LOCATING RESIDENTIAL ON-STREET ELECTRIC VEHICLE CHARGING INFRASTRUCTURE: A PRACTICAL METHODOLOGY

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ABSTRACT

Depending on the method of electricity generation, mass-market penetration of electric vehicles has the potential to reduce emissions of greenhouse gases and air pollutants considerably, and to reduce dependency on fossil fuels. This paper presents a novel methodology for Local Government Authorities (LGAs) to identify suitable locations for the initial provision of residential on-street Plug-in Electric Vehicle (PEV) charging infrastructure in urban areas to help remove barriers to PEV uptake. The methodology is practical for use by LGAs with limited financial resources as it is based on simple Geographic Information System (GIS) analysis of routinely available census and parking data to identify the spatial overlaps between areas where residents are most likely to be PEV users and areas where there is a high reliance on residential on-street parking. The methodology has been implemented in practice to determine a charging infrastructure installation strategy for Southampton, UK, where 128 streets (out of 1,924 in total) were recommended as suitable locations. These streets were reviewed by a group of experts during a workshop and confirmed as suitable locations for the initial installation of residential on-street charge points in the city.

KEYWORDS

Plug-in electric vehicle

Residential

On-street

Charge point

Infrastructure

1 INTRODUCTION

Electric Vehicles (EVs) for road transport, including Hybrid Electric Vehicles (HEVs), Plug-In Hybrid Electric Vehicles (PHEVs) and Battery Electric Vehicles (BEVs), rely fully or partially on an electric motor for propulsion (Bjerkan *et al.* 2016). EVs are widely seen as a potential solution to the problems associated with conventional Internal Combustion Engine Vehicles (ICEVs), such as greenhouse gas and air quality emissions, reliance on fossil fuels, and national energy security concerns; with EVs being particularly beneficial when charged from an electricity grid supplied by sustainable and renewable energy sources (Bjerkan *et al.* 2016; Mohamed *et al.* 2016; Rezvani *et al.* 2015; Silvia and Krause 2016; White and Sintov 2017). All major vehicle manufacturers offer, or intend to offer, an EV model within their ranges (Azadfar *et al.* 2015), and many governments have introduced policies to encourage their uptake (Bjerkan *et al.* 2016; Butcher 2017; Mohamed *et al.* 2016; Sierzchula *et al.* 2014; Silvia and Krause 2016). The large on-board battery used to supply the electric motor in BEVs and PHEVs can be recharged by connecting to the electricity grid via a Charge Point (CP) (Emadi *et al.* 2008; OU 2016; Yong *et al.* 2015). This paper addresses the specific issue of where to site such charging infrastructure as part of an initial area roll-out using a case study involving Southampton City Council (SCC), the Local Government Authority (LGA) responsible for Southampton, UK. Hereafter, the term Plug-in Electric Vehicle (PEV) is used to describe PHEVs and BEVs, but not HEVs because they do not use CPs.

Previous research suggests that virtually all owners of domestic PEVs charge their vehicles primarily overnight at home and, for convenience, have a strong preference for doing this instead of using public or workplace charging infrastructure (Alkhalisi and Waterson 2018; Anable *et al.* 2014; Green *et al.* 2014; Hutchins *et al.* 2013; Knight *et al.* 2015). If PEVs are to penetrate widely into the large market of domestic vehicles, prospective PEV owners are likely to require the capability to charge at home. Where a prospective PEV owner has off-street parking facilities (e.g. driveway, garage or allocated parking space), it is relatively straightforward to install a CP on their property, which contrasts with an owner who has only on-street parking facilities where a parking space may not be routinely available directly outside their property, and even if such a parking space was available, the safety and security of the charging cable crossing the public footpath from property-to-vehicle would be a concern.

The problem of access to charging infrastructure in residential on-street parking areas is recognized as a barrier to the widespread uptake of PEVs, particularly in UK urban areas where large amounts of such parking exists (APSE 2017; OLEV 2016). A way to remove this barrier is for LGAs to install CPs conveniently accessible to residents with vehicles parked on-street. UK central government is specifically encouraging this through the ‘On-street Residential Chargepoint Scheme’, which provides LGAs with grant funding (up to 75% of capital costs) for installation of on-street charging infrastructure to meet residential needs (OLEV 2016).

LGAs first need to understand where best to commence installation based on which residents are most likely to be receptive to PEV ownership in the future, but are currently restrained by a lack of off-street parking facilities. The aim of this study was to develop a simplistic methodology for use by LGAs with limited resources (Lowndes and McCaughie 2013) to help identify such suitable locations in urban areas. A review of the literature concerning PEV charging infrastructure locations is reported, particularly for on-street provision in residential urban areas, followed by the practical methodology for determining charging locations using a case study application in Southampton, a city on the South coast of England with a population (in 2016) of *circa* 255,000.

There are a number of other potential solutions to the problem of providing charging infrastructure for residents who lack off-street parking (i.e. potential alternatives to installing CPs conveniently accessible to residents with vehicles parked on-street):

i) using secured matting or a covered duct for the charging cable as it crosses the public footpath from property-to-vehicle;

ii) providing portable CPs wheeled up alongside vehicles and left overnight;

iii) constructing rapid charger (i.e. Direct Current Fast Charger (DCFC) systems) or battery swap stations in the local area (i.e. similar to the existing gas station model);

iv) creating additional off-street parking by paving over front gardens and installing drop-kerbs;

v) utilising any CPs in nearby public or commercial off-street car parks or vehicle depots that are unused overnight;

vi) installing wireless charging via electromagnetic induction pads embedded under on-street parking spaces and in the undersides of vehicles;

vii) encouraging residents to use public destination or workplace CPs instead of home charging (Croucher and Higgs 2015; OCC 2016; Griffiths 2017; Lane 2015; Cluzel and Hope-Morley 2015).

However, all these potential solutions have advantages and disadvantages with no single one having established superiority yet, meaning a patchwork of different approaches is likely to be implemented, particularly in the short to medium-term (Croucher and Higgs

2015). The methodology developed in this study is designed to be applicable when the solution selected by LGAs relates to the installation of residential on-street CPs (or any of the alternative solutions that also involve installing equipment on-street outside residents' homes).

2 CHARGING INFRASTRUCTURE LOCATIONS: A REVIEW

The general problem of identifying locations for PEV charging infrastructure has been addressed by a number of studies, with comprehensive reviews of the relevant literature having been conducted by Shareef *et al.* (2016) and Ko *et al.* (2016). Both reviews found that the vast majority of literature concerned locating non-residential public CPs, although some of these studies do also account for levels of residential accommodation and are therefore applicable throughout an urban area. In contrast, literature specifically concerning locations for residential CPs was very limited.

Concerning the locations for public CPs, a study by Huang (2016) proposed a model for designing city-wide public charging infrastructure, identifying strategic installation locations such as park-and-ride car parks, leisure venues and business parks at the initial stage. Wolbertus *et al.* (2016) analyzed the utilization of existing public CPs in Dutch cities, finding that roll-out policies at the city level can affect the way public charging infrastructure is used. Frade *et al.* (2011) used a modelling approach to estimate the number and locations of public CPs required in a mixed-use neighborhood of Lisbon, Portugal, based on optimizing the coverage of the estimated demand for PEV charging from residents and employers, finding a requirement for 324 CPs installed across 43 public car park locations. Further examples of similar optimization modelling approaches for public CP locations include studies for: the Lyon

Metropolitan Area, France (Baouche *et al.* 2014); Tunis, Tunisia (Bouguerra and Bhar Layeb 2017); Ankara, Turkey (Catalbas *et al.* 2017); Seattle, USA (Chen *et al.* 2013); a hypothetical Central Business District (Ghamami *et al.* 2016); a hypothetical town with a population of 10,000 (Giménez-Gaydou *et al.* 2014); Sioux-Falls and the state of South Carolina, USA (Li *et al.* 2016); and Beijing, China (Jia *et al.* 2014; Zhu *et al.* 2016). Element Energy (2016) considered the provision of on-street CPs (both public and residential) in London, UK and estimated that up to 174,200 PEVs (approximately 6% of total car and van stock) would require such infrastructure by 2025, based on estimates of the proportion of PEVs amongst the vehicle stock, and the percent of households and workplaces with access to off-street parking facilities, although specific locations for CPs were not identified.

Particularly relevant to the approach taken in this paper was a study by Campbell *et al.* (2012), which used UK census data to identify the spatial locations of anticipated PEV early adopters in Birmingham, UK. Cluster analysis was applied to the census data at Super Output Area (SOA) level (SOAs are aggregations of Output Areas, the smallest unit of UK census geography, explained in Section 3.3) using input variables identified as characteristics of PEV early adopters. The cluster analysis grouped the SOAs according to similarities in variable values, and therefore allowed the SOAs containing individuals most closely matched to PEV early adopters to be identified. The research demonstrated it was possible to use census data to identify the locations of potential PEV early adopters (i.e. similar to the approach taken in this paper), but did not then combine this with identifying the locations where a lack of off-street residential parking presented a barrier to PEV uptake.

A similar approach to identifying the locations of anticipated PEV early adopters was used in a study by Namdeo *et al.* (2014), which developed a model to predict the requirement for public and private charging infrastructure across a case study city-region in the North-East of England. Zones where potential PEV early adopters lived were identified by combining their characteristics with national statistics on socio-economic classification of households at UK census SOA level (i.e. similar to the approach taken in this paper). Also identified were the locations of commercial centers and parking hubs, and the locations of commuting trip destinations. Weighted overlay analysis based on assigned statistics representing the features of each zone was then performed using GIS to determine which zones were most suitable for charging infrastructure provision.

Lin and Greene (2011) suggest distinguishing between public and residential CPs during analysis. Such a distinction was not possible in this paper because CPs were all intended for use predominantly by residents, but located on-street where the public could connect at opportune times and where they contribute to expanding the overall city-wide CP network that SCC is committed to delivering; although public availability was regarded as a by-product of the main purpose of satisfying residents' requirements. In practice, CPs are unlikely to be used for overnight charging by anyone other than residents because parking space on the streets is predominantly occupied by residents' vehicles during this period.

The studies found in the literature were all primarily concerned with siting public rather than residential CPs. Very little research appears to address the specific problem of identifying suitable locations for the initial provision of residential on-street PEV charging infrastructure, in particular a practical, minimal cost approach that could be easily implemented by LGAs.

This is the research gap this paper aimed to fill by making the following three contributions to the domain: i) reviewing the current state of methodologies used to identify locations for PEV charging infrastructure; ii) developing an innovative methodology to allow LGAs to cost effectively identify suitable locations for the initial provision of residential on-street CPs; and iii) demonstrating the application of the new methodology in practice using a case study approach to determine a charging infrastructure installation strategy for Southampton.

3 METHODOLOGY

3.1 Overview

The approach taken is summarized in Figure 1 and details are provided in subsequent sections, but a brief overview of the methodology is as follows. Areas of Southampton where residents are more likely to be receptive to the idea of switching to PEVs (i.e. areas where residents correspond to the characteristics of PEV early adopters) were termed Matched Output Areas (MOAs). In parallel, areas of Southampton having a high reliance on residential on-street parking were termed High On-Street Parking Areas (HOSPAs).

Analysis was then performed to identify where MOAs overlapped with HOSPAs. These overlap areas were designated as Street Selection Areas (SSAs). All streets in each SSA were visually assessed for the extent of on-street parking allocation to produce a preliminary list of suitable streets. The final list of recommended streets was produced by a sense-check of the preliminary list through consultation with SCC's parking management team, and the addition of residents' requests for on-street CPs received by SCC (either directly or through a survey of Southampton's residents).

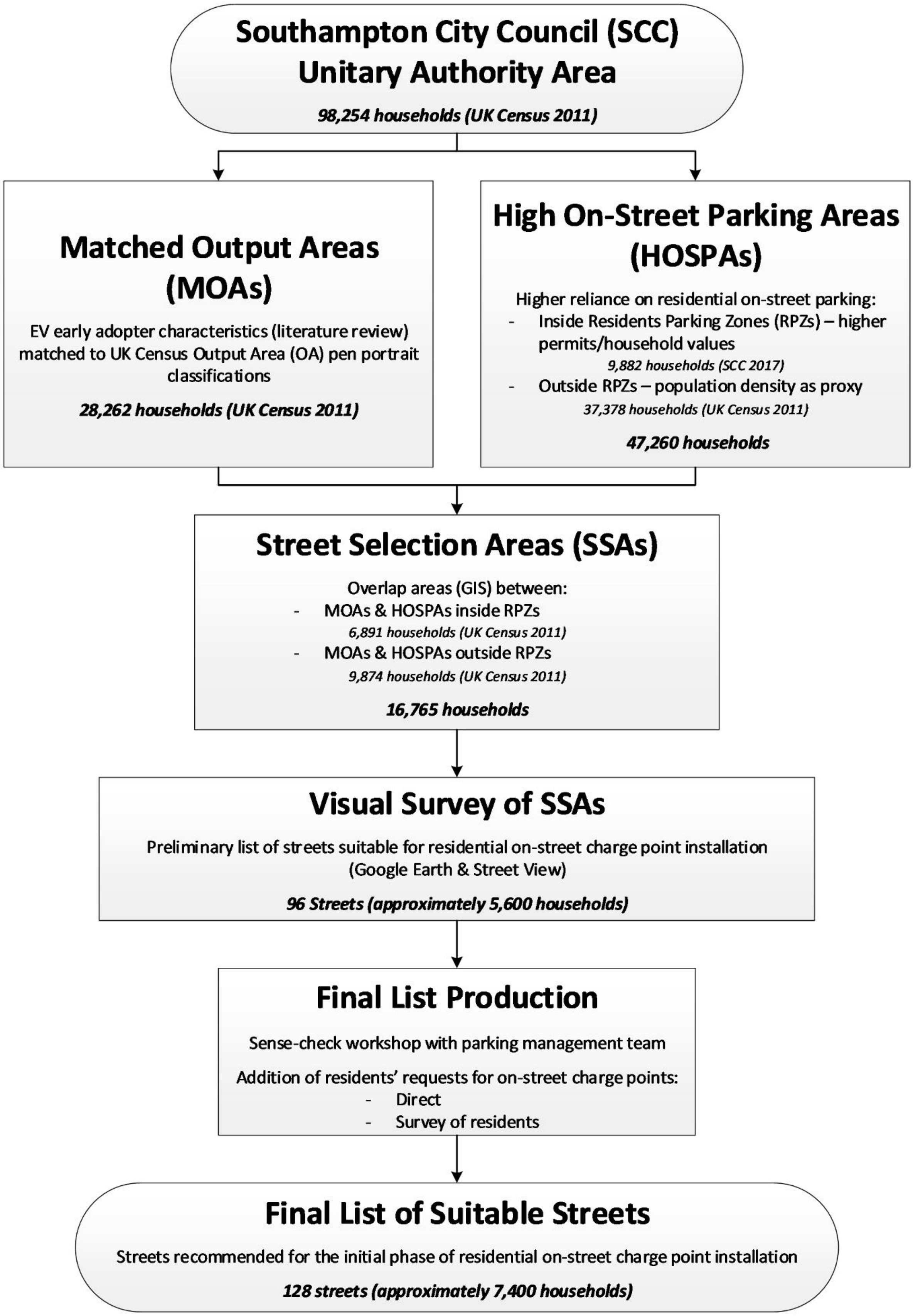

Figure 1: Flowchart of the methodology used to identify locations for the initial installation of residential on-street PEV charge points in Southampton.

3.2 Characteristics of PEV Early Adopters

Determining the characteristics of PEV early adopters was achieved by reviewing relevant academic literature. Whilst the different sources were not always in complete agreement, it was possible to generalize and extract the typical characteristics (Table 1). It is acknowledged that considering PEV early adopters as one homogenous group is likely to be a simplification of the true situation (Hardman *et al.* 2016; Mohamed *et al.* 2016), which could lead to some potential PEV users being erroneously excluded from the analysis (i.e. any residents who are PEV early adopters, but do not fit the profile of typical characteristics). However, using typical PEV early adopter characteristics is a convenient approach to identifying MOAs that satisfies the requirement for a practical methodology, and the simplification was therefore regarded as necessary and justified in the context of this study.

Table 1: Typical characteristics of PEV early adopters extracted from academic literature.

Early Adopter Characteristic	Underlying Reasoning	Reference(s)
High income	It is generally accepted that PEVs are expensive, and a higher income is required to meet the higher initial capital expenditure in comparison to purchasing equivalent ICEVs; although, if future models of vehicle ownership migrate towards leasing rather than outright ownership, PEVs may compare favorably with ICEVs because of their lower operational costs due to lower fuel costs and concessions such as exemption from vehicle excise duty and congestion/toll/parking charges.	Bjerkan *et al.* (2016); Campbell *et al.* (2012); Hardman *et al.* (2016); Mersky *et al.* (2016); Silvia and Krause (2016).
High socio-economic status	Used as an indicator of high income.	Bjerkan *et al.* (2016); Campbell *et al.* (2012); Plötz *et al.* (2014).
Home owner	Used as an indicator of high income.	Campbell *et al.* (2012).
Middle aged (approximately 25-65 years old)	Found to be a typical trait of PEV early adopters.	Bjerkan *et al.* (2016); Campbell *et al.* (2012); Hardman *et al.* (2016); Mohamed *et al.* (2016); Peters and Dütschke (2014); Plötz *et al.* (2014); Rauh *et al.* (2017).
Male	Found to be a typical trait of PEV early adopters.	Bjerkan *et al.* (2016); Hardman *et al.* (2016); Peters and Dütschke (2014); Plötz *et al.* (2014); Rauh *et al.* (2017).

Table 1 continued

Multi-car household	Multi-car households can have a PEV in addition to an ICEV, with the ICEV providing the ability to undertake any journeys currently beyond the range of PEVs.	Alkhalisi and Waterson (2018); Bjerkan *et al.* (2016); Campbell *et al.* (2012); Hardman *et al.* (2016); Hardman *et al.* (2017); Mohamed *et al.* (2016); Peters and Dütschke (2014); Silvia and Krause (2016).
Drive a car to work	Individuals who drive to work are more reliant on their car, and travel more annual kilometers making a PEV attractive due to lower operating costs.	Campbell *et al.* (2012); Plötz *et al.* (2014).
Multi-person household	Found to be a typical trait of PEV early adopters.	Bjerkan *et al.* (2016); Mohamed *et al.* (2016); Peters and Dütschke (2014); Plötz *et al.* (2014).
Well educated	Higher levels of education have been strongly linked to a likelihood of having prior knowledge of new vehicle technology such as PEVs.	Bjerkan *et al.* (2016); Campbell *et al.* (2012); Hardman *et al.* (2016); Mohamed *et al.* (2016).
Interest in efficient vehicles	PEVs have lower fuel costs compared to ICEVs.	Alkhalisi and Waterson (2018); Green *et al.* (2014); Silvia and Krause (2016).
Interest in environmental issues	PEVs are associated with reduced emissions compared to ICEVs conferring environmental benefits in terms of climate change and air quality.	Alkhalisi and Waterson (2018); Green *et al.* (2014); Hardman *et al.* (2017); Langbroek *et al.* (2016); Mohamed *et al.* (2016); Plötz *et al.* (2014); Silvia and Krause (2016); White and Sintov (2017).
Interest in new technology	PEVs are associated with technological innovation compared to ICEVs.	Alkhalisi and Waterson (2018); Hardman *et al.* (2017); Plötz *et al.* (2014); Rauh *et al.* (2017); Silvia and Krause (2016).

3.3 Matched Output Areas

UK census Output Areas (OAs) were used to identify the locations populated by residents within Southampton whose characteristics most closely corresponded to those of PEV early adopters. OAs are the smallest unit of UK census geography, with Southampton being divided into 766 areas (Figure 2). OAs are generated from cluster analysis of census data to group together (as far as possible) households that are socio-economically similar. Generation of the OAs is also based on a target population and number of households of 312 and 125, respectively (Cockings *et al.* 2011; ONS 2012).

The characteristics of OA residents are classified by the UK's Office for National Statistics (ONS) into 8 supergroups, which are sub-divided into 26 groups, which in-turn are sub-divided into 76 subgroups. Each OA is classified using a three-character alphanumeric code, with the first, second and third characters indicating supergroup, group and subgroup, respectively. Qualitative written descriptions (i.e. pen portraits) are used to define all the supergroups, groups and subgroups, illustrating the characteristics of OAs in terms of their demographics, household composition, housing, socio-economic characteristics and employment patterns (ONS 2015). The pen portraits provide greater insight into the characteristics of OA residents compared to a straight examination of the statistical outputs of the cluster analysis used to generate the OAs (ONS 2015).

Pen portraits having the closest correspondence to the typical characteristics of PEV early adopters (i.e. qualitative characteristics in Table 1) were identified. For brevity, full descriptions cannot be included, but details of the identified classifications[1] are available in ONS (2015). OAs with these classifications were designated as Matched OAs (MOAs), and the locations of MOAs in Southampton were then plotted on a map (Figure 2). In accordance with a general policy of over-inclusion, when there was any doubt about whether or not a pen portrait matched with EV early adopter characteristics, the classification was retained rather than rejected.

Lin *et al.* (2014) suggested an appropriate metric for determining where the installation of CPs would have the greatest impact on encouraging PEV uptake was to identify areas where

[1] The alphanumeric codes for the identified classifications were 2a3, 2c1, 2c3, 2d1, 2d2, 3d1, 5a1, 5a2, 5a3, 5b1, 5b3, 6a1, 6a2, 6a3, 6a4, 6b1, 6b2, 6b3 and 6b4.

the highest increase in propensity to switch to PEVs was generated. However, areas with the highest absolute propensity to switch were used as MOAs in this paper to accommodate SCC's desire to maximize the likelihood of new CPs actually being used. Additionally, areas of high absolute and high increase in propensity to switch following CP installation are likely to be co-located because pre-existing absolute propensity to switch is likely to be low across Southampton due to the fairly limited pre-existing provision of workplace or public CPs as alternatives for those without residential CPs.

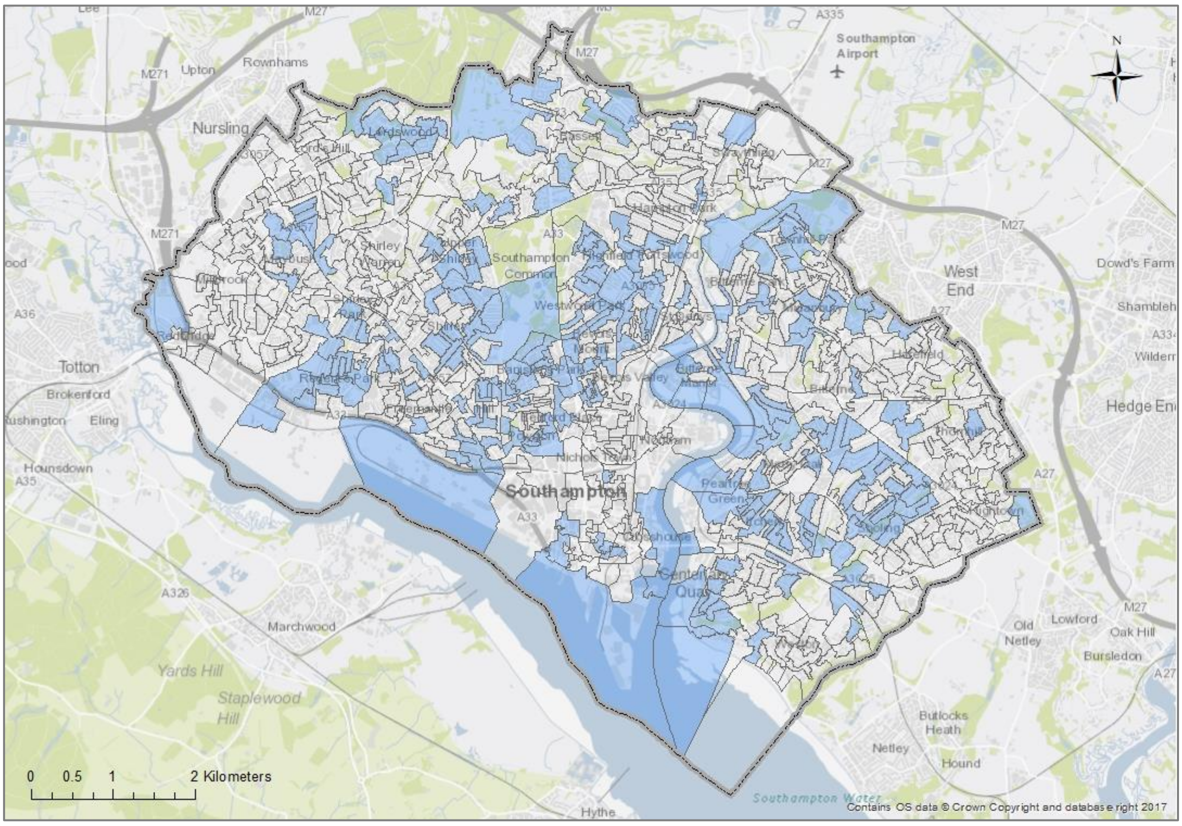

Figure 2: Map of MOAs.
The boundaries of all 766 census OAs are shown by gray lines. MOAs are shown by blue areas, which constitute 29% (220) of the total number of OAs. The boundary of SCC Unitary Authority is shown by the black dashed line with a gray background.

3.4 High On-Street Parking Areas

Areas of Southampton with a high reliance on residential on-street parking (High On-Street Parking Areas, HOSPAs) were identified using two methods: i) HOSPAs inside Residents Parking Zones (RPZs); and ii) HOSPAs outside RPZs.

3.4.1 HOSPAs Inside RPZs

In many cases, RPZs are implemented in urban areas where residential off-street parking facilities are lacking to reserve the (often limited) available on-street parking spaces for residents of the area, who buy a permit from the LGA allowing them to park on-street within the RPZ. However, in other cases, RPZs are implemented in urban areas where residential off-street parking facilities are broadly sufficient to meet residents' needs, and the RPZ's purpose is only to prevent commuters or users of local amenities parking in a residential area and walking or taking public transport to their final destination. In other words, not all RPZs are necessarily HOSPAs.

The method used to identify RPZs that were HOSPAs (i.e. HOSPAs inside RPZs) was based on analyzing data on sales of residents' parking permits. For each zone, the number of permit sales and the number of eligible households for 2017 are shown in Table 2. Zones 17 and 18 had very small numbers of eligible households, and were therefore excluded from the analysis because of the potential for their data to be anomalous. Zones 19, 21 and 24 were excluded from the analysis because they do not contain residential properties. The zones are ordered in descending values of permit sales per eligible household, with the top half of the order (i.e. the 10 zones with permits/household values ≥ the median for the 19 zones included in the analysis) considered representative of RPZs with a higher reliance on residential on-street parking. Zones in the top half (including Zones 17 and 18 for completeness) were designated as HOSPAs inside RPZs, and their locations are shown in Figure 3.

Table 2: Residents parking permit sales in Southampton during 2017.

RPZ	RPZ Name	Permits Sold	Eligible Households	Permits/Household
17	Golden Grove	9	6	1.50
18	Rockstone Place	29	25	1.16
4*	Newtown/Nicholstown	1,244	1,675	0.74
1*	Polygon	623	954	0.65
5*	Bevois Town	792	1,293	0.61
3*	Woolston	160	317	0.50
12*	Battle Roads	322	656	0.49
13*	Bitterne Manor	183	373	0.49
15*	Northam	359	732	0.49
16*	Shirley	276	567	0.49
6*	Highfield	479	1,062	0.45
7*	Coxford	990	2,222	0.45
22	Holyrood Estate	195	450	0.43
10	Flowers Estate	528	1,236	0.43
11	Hampton Park	337	819	0.41
23	Alexandra Quay	62	157	0.39
8	Freemantle	336	1,020	0.33
20	Kingsland	64	200	0.32
14	Itchen	163	544	0.30
2	Woolston	47	165	0.28
9	Glen Eyre	333	1,198	0.28
19	Cemetery Road	na	0	na
21	Guildhall Square	na	0	na
24	Hollybrook Cemetery	na	0	na
	Totals	7,531	15,671	

Asterisks indicate table rows representing the top half of zones with a higher reliance on residential on-street parking. na is not applicable. Visitors' permits are not included in the data, i.e. numbers of permits sold applies to permits for residents' own vehicles. Residents are not charged for permits in Zones 13, 14 and 15. Source: SCC.

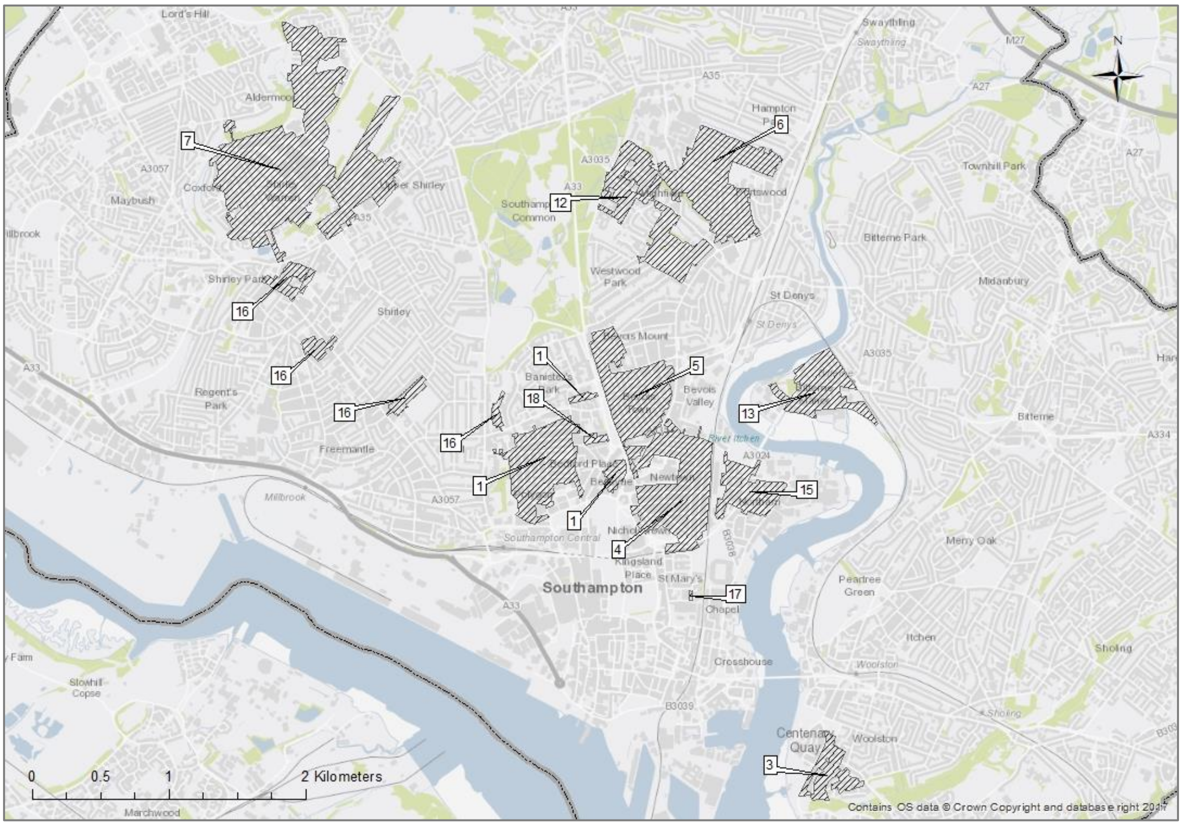

Figure 3: Map of HOSPAs inside RPZs.
HOSPAs are shown by hatched areas. Labels refer to RPZ numbers in Table 2. Zones 1 and 16 are constituted by multiple non-contiguous areas. The boundary of SCC Unitary Authority is shown by the black dashed line with a gray background.

3.4.2 HOSPAs Outside RPZs

There may be areas of a city where residential off-street parking facilities are lacking and residents must therefore rely on on-street parking, but which have not been included as part of the city's residents parking permit scheme. Hence, HOSPAs outside RPZs were also identified: i) to ensure the analysis was not too narrowly focused on RPZs, excluding potentially suitable streets just because of their location outside these zones; and ii) as it could be argued that busier RPZs experience the greatest pressure from residents on the available parking spaces, leading to an increased likelihood of conflict with residents owning conventional ICEVs if spaces are reserved for PEV charging, a situation which may be politically unacceptable to Local Government Authorities (LGAs).

In the absence of parking permit data, the alternative method used to identify HOSPAs outside RPZs was based on using OA population density as a proxy for the likelihood that an OA's residents would rely on residential on-street parking because high population density means there is less open space to provide off-street parking facilities. The median value of population density for all 766 OAs in Southampton was 66.35 persons per hectare (ppha) based on UK census data.

Based on this median value, OAs with population densities greater than a threshold of 66 ppha were designated as HOSPAs. For example, a particular OA with a population of 365 and an area of 3.51 hectares has a population density of 365/3.51 = 103.99 ppha, and was therefore designated as a HOSPA. Any OAs that overlapped with HOSPAs identified via the 'Inside RPZs' method (i.e. OAs that overlapped with RPZs in the top half for values of permits/household in Table 2) were then removed to avoid duplication. Figure 4 shows the locations of HOSPAs outside RPZs. Comparison of Figure 4 with Figure 3 suggests there are a substantial number of HOSPAs outside RPZs in addition to those inside RPZs, which demonstrates the importance of ensuring the analysis was not too narrowly focused on RPZs.

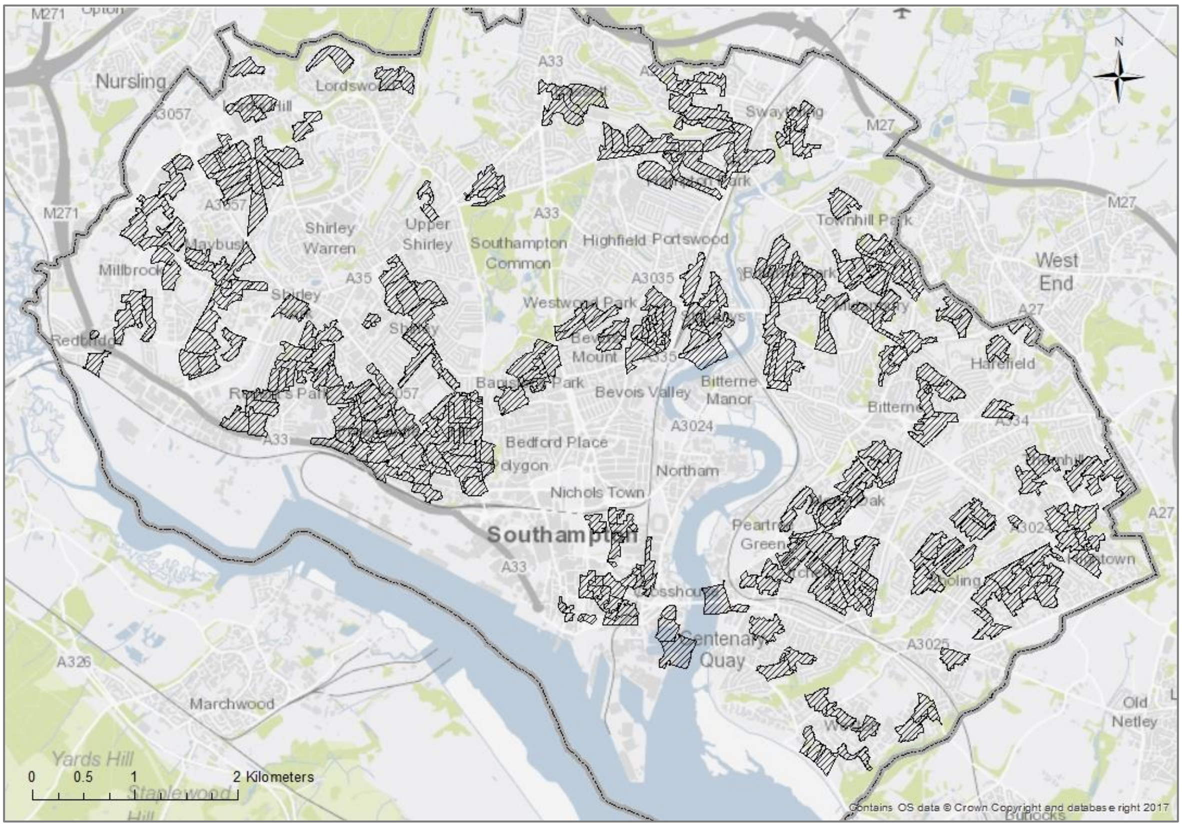

Figure 4: Map of HOSPAs outside RPZs.
HOSPAs are shown by hatched areas. The boundary of SCC Unitary Authority is shown by the black dashed line with a gray background.

3.5 Street Selection

Utilizing Geographic Information System (GIS) software (ArcGIS 10.5), the overlap areas between MOAs and HOSPAs were identified. The MOAs that overlapped HOSPAs were designated as Street Selection Areas (SSAs) and are the locations in Southampton likely to contain the streets most suitable for the initial provision of residential on-street PEV charging infrastructure. SSAs formed by the overlap of MOAs with HOSPAs identified with the 'Inside RPZs' method were designated as RPZ-SSAs; and those formed by the overlap of MOAs with HOSPAs identified with the 'Outside RPZs' method were designated non-RPZ-SSAs. In accordance with the general policy of over-inclusion, even where the overlap areas between MOAs and HOSPAs were small, MOAs were retained as constituents of SSAs. This meant that

RPZ-SSAs were typically not entirely contained within RPZs because overlapping MOAs extended beyond RPZ boundaries. Figure 5 shows SSA locations.

Not every street within the SSAs was suitable for the provision of residential on-street CPs because some streets had residents parking that was predominantly off-street. Therefore, a visual survey of SSAs was conducted to identify the specific streets where residents parking is predominantly on-street. This survey involved using Google Earth and Street View software to visually inspect each street in the SSAs to determine whether residents parking was predominantly on-street or whether it was predominantly off-street in facilities such as driveways, garages or allocated parking spaces. The 96 streets selected as suitable were compiled into a preliminary list.

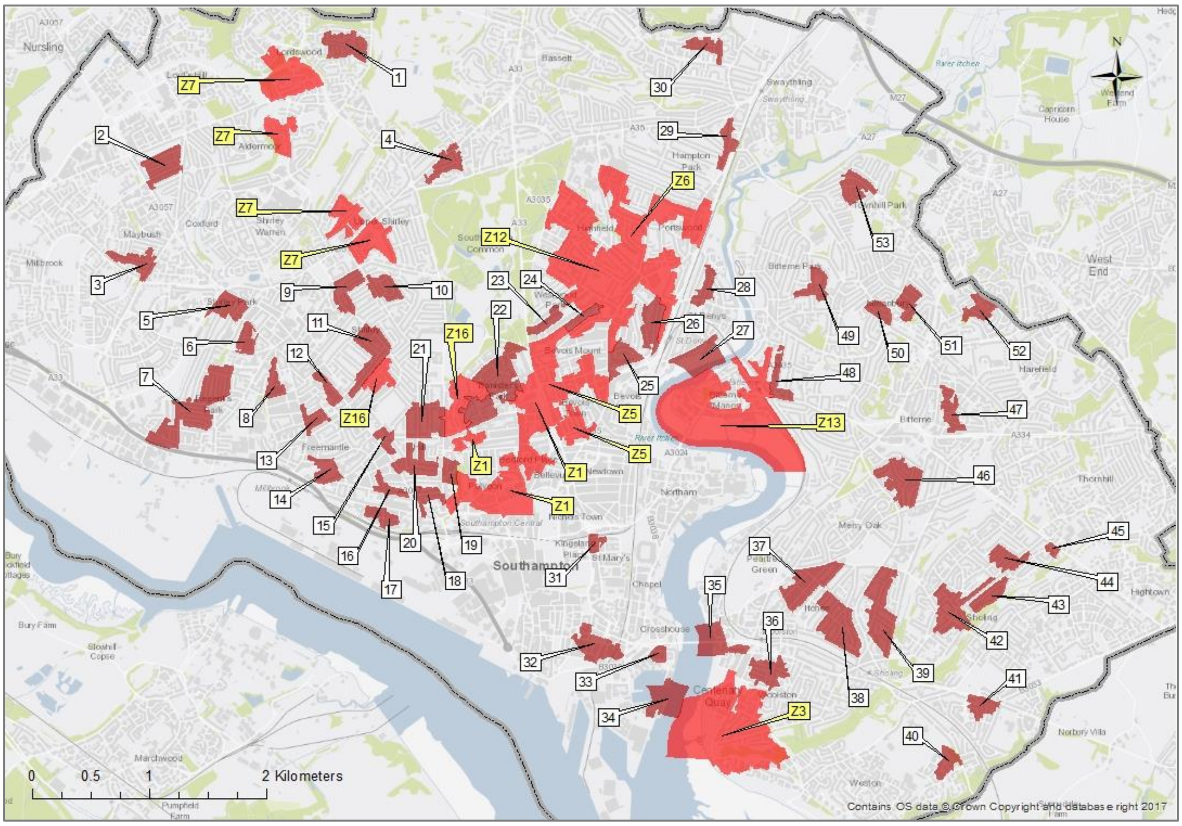

Figure 5: Map of SSAs.
SSAs are shown by red areas. RPZ-SSAs are shown in light-red with yellow labels and non-RPZ-SSAs are shown in dark-red with white labels. Yellow labels refer to the RPZs with which the RPZ-SSAs overlap (i.e. zone numbers in Table 2). The boundary of SCC Unitary Authority is shown by the black dashed line with a gray background.

3.6 Final List of Streets

The analysis used to generate the preliminary list of suitable streets was theoretical and therefore a real-world sense-check was applied whereby SCC's parking management team were directly consulted on the merits of the list. A workshop protocol was developed, and SCC Parking Enforcement Officers recruited as participants because they had the necessary on-the-ground familiarity with the streets. The number of participants in the workshop (three) was constrained by the number of volunteers that could be released from their normal work duties by their employer (i.e. SCC) and made available to participate. The sample was considered sufficient because the participants possessed considerable experience of Southampton's street network (average experience as a Parking Enforcement Officer was 10 years per participant) and all reasonable efforts were made to maximize participant numbers.

The group of participants was shown a street view image of each street and asked two questions: (1) do residents predominantly rely on on-street parking?, to which the response was either yes or no; and (2) do residents' vehicles indicate they are likely to be in the market for PEVs, which tend to be more expensive than equivalent ICEVs? The response to (2) was more subjective and therefore simplified by classifying typical residents' vehicles into three categories: A for higher-priced; B for mid-priced; and C for lower-priced. The group of participants was free to decide which types of vehicles constituted the three categories, facilitated by some example guidance, and was then asked to classify each street as A, B or C.

Streets selected for the final list were those that predominantly rely on on-street parking and have typical residents' vehicles classified as A or B because owners of type C (lower-priced) vehicles are less likely to be in the market for (higher-priced) EVs. The general opinion of the workshop participants was that the preliminary list was a sensible selection for the initial installation of residential on-street PEV CPs, with 92 of the 96 streets being selected for the final list; i.e. general validation of the results of the theoretical analysis.

The last step in compiling the final list of streets was the addition of any residents' requests for on-street CPs. Occasionally, SCC receives requests directly from residents without off-street parking facilities who want to charge a PEV at home and enquire about whether the Council can provide a residential on-street CP. SCC has been recording the details of such requests, and the relevant streets have been added to the final list. However, recording has occurred only relatively recently, resulting in just six requests to date (one of which was already on the final list via the theoretical analysis) and a survey was conducted to search for further residents' requests. The survey was distributed online by SCC to the Council's People's

Panel, which is a standing group of approximately 1,600 Southampton residents (18+ years old) who have consented to being regularly approached about survey participation. There were 648 (40%) responses.

The two key survey questions were: (1) do you have off-street parking facilities at your home?, to which participants were offered a yes/no response; and (2) to what extent do you agree or disagree with the following statement: "I would consider getting a Plug-in Electric Vehicle if I had a convenient place to park at home for vehicle battery charging"?, to which participants were offered a five-point Likert scale response ranging from 'strongly agree' to 'strongly disagree'. Any participant who strongly agreed with the statement in (2), but indicated they did not have off-street parking facilities at home in (1), was assumed to be a resident's request for a residential on-street CP and added to the final list. The survey resulted in 45 residents' requests, including 4 streets that were duplicated and 10 streets that were already on the final list via the theoretical analysis or direct residents' requests, leaving 31 new additions.

Based on demographics collected during the survey, the characteristics of the group of 45 participants who were assumed to be residents' requests have a reasonable correspondence with the characteristics of PEV early adopters shown in Table 1: 73% were home owners, 76% were 25-65 years old, 62% were male, 31% were from multi-car households, 69% were from multi-person households and 71% were well educated (above UK A-Level qualifications). However, the distribution of characteristics for the group of 45 residents' requests was found to be not statistically significantly different (Wilcoxon signed-rank test $p=0.50$, i.e. not significant for $p<0.05$ level) from the distribution of characteristics for the group of all survey participants together, meaning the group of all participants also had a reasonable correspondence to PEV early adopters, although the group of 45 residents' requests did have a slightly closer correspondence. A probable reason for the anomaly of a low percentage for multi-car households (31%) is that residents' requests were defined as homes without off-street parking, and this limited availability of convenient parking space is likely to be a disincentive for multiple vehicle ownership.

4 RESULTS

The application of the methodology to the case study urban area resulted in a final list of 128 streets (out of 1,924 in Southampton in total) identified for the initial installation of residential on-street charging infrastructure. For reasons of confidentiality, the final list cannot be reproduced here, and is obviously Southampton-specific with limited relevance to the wider readership. However, Figure 6 shows the general distribution of the final streets across Southampton.

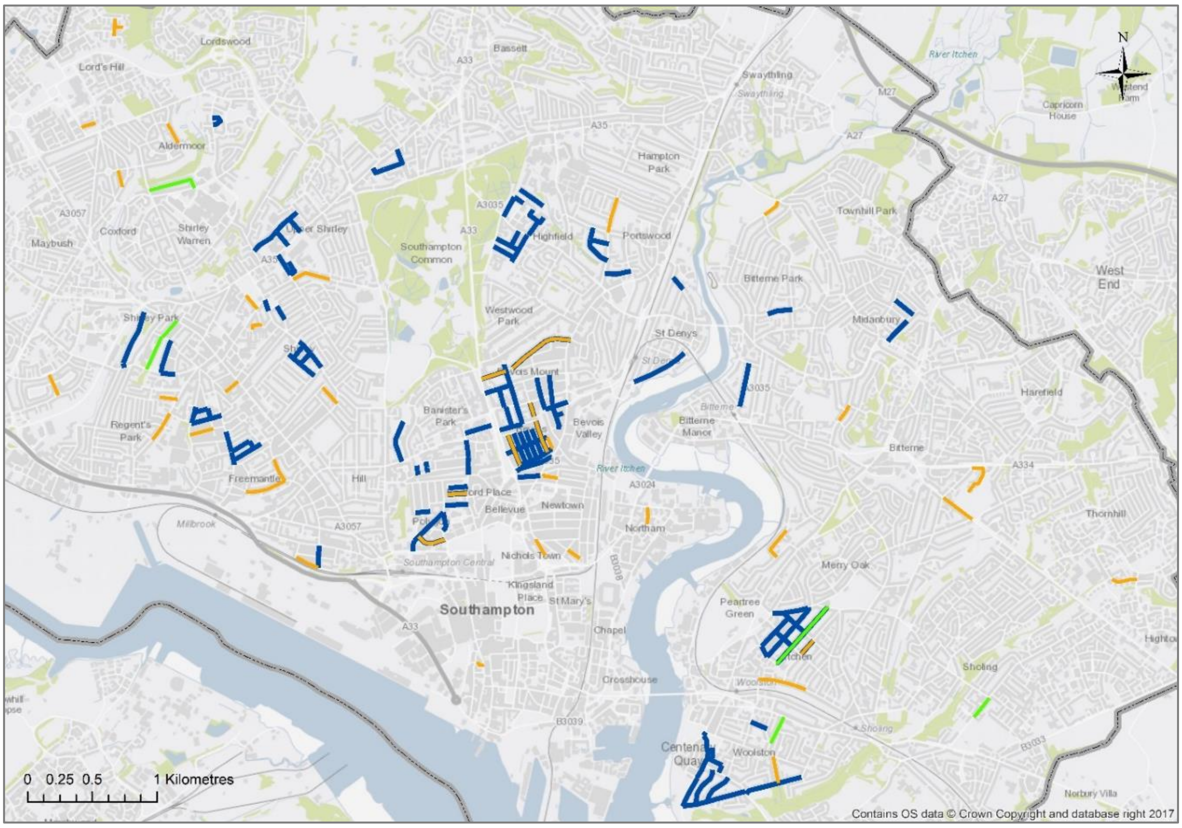

Figure 6: Map of the distribution of final list streets.

Final list streets are shown by blue, green and orange lines. Green and orange lines indicate the location of direct and survey residents' requests, respectively. Where residents' requests overlap exactly with theoretical identification, streets are shown by orange or green lines with a blue edge. The boundary of SCC Unitary Authority is shown by the black dashed line with a gray background.

5 DISCUSSION

This paper has demonstrated a practical methodology for LGAs to identify suitable streets for the initial provision of residential on-street PEV charging infrastructure in urban areas. The proposed methodology is likely to be practical for LGAs to use within limited resources because it is based on non-specialized, routinely available data: census data are collected anyway by governments and are usually freely accessible; and RPZ schemes are typically administered by LGAs who are therefore responsible for the associated data. Additionally, the methodology does not require any advanced skills or training in the use of GIS software. As well as being practical, the methodology was successful, producing a list of streets that was generally assessed as appropriate by a group of people (i.e. workshop participants) very familiar with the case study area's streets. In summary, a simple theoretical analysis of a large urban area was used to select a preliminary list of potentially suitable streets, such that the number of listed streets allowed a workshop approach to be a practical option for list validation. The preliminary list was successfully validated by workshop participants (professional parking officers) based on their extensive real-world experience, prior to a final list of suitable streets being produced, which included the addition of residents' requests.

A factor that could narrow down the final list of suitable streets is proximity to public transport access points. Residents with convenient access could potentially have reduced requirements for road vehicles, and installation of CPs may encourage an undesirable mode-shift from public transport to PEVs. For example, a resident living in close proximity to a stop on a convenient bus route may currently prefer to use public transport, and the installation of a residential on-street CP outside their home may encourage them to switch to a PEV road vehicle instead, which may not be the desired effect of local transport policy. However, an assumption that access to public transport was constant across residential areas was used in the methodology (i.e. variation in proximity to public transport access points was not included in the analysis) to retain simplicity.

The methodology has been employed by SCC to determine the strategy for the program of installing residential on-street charging infrastructure in Southampton. Having used the methodology to produce a list of suitable streets for the locations of CP installations, SCC is currently (March 2019) engaged in the next steps of the procurement process, which are to identify a supplier of CP equipment and to complete the application for grant funding from the ‘On-street Residential Chargepoint Scheme’. The first CPs are expected to be installed before the end of 2019, with subsequent installations planned as resources allow.

The methodology was designed to be practical for LGAs to use within restricted resources to provide rapid, early assessments of large urban areas to identify potential locations suitable for the initial installation of residential on-street CPs. Therefore, the methodology produces a manageable list of potential locations as a precursor to more in-depth (and costly) explorations of site-specific feasibility factors such as equipment and installation costs, funding sources (e.g. business case for any non-grant funded costs, any residents’ contribution to costs), capacity of the electricity grid to supply newly installed charging infrastructure, and any local parking restrictions.

The equity of LGAs using general taxation (i.e. grant funding) to provide facilities for wealthier residents (i.e. wealthier residents are likely to have a higher propensity to switch because PEVs typically have higher purchase prices than comparable ICE vehicles) was a concern. However, LGAs’ desire to maximize the likelihood of new CPs actually being used was considered to outweigh equity issues, particularly as the locations identified by the methodology were intended to be initial installations prior to roll-out of residential on-street CPs at all locations where required throughout an urban area.

The results of the methodology application to the case study urban area are Southampton-specific and therefore of limited relevance to a wider readership; however, the methodology is designed to be transferable to other urban areas. Within the UK, census data, OA classifications and RPZ data are available in the same way as for Southampton. Outside the

UK, census and RPZ data are typically available, but the process of matching OAs to PEV early adopters is likely to be country-specific because OA residents' characteristics are likely to be classified according to different schemes.

6 CONCLUSIONS

This paper provides a practical, systematic methodology for LGAs to identify locations for the initial installation of residential on-street PEV CPs. Provision of such infrastructure removes a recognized barrier to the purchase of PEVs, therefore encouraging their uptake and contributing to the realization of associated environmental benefits. The methodology has already been used in practice by SCC and is designed to be transferrable to other urban areas, both within and outside the UK. However, a limitation is that the transferability has not yet been tested, which is a subject for future work. Another limitation is that the methodology does not account for detailed site-specific factors, and is intended as a precursor to more in-depth site surveys, which could include an assessment of the impact of a site's proximity to public transport access points.

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