchers to further extend understanding regarding transport behaviour specifically and social process more generally.

The identification of a substantial degree of spatial variance in the quantity of EVs registered across the UAs of Scotland opens possibilities for further research in a number of different areas. The cross sectional analysis offered in this paper could be further extended through the application of spatial regression models. Models of this variety could offer insights regarding the explanatory power of different area characteristics over EV adoption and also investigate spill-over effects to determine if the quantity of EVs registered in a particular UA is affected by the characteristics of neighbouring UAs. Furthermore, future research may want to consider investigating the temporal diffusion of EVs and how these diffusion processes vary across different areas. This line of inquiry could also be advanced by research which compares the diffusion of EVs with similar innovations such as Hybrid Electric Vehicles and photovoltaic tiles.

With the research presented in this paper representing an initial examination of the EV registration data in Scotland, it is important to recognise a number of limitations which exist. Firstly, the variable measuring the quantity of EVs registered in a UA includes registrations by both private households and fleets. Conducting the analysis at the UA level means that the spatial resolution is somewhat coarse and thus cannot account for intra UA variation in variables. Moreover, the analysis presented in this paper simply considers the relationships between the quantities of EVs registered in UAs and other UA characteristics and does not evaluate the causal links which might be promoting the observed variation in EV adoption across the UAs of Scotland. Indeed, there is a substantial quantity of other characteristics of UAs (such as age of UA existing car fleet, number of HEVs registered in a

UA etc.) which are not considered in this analysis that may hold relationships with the quantity of EVs registered. Lastly, with EVs having only been made available to purchase in the mainstream automotive market for the past 4 years, it is likely that the spatial patterns which are being observed will be volatile. Indeed, it would be interesting to repeat this analysis in a further 4 years to determine if UAs which are forerunners in EV adoption in 2014 (Table 2) have retained their positions.

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