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Spatial planning of public charging points using multi-dimensional analysis of early adopters of electric vehicles for a city region

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Abstract

The success of a mass roll out of electric vehicles (EVs) is largely underpinned by establishment of suitable charging infrastructure. This paper presents a geospatial analysis exploring the potentials for deployment of publicly accessible charging opportunities based on two traits – one, trip characteristics (journey purpose and destinations); two, availability of adequate charging (space and time). The study combined census statistics indicating lifestyle trends, family size, age group and affordability for an administrative region in the North-East England to identify three categories of potential EV users – ‘New Urban Colonist’, ‘City Adventurer’ and ‘Corporate Chieftains’. Analyses results indicate that Corporate Chieftains, primarily residing in peri-urban locations, with multi-car ownership and availability of onsite overnight charging facilities form the strongest group of early adopters, independent of public charging provision. On the other hand, the New Urban Colonists and City Adventurers, primarily residing in inner city regions were also considered as potential for early uptake but dependent largely on public charging facilities. For effective EV diffusion development of a purpose-built public charging infrastructure, both for provision of on-street overnight charging facilities in residential locations as well as for fast charging at parking hubs (park and ride, amenities and commercial centres) is recommended to be prioritized in order to overcome the limitations of non-availability of private off street parking to these users.

Keywords: charging infrastructure; electric vehicle; GIS; public charging; socio-demographic

1. Introduction

Alternative fuelled vehicles (AFVs), specifically through diffused adoption of plug-in hybrid electric (PHEVs), full battery electric (BEVs) and hydrogen fuel cell (FCs) vehicles, are expected to play a major role in decoupling transport's ~93% dependence on liquid fossil fuels [1]. In this context the development of a coherent policy in the area of electric road transport is being considered as a viable investment in offsetting transport-related climate change effects associated with conventional vehicles over near-term [2]. The UK Department for Transport (DfT) has set up an Office for Low Emission Vehicles, committed to development of an ultra-low emission vehicle market – facilitating better energy security while addressing issues related to CO₂ emissions and air quality in cities [3]. However, the current drive for securing the future of mobility through electrification, at least over the short to medium term, is faced with technological, infrastructural and behavioural hurdles that need to be overcome in order enable mass market penetration [4].

Recent studies suggest development of suitable public charging opportunity as a compromise in effectively mitigating the range anxiety rather than development of longer-range vehicle capability [5]. Optimal location of charging points presents a real challenge in developing a sustainable EV infrastructure. This has led to consortiums of companies in the transport, energy and power electronic sectors working together on projects connected with the initiation of commercial charging terminals for EVs, as well as fast charging public stations [6]. The C40 Electric Vehicle Network (C40 EVN), based on policy analysis exercise on the deployment of EV charging infrastructures in C40 cities – a group of the world's largest cities - has facilitated the successful introduction of EVs through collective municipal actions, including planning and deployment of charging infrastructure, streamlining permitting processes associated with charging infrastructure, providing monetary and non-monetary incentives and mobilizing demand for EVs in city fleets [7]. The study assessed the potential barriers (policy, technological, economic, etc.) to the deployment of Electric vehicle charging point infrastructure.

Currently the debate on the best set up for the provision of public charging point (PCP) infrastructure is wide open, given the technology and the implementation plan is still in its infancy. A recent system dynamics model of the UK take-up of EVs has provided modest market share forecasts, expected to evolve over the next 40 years [8]. However, it is envisaged the uptake of EVs will largely depend on two crucial factors – a. oil price fluctuation; and b. consumer acceptance. In the UK, a London-wide EV charging network is being installed as part of the ‘Source London’ initiative, with an aspiration for establishing as the EV capital of Europe (with a target of installing 25,000 charging points by 2015, including 500 on-street charging points and 2,000 charging points in off-street public car parks and Tube/ Overground rail station car parks) [9]. Based on the UK government projection, there will be acceleration in the uptake of plug in vehicles nationwide from 2015-2020 [10], henceforth increasing the demand for a more spatially optimized charging point infrastructure over this period. By 2015 the government expects to see a steady rate of growth, with most users commuting short distance from suburban locations. The market will then have the opportunity to expand as the acceptance of the new technology grows and its range anxiety issues decline. In the short term at least the majority of recharging in the UK is expected to occur at home, with further recharging opportunities provided in public charging bays, provided by the government schemes such as Plugged in Places scheme, or at work if the employers join these schemes [10].

Limiting the scope for developing an implementation strategy for PCPs is the fact that till date (2012) there is little information on profiling of early EV adopters. A recent survey in the US has identified potential socio-technical barriers to consumer adoption of EVs, particularly highlighting the perceptions and preferences of technology enthusiasts as potentials early adopters [2]. In the UK, a statistical methodology based on hierarchical cluster analysis to census data characterizing the age, income, car ownership, home ownership, socio-economic status and education has been applied to identify potential early adopters of a range of AFVs (predominantly for the uptake of EVs) using a case study for city of Birmingham [4]. Public charging points are considered to generate greater awareness and marketing potential for the roll out of EVs [9]. However, recent insight into the business case of public fast chargers for EVs indicate the current market outlook to be uncertain for triggering a large-scale roll-

out, unless investment costs can be severely lowered [11]. During the current phase of austerity in public spending by governments this however requires well-informed decision making on the choice of strategic locations upfront for installation of cost-effective charging points, especially with regard to targeting areas of potential EV uptake. This is vital to create a region-wide charging network independent of individual/ household charging facilities.

The aim of the paper is to develop a methodological approach to test the feasibility of an optimal ‘public’ charging point (PCP) implementation scheme, utilising multi-dimensional spatial data analysis which combines the underlying socio-economic traits and travel patterns with the built-infrastructure. The first part presents a case study for the Tyne and Wear region of North East England, utilizing an integrated, multi-criteria spatial analysis approach for identification of suitable locations for purpose-built PCPs, coupling the underpinning socio-economic traits of the potential users with the available information on trip characteristics (journey types and origin-destination). This is followed by results and pertinent discussion, suggesting the potential for developing cost-effective PCP by concentrating on favourable traits, both in the inner-city and out-of-town locations. Towards the end, based on our results, viable recommendations have been made, supporting mass uptake of transport innovation through adequate infrastructure planning, specifically catering to the demands of early adopters.

2. Methods

2.1 Study description

The case study is based in the Tyne and Wear county of the North East England, comprising of five local authorities (South Tyneside, North Tyneside, City of Newcastle upon Tyne, Gateshead and the City of Sunderland) and a total population of over 1 million [12]. It has been considered appropriate on its merits of being a suitable test bed for evaluation of the regional spread of early adopters of EVs, relying on both private and public charging points. Pertinent to this, the region is currently witnessing a huge push from the UK government funded Plugged in Places scheme on promotion of low-emission vehicles [3,10]. In addition, crucial to the scope of this study in promoting public charging infrastructure

at workplaces and publically available charging locations, the proportion of travel to work by car in the Tyne and Wear region is reported as 58.7%, which is in a comparable range of the 61% share observed nationally [13].

2.2 Data analysis and assumptions

As a first step, a hierarchical structure was developed based on a number of criteria to ascertain the most appropriate location of PCPs. A shortlist of key determinants of EV adopters was generated utilising recent literature [4,14,15,16,17]. The main features included – gender, age, level of education, occupation, level of household income, number of vehicles owned, environmental awareness, interest in new technologies, sensitivity to government incentives, and knowledge about fuel economy. This led to primary data acquisition from a range of census information statistics as detailed below.

Table 1 lists the key variables applied to this analysis, the rationale for including them based on the literature reference along with their information source. As can be noted, the majority of spatial information on socio-demographics, accessible as digitised map layers with boundary information in GIS format, was obtained from the UK Census Dissemination Unit (Casweb) [13]. However, the trip origin-destination data could not be collated within the Casweb system and was alternatively accessed from the Centre for Interaction Data Estimation and Research (CIDER) [18], mainly covering information on traffic flows pertaining to commuting patterns. The latter dataset enabled generation of intra-regional origin-destination statistics used in the spatial analysis (**section 2.3.1**). The following four constraints were applied to identify the potential for setting up PCPs which duly accounted for the emerging trends in potentials for early adopted charging privately at home. Adequate assumptions were made while interpreting census information from a particular selection of data sets, as described below where applicable. This was deemed essential due to the limitation of available information in projecting the EV uptake potential directly.

110

111 2.2.1 Off Street Parking

112 In the UK, less than 40% of urban households have off street parking availability though around 70%
113 of suburban residential households have off street parking availability [19]. For households that do not
114 have off street (garage) parking, and those who park on the street or in public garages, PCPs are key to
115 early uptake [14,20]. We assumed that only detached and semi-detached households have off street
116 parking while remaining residents park their vehicles on-street. This has been adopted across the Tyne
117 and Wear region in order to estimate the demand for PCPs (trickle charging point at strategic residential
118 locations).

119

120 2.2.2 EV User Demographics

121 The UK Office of National Statistics has generated 14 categories of occupations, ranging from
122 employers in large organizations to those who have never worked and long-term unemployed [13]. A
123 recent study derived the representative socio-economic status of early adopters for a UK city (assuming
124 direct association with higher income levels) by combining two occupation groups – ‘Higher
125 professional occupations’ and ‘Lower managerial and professional occupations’ [4]. Extending this
126 approach further, our potential EV adopters (i.e. innovators) were assumed to be representing the top 3
127 rankings of these socio-economic categories, including ‘Employers in large organizations’, ‘Higher
128 managerial occupation’ and ‘Higher professional occupations’. It was assumed that these cohorts in
129 turn would lead the way to mass market adoption of EVs.

130

131 2.2.3 Young Professionals

132 Recent industry surveys for the EU and the US suggest that early adopters of BEVs will be generally
133 male, between 18 and 34 years of age [14]. Further, young professionals are viewed as being strongly
134 attached to technology and the media, and are known to have early adoption traits [19]. Although recent
135 studies have highlighted the extension of this age-group to include both early- and middle-aged

professionals (20-55 years) [4,16] the latter, relatively older age group of professionals, has been considered as more affluent (and owning semi- or detached houses with off-street parking) and thus having lower demand for PCPs. In the data selection process of census area statistics provided by Casweb, data sets categorised by age groups can be matched to economic demographics. However, the age groups concerned are particularly large (e.g. 20-24, 25-34, 35-54). Therefore, this study has considered the age band of the demographic group representing young and professional (or young urban professional), referring to members of the upper middle class in their 20s and 30s. Along these lines, the age boundaries of 20-24 and 25-34 were chosen to symbolise young urban professionals.

2.2.4 Socio-economic Classification

A recent study for the UK HEV adopters (N=1263) has reported 39% with household income over £48,000 net per year (~\$78,000 USD, 2011), and 58% possessing an extra car [17]. Although a PCP infrastructure framework has been developed in the UK for London as part of the London Strategy [21] similar guidelines are still not available for other regions. This study therefore adopted the London Strategy with slight amendment to the socio-economic characteristics of the region (for example the ‘global connection’ category was omitted for the Tyne and Wear since this was considered specific to the most affluent features of areas in central London and it did not conform to socio-economic classification of central city wards in the North East). On this basis, the resident population was divided into the following three cohorts, essentially reflecting their distinct characteristics – New Urban Colonists; City Adventurers; Corporate Chieftains. These three cohorts were synthesised from the mosaic types of current EV and hybrid car users in London [21] and populated with the local socio-demographic information for the study area, utilising already established set of criteria for early adopters as identified in recent literature from Cluster analysis [4]. ‘New urban colonists’ were assumed to include small households (with either single or couple with no children) as well as other households (implying multi occupancy households). The emphasis on ‘single or couples’ was assumed to provide a distinct classification. ‘City adventurers’ were considered as young professionals and ‘Corporate chieftains’ were represented by senior management professions with detached houses.

The spatial location of these cohorts within the study region was established through selection of appropriate household composition with National Statistic Socio-economic Classifications (NS-SeC) [12]. It was noted that some of the traits between the three cohorts would be overlapping. To account for this anomaly, census data with high ranking NS-SeC classifications and the age groups of 20-24 and 25-34 were chosen as representative of all three cohorts. Further, the data on Corporate Chieftains was collected by gathering separate information from ward totals of detached housing and the assumption that managers meant the classification for the highest NS-SeC category ranking. This is along the lines of an earlier study [4] who also used socio-economic status as an indicator of income by assuming occupation group ‘professionals and managers’ to be representing those expected to have a higher income than other occupation groups. In previous studies education has been considered as an important factor in determining AFV uptake potentials [16,22]. However, a recent study for the City of Birmingham, UK reported some wards with high student population, having higher education levels but are not affluent home-owners, yet having multiple cars in the household [4]. Such contradictory results demonstrate the need for extra caution in applying specific demographic characteristics to a given area while assessing the EV adoption trends, in particular for determining locations of PCPs. Based on this argument education level was not considered a reliable trait while evaluating early adopter potentials and hence omitted from subsequent spatial analysis in profiling of early adopters of EVs in this study.

2.3 Spatial Analysis

Suitable locations for installing PCPs were identified on the basis of two metrics – one, trip destination; two, EV adoption potential. A dedicated spatial software tool (ArcGIS v10) was used to integrate the GIS-enabled demographic and travel datasets acquired at the Super Output Level (SOA). Various spatial layers were computed from census statistics and compared between different areas of the Tyne and Wear region through application of geoprocessing tools to establish the favorable traits, including

distribution of affluent households (characterized by detached houses, multi-car ownership), Park and ride facilities, and Regional Centres (industrial facilities, large retails, business parks and amenities, prominent transport hubs including the regional airport) (**Figure 1**). This allowed for deriving relationships in the data that could not have been readily apparent in databases or spread sheets. GIS outputs with graduated colour ramps highlighting key areas of interest (i.e. hotspots) were generated for evaluation and interpretation of the spatially varying totals between wards across the study domain.

<Place Fig 1 here>

The following sections describe the steps applied in characterizing the profile of potential early adopters.

2.3.1 Intra-regional origin-destination mapping

In this step, commuting and other major trip purpose journeys were identified for the study region using the ward census data. While analysing commuting patterns the focus was mainly on car trips and not on overall commuting patterns from all modal forms. This was done to focus the implementation of charging infrastructure for personal transport users (mainly cars). The origins and destination of all commuting journeys were only calculated within the Tyne and Wear region. For commuting trips originating outside the study domain only the portion of the trip falling within the study boundary were considered for consistency in finding suitable charging point locations. Following the recommendations of a recent study [5], the spatial analysis coupled vehicle range and trip length as a function of trip journey purpose to locate PCPs. Constraining the origin-destination mapping by EV range requirements was considered relevant for ensuring the commuters' concern on non-reliability of EVs for essential trips. On this basis mappable information of the most likely destinations for EVs were generated, thus facilitating the derivation of viable PCP installations in areas with high proportions of car commuting trips.

2.3.2 Electric vehicle adoption potential zoning

This step utilized the socio-economic demographic information, acquired using the criteria described in **Section 2.2.4**, to determine the spatial distribution of New Urban Colonists; City Adventurers; Corporate Chieftains in the Tyne and Wear region. These were treated as early uptake ‘hotspots’ within the study area, the former two groups relying heavily on deployment of PCPs [21] while the latter group was assumed to only use PCPs, especially those located at workplace, for top-up and emergency charging. Based on outcome of this analysis, a detailed exploration was conducted into the location of charging points within hotspot areas. The feasibility of locating PCPs in such areas were analyzed on the basis of recently published UK National Planning Policy Framework guidance for green transport (i.e. potential for reducing environmental impact, mainly CO₂ emissions compared to equivalent standard vehicles depending on the embodied energy of the vehicle and the source of the electricity) on encouraging local authorities in incorporating charging infrastructure for EVs at suitable sites and to consider adopting policies to include plug-in vehicle recharging infrastructure in new workplace developments [23].

2.3.3 Weighted overlay analysis

This step assessed the strategic locations for PCP installations, taking into consideration the multi-criteria assessment underpinning successful deployment and usage of the facilities. The key constraint was the choice of public charging infrastructure (rapid or trickle charging) that would allow EV users to recharge their batteries at varying rates, depending on trip purpose and parking duration (essentially determined by the location of the PCP). The layers of spatial information were overlaid to assess the favourable hotspots for public charging locations in order to develop a cost-effective PCP infrastructure. In order to reduce the investment costs it was considered necessary to first filter out the zones with

majority of charging occurring privately on off-street premises; the cohort with least dependence on public charging consumer share. For this purpose, multi-criteria evaluation parameters were established for both public and private charging categories through combination of data layers generated in Sections 2.3.1 and 2.3.2 (**Table 2**). An integrated analysis was performed using the ‘weighted-overlay analysis’ tool available in ArcGIS Spatial Analyst toolbox. It is important to note that the Weighted Overlay tool accepts only discrete raster (integer values) as input. This makes it possible to perform arithmetic operations on the raster that originally held dissimilar types of values. For this purpose all the spatial information was first converted into classified datasets using raster pre-processing tools. The input raster were weighted by importance and added together to produce an output raster. A discretised evaluation scale from 1 to 10 (with 10 being the most favorable) was applied to represent the level of suitability of the locations for both private charging users and for installing PCPs.

3. Results and Discussions

3.1 *Spatial analysis of potential EV users*

3.1.1 Origin-destination dependence

Outputs from first step analysis of the commuting patterns of car users in the region provided a clear indication of possible destination areas for potential EV users across the Tyne and Wear region. Commuting patterns within the region enabled an assessment of the feasible locations for developing public charging infrastructure. For this purpose ward-level commuting totals were split up into five class intervals to cover the bulk of the commuting trips into each ward (**Figure 2**). These were then used to symbolize the varying levels of commuting destination levels across the region. This was generated by dividing the maximum car commuting ward totals by the number of classifications necessary to show clear results. Car commuting hotspots (shown as darker colors in **Figure 2**) were found to have over 78% car use as compared to a mean of 55% noted across the Tyne and Wear region.

This indicates the potentials for PCP infrastructure installed in these locations in encouraging early EV uptake due to the high proportion of car commuting dependence in the ward area.

The largest frequency came from smaller total commuting destination totals which were normally under 2000 car commuters. These wards symbolize residential areas, to which fewer people commute. At the far end of the scale we see 4 wards which have very large car commuting totals, these wards are known to be central workplace areas to which a large majority of the region's working population commute to. These came from wards of Newcastle, Sunderland and Gateshead City Centres. Between Sunderland and Gateshead also lies a ward with high commuting destination trips. This ward, known as Washington North, is home to the Nissan automotive plant which is the largest private sector employer in the City of Sunderland region. This and other industry in the ward, resulted in a large total of car commuting destination trips. Also a contributory factor to the high total of car trips could be due to the lack of availability of commuting to Washington North through other transport modes, in particular public transport. From this analysis it appears work-based charging infrastructure would encourage employees working in these regions to join early adopters. However, to raise awareness, public installation in such areas is also highly recommended. This is along the lines of current focus in promoting workplaces as the second main pillar of the UK plug-in vehicle recharging infrastructure. This has been considered more applicable to Plug-in Hybrid Electric Vehicles (PHEVs) or Extended-Range Electric Vehicles (EREVs), as these may need a different pattern of charging to deliver their maximum environmental and financial benefits, making the benefits of workplace top-up recharging potentially significant [3].

<Place Figure 2 here>

It is noteworthy that some city centre areas (in particular for Newcastle upon Tyne) show low percentages of car commuting trips, compared to other modal choices. This is along the lines of finding from Birmingham [4] which also reported higher use of public transport while travelling to work in the inner city wards of Birmingham. However, we note that this area is also attractor to car trips with a number of regional centres (see star shapes in top-centre locations in **Figure 1**), primarily leisure and

shopping activities within city centre regions. Locating PCPs at selected locations would encourage car users to use these facilities, specifically if they are subsidized over the weekends. On the other hand, supermarkets and large retail outlets also hold a huge potential of attracting these group of users with provision of EV charging points as they are well known to people in the region, and also enable the introduction of fast charging (rapid-charging points) without the need to strengthen electricity supply.

3.1.2 Socio-economic dependence

Analysis of the socio-demographic GIS layers generated from Census data enabled locating the following three cohorts of residents in the region spatially - New Urban Colonists, City Adventurers and Corporate Chieftains. This analysis was conducted in several stages. The first step involved locating the specific areas of the Tyne and Wear regions where New Urban Colonists were most concentrated. This was faced with some limitation at the outset as it was found that when the data was gathered the majority of the study area failed to constitute a considerable population size (more than 16 households per output area) under this particular classification (**Figure 3**).

<Place Figure 3 here>

From **Figure 3** it can be noted that the highest density of New Urban Colonists are located mainly in the North of the region, typically representing small families in the suburbs of Newcastle upon Tyne. Further, two areas that stand out from the trend of early uptake groups were found to be located in the North Tyneside LA (middle-east part of the map). Evidently this reflects the fact that greater part of the resident population living in a household either singly or as a couple without children, prefer to live in inner suburb areas of Newcastle compared to other areas of Tyne and Wear. Therefore, the likelihood of early adoption of EVs in this socio-economic category would strengthen the case for installing more charging points in the suburbs of Newcastle upon Tyne compared to other metropolitan districts in the region. This is along the lines of a recent study [4] which found the majority of the wards (almost 60%) favoring the uptake to be located furthest from Birmingham city centre.

<Place Figure 4 here>

The next step analysis involved classification of City Adventurers mosaic type in the Tyne and Wear region. Due to the high NS-SeC rating when collecting the census data, the largest concentrations of the City Adventurers were mostly located in similar areas to the New Urban Colonists in Newcastle upon Tyne and on the mid-eastern flanks, albeit representing greater population densities (**Figure 4**). Urban areas of Gateshead and Sunderland were again noted to provide insignificant amounts of the target demographics for early EV uptake. However, the corridor of a motorway (the A19 situated on the borders of Holystone and Valley) showed significantly high levels of City Adventurers compared to the rest of the Tyne and Wear region (93 City Adventurers compared to a regional mean of 14 per Census output area). This is essentially underpinning the dominant influence of young professionals residing in these locations.

< Place Figure.5 here>

Mapping Corporate Chieftains through census data set was a particular challenge, due to the unavailability of data sets that could co-determine spatial distribution of detached houses and location of population with the highest NS-SeC rating. This was overcome by combining two separate data sets in a GIS layer, symbolizing the most likely locations of this mosaic type. The outputs suggest this resident group to be predominantly occupying peri-urban locations, marked with lower population densities compared to New Urban Colonists and City Adventurers cohorts (and in some wards with nil values) (**Figure 5**). This is in agreement with the quantities of detached housing in output areas being moderately correlated with the highest ward totals of NS-SeC category 1 rankings. This category was considered as the strongest cohort for early EV adoption, independent of PCP infrastructures. Nevertheless, this information was deemed essential for developing a cost-effective installation plan, diverting resources to alternative locations instead of reinforcing PCPs in such areas with lower demand for on-street charging.

3.2 Charging Infrastructure Development

Having established the spread of potential early EV users in the study region based on the adopted methodological framework into the three earmarked categories, the next step analysis involved ascertaining the share of those users who would be benefitted from setting up of a public charging infrastructure. An elimination approach was applied, first establishing the spatial distributions of users with private charging facility on their premises followed by a detailed analysis of potential locations for PCPs through weighted overlay spatial statistics, using a combination of criteria listed in **Table 2 (section 2.3.3)**.

The private charging hotspots (**Figure 6**) seem to map quite closely onto the spatial distribution of Corporate Chieftains, as this cohort was characterized by ownership of detached houses and more than one vehicles (see **Figure 1**). The output zones are mapped alongside the Tyne and Wear road network, the location of Park and Ride facilities (large circles) and the Regional Centres of commercial interest (stars; as defined in **Section 2.3**). It can be clearly noted that private EV charging potentials are higher on the peripheral locations, away from the Park and Ride and Regional Centre. Interestingly, the potential zones for locating PCPs, output from the weighted-overlay spatial statistics, show complete contrast (**Figure 7**) and somewhat complementary to the spatial distribution of private charging locations.

<Place Figure 6 here>

Based on the spatial assessment in **Figure 7**, two categories of potential PCP locations, of particular relevance to both the New Urban Colonists and the City Adventurers, were noted – one, inner-city residential locations; two, out-of-town parking lots and commercial centres. The following sections

describe in details the design recommendations for these two categories of PCPs and their potential usage. Apart from serving the users with restricted off-street charging facilities (identified above) it is envisaged they would be useful for Corporate Chieftains as either ‘top-up’ charging or as ‘visible comfort for curbing the range anxiety’ issues and would also offer charging provisions to long-distance car users travelling to the region.

<Place Figure 7 here>

3.2.1 Inner-city locations

Depending on their locations, PCPs in inner-city locations are aimed to cater to the needs of the local residents as well as shoppers and employees. We have shown a high proportion of the early EV users to be residing in inner city regions, typically New Urban Colonists and City Adventurers with limited off-street parking. In these locations it would be crucial to provide access to publicly accessible, on street charging infrastructure. Otherwise, although it has been concluded that early uptake of EVs in such areas is likely, the lack of overnight charging could become a significant deterrent for mass uptake. For effective implementation, ideally each residential street with high uptake potential would have to be installed with PCPs. This would be advantageous for two reasons - one, for generating EV awareness and best practice; two, for provision of a dedicated parking space for EVs which would be highly beneficial for end users overcoming the insecurity issues in finding parking space in such areas. It is envisaged, both these initiatives in turn would potentially induce further uptake.

Implementation plans for developing dedicated PCPs, especially for on-street charging, are already well underway for inner London as part of ‘on-street parking location plan’ [20]. These designs have prioritized both good visibility and good access to the parking bay for promoting early uptake. Such PCPs are located at either end of terracing, primarily because the end bay offers good visibility and easy access for users. In addition, high footfall from any adjoining main road is also potential for developing

highly visible PCPs, creating further awareness. Overall, such infrastructure design is aimed to raise awareness and create growth in the EV market. For practical reasons the locations of such on-street PCPs in residential areas would be more appealing than those situated in isolated car parks. In addition, access to overnight charging would be also relevant to the economy of EV users through provision of off-peak tariff.

3.2.2 Peri-urban locations

The consumers of public PCPs in peri-urban locations would be most benefitted from installations in public car parks, Park and Ride facilities and regional centres of amenities, business parks, and local supermarkets. This would potentially also instigate usage by local residents frequenting these locations, specifically tying with the shopping and leisure activities. As shown in **Figures 3 and 4**, one of the most highly populated areas for New Urban Colonists and City Adventurers in the study area is located in the top-central part of the region, just on the outskirts of the city. These areas have several Park and Ride facilities (Figure 1) which hold huge potentials for enhancing uptake to the target groups living in these locations with shortage of off-street charging facilities. Typically, following the London guidelines on ‘public car park location plan’ [20], up to two PCPs are recommended as best practice for installation in public car parks. This is in agreement with earlier studies [4,7] recommending installations of PCPs in workplace parking, Park and Ride sites, retail areas and leisure facilities. However, it has been suggested that cities should only design EV strategies suiting their individual circumstances, mainly socio-demographics and parking availability [7].

In case of adequate provision of local renewable energy (e.g. wind, biomass, tidal) supply in peri-urban regions this initiative would also facilitate building of a ‘balanced system’ for charging EVs, supported by local energy from renewable sources. Within the map above are areas that can be classed as high value commercial locations for siting PCPs. The locations will provide further awareness and appeal for the installation of a commercially viable charging infrastructure. Several locations in the output hotspot area for locating public PCP in Tyne and Wear are of commercial interest (as can be noted from

Figure 1), thus strengthening the awareness raising for potential early adopters by appropriate selection of installation sites in visible locations within these car parks (e.g. close to entrances or exits).

4. Conclusions and Future works

Implementation of a well distributed PCP infrastructure is essential, both for supporting EV drivers and for promoting a sustainable EV market. In terms of public infrastructure development, especially borne out of the current austerity measures, strategic PCP locations would pave way for furthering the EV agenda by reducing the range anxiety while facilitating on-street charging solutions. Crucial to the successful implementation of the charging infrastructure, however, is the availability of information on the projected spatial location of would-be EV users.

This study adopted a spatial analysis framework, utilising a combination of socio-demographic traits and travel patterns, to determine early EV uptake potentials in order to develop a charging infrastructure for the North East England. The key constraints applied were family size, age group, car travel patterns and affordability. In the absence of any established metrics a combination of indicative census statistics were used to identify three categories of potential EV users – New Urban Colonist, City Adventurer and Corporate Chieftains.

The study showed spatial distribution of private and public charging needs across the Tyne and Wear region, based on assumptions of early EV adoption potentials. Locating zones with high private EV charging potentials were helpful in demonstrating the non-urgency for installing PCPs in these locations, as it is anticipated these households will have access to overnight charging on their private premises. Specific to innovation in urban planning, our study showed two categories of potential EV users utilizing PCPs. First, a general uptake potential in the inner-city, residential pockets, marked by New Urban Colonists and City Adventurers with on-street parking. These areas were identified as worthy of public infrastructure development in the targeted wards in the immediate future. Second, covering out-of-town, non-residential premises, with opportunities for strengthening EV market

potentials. We consider the outcomes from this study equally extendable to other cities and metropolitan areas around the UK with comparable socio-demographics and travel patterns (primarily commuting using personal transport). It is also felt that apart from serving the first generation of EV users the extensive development of public charging points will also reduce range anxiety for those considering purchasing into the market. In the next step, extending the outputs presented here in developing an implementation plan for a cost-effective solution, would entail detailed assessment of total cost of such system, including the precise number and type of PCPs to be located at the hotspots. All this has to be targeted in potential uptake areas, where public charging point installations will provide the most impact.

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