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Considerations for future electric vehicle infrastructure in Bristol

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Abstract

In this work, considerations for delivering a holistically considerate best approach for EV (Electric Vehicle) infrastructure in Bristol, UK are examined.

EVs are considered a leading method to reduce emissions from transport. With Bristol City Council (BCC) declaring a “Climate Emergency” and aiming to reduce emissions to net-zero by 2030, and become a “sustainable, healthy and fair” city as a part of the Bristol One City Plan by 2050, this work examines how an evidence-based approach could facilitate the development of EV infrastructure in Bristol.

Following a review of academic and policy literature, this work analyses barriers to EV infrastructure in Bristol inclusive of insights from semi-structured interviews conducted with local stakeholders. The main barriers identified are capital cost, “Range Anxiety” and behaviour, power supply issues, and Bristol’s high proportion of on-street parking.

Following these findings, a localisation of the research base and EV impact upon sustainability is discussed with respect to One City Plan by BCC. In this discussion, EV infrastructure is illustrated to positively impact the themes of Environment, Health and Wellbeing, and Skills and Learning. However, EV infrastructure will have a lesser impact upon on Homes and Communities, Connectivity, and Economy themes.

Finally, a four-principled best approach for Bristol is recommended from the findings and discussion. Firstly, BCC should act as a lead stakeholder in fostering local EV infrastructure policy. Secondly, EV infrastructure should be inclusive of all EV users; including simpler payment/access for charging and variegated charging facilities. Thirdly, EV infrastructure should support a multi-modal transport shift, in order to reduce congestion on Bristol’s road network and incentivise active/public transportation use. Lastly, EV infrastructure should be adaptable and future-proof, resilient to future uptake and emergent technologies.

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Abbreviations / terms

BCC:	Bristol City Council
BEIS:	Department for Business, Energy and Industrial Strategy CAV: Connected Autonomous Vehicle
DfT:	Department for Transport EV: Electric Vehicle
GHG:	Greenhouse Gas
ICV:	Internal Combustion Vehicle MaaS: Mobility as a Service
OLEV:	Office for Low Emission Vehicles
"Range Anxiety":	The fear that charging stations are currently too infrequent for EVs, thus disincentivising longer journeys with EVs.
"Rebound Effect":	Effect of a transportation scheme indirectly increasing private vehicle usage, rather than decreasing the use of private vehicles.
TOUT:	Time of Use Tariff V2G: Vehicle to Grid
WofE:	West of England Combined Authority

Informant coding

The interview coding is as follows:

Job Title of Informant (if required, anonymised)	Abbreviation/Coding
Surface Access Strategy Principal Officer	SASPO
Councillor	Cllr
Transport Consultant	TC
Academic in Transport Policy	ATP
Business Initiative Manager	BIM
Transport Policy and Strategy Manager	TPSM
Principal Officer – Transport Projects	POTP

1. Introduction

This work seeks to deliver a holistically considerate best approach for EV infrastructure in Bristol, UK. This work is delivered in conjunction with Bristol City Council and City Office, supporting future policy decisions by BCC by using existing desk research and stakeholder input to deliver a series of pragmatic policy principles.

The city of Bristol has recently declared a climate emergency (BCC, 2019a), with an ambitious aim to achieve net carbon neutrality by 2030. Achieving carbon neutrality will require a significant undertaking by Bristol to reduce GHG emissions from all sectors, including transport (BCC, 2018a). 25% of Bristol's total GHG emissions stem from the transport sector (BCC, 2019b); whilst the West of England produces 29% of its emissions from transport- or 1,700kt/CO_2 equivalent (WofE, 2017; Travelwest, 2019). Reducing emissions from private ICVs, which make up 53% of transport used for commuting journeys in Bristol will have a significant impact on reducing Bristol's carbon footprint (BCC, 2018b).

As such, the use of EVs is increasingly considered as an immediately accessible and proven replacement for ICVs to reduce transport emissions (Madina et al, 2015). By using a battery- powered motor-driven drivetrain, an EV produces net zero CO_2 emissions at the point of use, nor NO_2, SO_2 or other particulates derived from the combustion of fossil fuels (Hawkins et al, 2013; DfT, 2018). EVs have also been considered as being able to provide wider co- benefits to air quality, society and economy (Bakker et al, 2014; DfT, 2018; POTP). As such, this work investigates how EV infrastructure, a requirement for the uptake of EVs, could be best developed with holistic considerations for Bristol.

There are two background motivations that this work considers in developing the best approach for EV infrastructure in Bristol. These are the technical background of EV infrastructure, and the Bristol One City Plan. Both motivations form the background of this work to develop the best approach.

1.1. Background motivations

1.1.1. EV charging infrastructure

If the adoption of EVs is to occur in Bristol, both private and public charging facilities will be required for their usage. This is as well supporting EVs to travel longer distances (DfT, 2018), encouraging consumer uptake (Hall et al, 2017) and provide consumers with security against “Range Anxiety” (Hall and Lutsey, 2017). However, EV charging is a different proposition to the refuelling of an ICV due to the time taken and reduced infrastructure required to charge an EV (Zapmap, 2019a). This means that EV charging stations are often installed in a range of non-conventional sites, such as car parks and in domestic locations (Bonges and Lusk, 2016, TC). As such, implementing such infrastructure requires a wider understanding of the technical background involved with EV charging infrastructure.

Currently, there are significant differences between charger types, relating primarily to charging speed, power output and cost. EV Chargers in the UK can be separated into three main categories:

- Slow (Level 1): Chargers predominantly used at homes and businesses, providing a slow charging rate for EVs using low power sockets, being typically priced between £250 to £750 (Zapmap, 2019a).
- Fast (Level 2): Chargers predominantly located in car parks, destination sites and some homes which provide a moderate speed of charge for EVs with dedicated sockets, being typically priced around £1,500 to £2000 (Zapmap,2019a).
- Rapid (Level 3/DC Charging): Commercial chargers predominantly located in dedicated charging hubs and/or service stations akin to traditional ICE refuelling stations, providing the fastest consumer-available charging through dedicated high- power sockets (Hall and Lutsey, 2017; Wolbertus and Van den Hoed, 2019; Zapmap, 2019a). Rapid Chargers are often priced at commercial rates, making them financially inaccessible for personal ownership in domestic charging, and often require a significant distribution grid power outlay (Bakker et al, 2014; Van den Hoed, 2019; SASPO;TC).

Table 1: A table illustrating different charger types, power output and time to charge. Information is provided from Hall and Lutsey (2017), Wolbertus and Van den Hoed (2019) and Zapmap (2019a).

	Charger Type		
	Slow (L1)	**Fast (L2)**	**Rapid (L3/DC Charging)**
Power Output	Up to 3kW (AC)	7-22kW (AC)	43kW (AC), 50kW- 350kW (DC)
Time to 90% Charge (on average)	6-12 Hours	2-4 Hours	15-40 Minutes

With public charging stations, there are over 14,000 public charging stations currently installed across the UK (Zapmap, 2019b), with more planned under DfT (2018), BEIS (2017) and local government plans (BCC, 2019a). Level 3 chargers are also growing in number as a growing number of EVs are now compatible with DC chargers, with 2,300 now installed across the UK (Hall and Lutsey, 2017; Zapmap, 2019b). With respect to Bristol, 150 charging stations are installed across the city, with an additional 120 charging stations planned to be installed in the WofE between 2019-2022 under the Go Ultra Low West scheme (BCC, 2018b; Zapmap, 2019b, POTP). At the time of publication, there are ~10 L3 charging points in Bristol, with new rapid charging hubs being developed across the WofE in the Temple Quarter Enterprise Zone, Portishead, Filton and Bath (BCC, 2018b; Travelwest, 2019; Zapmap, 2019b). Charging points in both national and local contexts have so far been developed as a predominantly commercial market venture in the UK, although some schemes such as SourceWest are being developed as private-public partnerships to develop EV charging infrastructure (BCC, 2018b). Due to the growing numbers of EVs in the UK, the DfT (2018) has suggested that an 83% increase in the number of charging stations will be needed over the next 20 years in order to cope with demand; although other literature and stakeholders suggest that the current EV network is sufficient for practical demand and will be absorbed by market response (Morrisey et al, 2016; Wolbertus and Van den Hoed, 2019; POTP).

Beyond public charging provision, the development of private charging in the UK has been supported through a variety of publicly funded subsidy schemes. This includes the Electric Vehicle Homecharge Scheme (EVHS), which provides a £500 subsidy for domestic charger installation, whilst a £500 voucher is available through the Workplace Charge Scheme (WCS) for workplace chargers. Both grants are provided by OLEV and are intended to provide home and workplace security in charging and in turn improve EV uptake, but involve stipulations. EVHS and WCS grants are planned to be only provided for smart-metered charging stations (DfT, 2019) and are only available for residences/workplaces with off-street parking (DfT, 2018). In addition, the On-Street Residential Charging Scheme (ORCS) is available from the DfT as a grant to support local authorities in providing on-street chargers but is under-utilised due to on-street charging and parking complications (DfT, 2018; Future Cities Catapult, 2018). Lastly, these grants combine with the DfT Plug-in Grant, subsidising £5,000 of the cost of a new EV to mitigate for their high price point on the current market (DfT, 2018).

Beyond subsidies, EV infrastructure itself comes with additional technical complexity for infrastructure planning. These include the capital cost of an EV charger, maintenance, electricity usage, installation, planning permission and power supply requirements and user interface design (Madina et al, 2015). Such aspects are important to consider in EV infrastructure as they are challenges that need to be overcome through not only financial and technical solutions, but also through intangible, social-capital driven resolutions to support consumer use (Hall and Lutsey, 2017). Lastly, with EVs being in a relatively early phase of development, future changes in the transport sector could be highly disruptive in the way EVs are used and charged. This includes the impact of CAVs, MaaS schemes and induction charging systems, which could disrupt the profiles of journeys people take with EVs, accessibility to vehicles, and reshape how charging is undertaken respectively (Parkhurst and Seedhouse, 2019).

As a result, the overall state of EV charging infrastructure is considered as such in this work as a motivation towards delivering technically feasible and holistically considerate EV infrastructure in Bristol.

1.1.2. The Bristol One City Plan

If the adoption of EVs is to occur in Bristol, both private and public charging facilities will be required for their usage. This is as well supporting EVs to travel longer distances (DfT, 2018), encouraging consumer uptake (Hall et al, 2017) and provide consumers with security against "Range Anxiety" (Hall and Lutsey, 2017). However, EV charging is a different proposition to the refuelling of an ICV due to the time taken and reduced infrastructure required to charge an EV (Zapmap, 2019a). This means that EV charging stations are often installed in a range of non-conventional sites, such as car parks and in domestic locations (Bonges and Lusk, 2016, TC). As such, implementing such infrastructure requires a wider understanding of the technical background involved with EV charging infrastructure.

Given the potential of EVs to reduce Bristol's transport emissions, other holistic considerations surrounding Bristol's sustainability are also included as a background motivation. In this regard, this work considers the Bristol One City Plan; a visionary document by the City Office defining as a core message that:

"In 2050, Bristol is a fair, healthy and sustainable city. A city of hope and aspiration where everyone can share in its success." - Bristol One City Plan (BCC, 2018a)

Bristol is the largest city in the South West region of the UK, with 1.1 million residents living across the wider WofE region, a combined authority with an economy worth £31 billion (WofE, 2017b). The city is highly polycentric with multiple local centres and has a high net commuter inflow due to Bristol's role as a hub city in the wider West of England region (BCC, 2019b). 33,000 new houses are set to be built in Bristol alone (BCC, 2019a) with demand for 100,000 new houses in the wider WofE being expected in the next 20 years (WofE, 2017b). Such continued growth in Bristol has led to significant uncertainty surrounding Bristol's delivery of wider sustainable development objectives and resilience to external shocks (BCC, 2016;2018a).

There are already significant challenges to Bristol in connectivity, economy and environment. With road traffic, this includes average speeds during rush hour being as slow as 6mph on some city corridors, with a city-wide average of 16mph (BCC, 2018b). BCC (2018b) suggest that road traffic in Bristol would have to decrease by 53% in the next 20 years just to maintain current levels of congestion, due to a forecasted increase in population and road traffic in the city. This adds further pressure in solving Bristol's traffic challenges, as it is already among the worst in the UK Core Cities outside of London and has a direct negative impact upon Bristol's economy and living standards (BCC, 2018b; Cllr, ATP, BIM). Other challenges include a growing financial, social and educational inequality of the city's poorest wards compared to richer wards of the city (BCC, 2011; 2016; 2018a), air pollution registering over double EU recommendations in parts of the city centre, causing 300 early deaths from poor air quality (BCC, 2018a; Cllr), and Bristol's increasingly dated housing stock (Cllr). This is the context in which the Bristol One City Plan has been created, creating a sustainable vision of Bristol in 2050.

Inspired by the UN SDGs and other global One City Plans, the Bristol One City Plan is developed as a visionary document in response to both current and future challenges Bristol faces (BCC, 2018a). In order to deliver this vision, the One City Plan document considers six different themes. These are Environment, Economy, Connectivity, Homes and Communities, Skills and Learning, and Health and Wellbeing. The plan is projected through decade-long intervals (2019-2030, 2031-2040, 2041-2050), with individual years containing specific targets within each theme (BCC, 2018a). As the document itself states, the One City Plan is not an overriding document designed to steer BCC or other stakeholders into set policies or targets, but rather a sustainable vision of Bristol by 2050, considerate of the community, business and citizens of the city. This means that whilst certain targets are vague or intangible, the document is set to undergo wider stakeholder consultation and iteration in subsequent updates (BCC, 2018a).

In this regard, the Bristol One City Plan provides an excellent insight into Bristol's ambitions to achieve sustainable development, directly mentioning targets for EVs in the themes of Environment and Connectivity. For example, by 2027 the plan projects that there will be a "comprehensive charging network for electric vehicles across the city" in the theme of Environment; a vision alluding to a wider set of initiatives to deliver such a goal (BCC, 2018a, TC). The plan suggests that EVs are a component as a part of a multi-modal transport system in Bristol; which includes drone deliveries, Mobility as a Service (MaaS), CAVs (Connected Autonomous Vehicles), mass transit systems and autonomous freight. Other themes, such as Skills and Knowledge, Homes and Communities and Health and Wellbeing also showcase the wider interconnections that arise from the use of low carbon transportation across the city (BCC, 2018a). The themes of the One City Plan thus help frame the discussion of this work, providing a platform upon which to synthesise sustainable development in Bristol with future EV infrastructure development.

As such, the multi-dimensional approach of the One City Plan provides a good reference point for broader considerations to be synthesised in the development of EV infrastructure in Bristol.

1.2. Research aim and objectives

Mindful of the background motivations, this work has a research aim to explore how private EV infrastructure could be localised and developed in Bristol using a holistic evidence-based approach; bridging the gap between wider policies involving EV infrastructure and the wider sustainability concerns of Bristol.

To deliver the research aim, the first research objective will be to review existing barriers to EV infrastructure in Bristol, derived from desk research and stakeholder interviews. This objective is produced in the findings, displaying key barriers for EV infrastructure in direct relation to Bristol and in a wider context.

This is followed by the second research objective; the delivery of a localised best approach, detailing key principles for stakeholders involved in developing EV infrastructure in Bristol. This is synthesised in the discussion with considerations for the Bristol One City Plan themes and is delivered through a series of key principles as policy recommendations.

In order to achieve the research aim and objectives, this work looks to initially review the academic and policy-based research surrounding EV infrastructure as a part of a literature review (Chapter 2). The findings of barriers to EVs and their associated infrastructure are then assessed, inclusive of the insights obtained from seven semi-structured interviews of local transport stakeholders in the city of Bristol (Chapter 4). This work then proceeds to discuss the benefits and costs of EVs and their associated infrastructure in Bristol, using the holistic sustainability themes of the Bristol One City Plan to achieve this (Chapter 5). Lastly, four principles for EV infrastructure are recommended as a part of the best approach that is delivered from the discussion and wider findings (Chapter 6).

2. Literature review

The literature review of this work captures a range of published sources, reviewing areas of strength and deficiency in literary material relating to EVs and associated infrastructure to deliver the research objectives. EVs and their associated infrastructure have been studied by academic fields as diverse as engineering, the social sciences, geography and urban planning, which supplements policy publications by public and private stakeholders.

This assessment of the literature will synthesise the literature by moving from a wider view of theory and consumer practice (2.1), towards case studies of EV infrastructure in practice (2.2), and the wider policy considerations for EV charging (2.3). Finally, the literature surrounding Bristol (2.4) will be reviewed. Due to the EV sector being relatively young and subject to technological change, this work prioritises literature published in the last five years in line with reviews of EV deployment planning (TC, POTP). In a similar manner, technical engineering concerns are included where relevant but are not the focus of this study; as this work aims to investigate more holistic implications of EVs over technical details involved in their operation.

This work considers that while the literature has comprehensively detailed a wide range and depth of knowledge surrounding EV infrastructure, inclusive of stakeholder involvement, the literature has remained predominantly issue dominant. EV infrastructure is rarely synthesised with wider concerns of sustainability at a local scale beyond EVs reducing emissions and improving air quality. This literature review considers that while EV infrastructure is included in city visions such as Bristol's One City Plan, it is rarely synthesised with regards to other socioeconomic and environmental co-benefits. As such, this work seeks to bridge this gap across these fields of literature in providing a holistically considered best approach for EV infrastructure in Bristol.

2.1. Theories of adoption and consumer uptake

Firstly, theories of adoption and analysis of consumer decision-making are reviewed in how consumers to make choices with regards to the purchase and acquisition of EVs that are then used in EV infrastructure networks.

One theory behind EV uptake is Rogers (2010) Diffusions of Innovations theory. Diffusions of Innovations casts light on how new technology spreads through society, using a gaussian- distribution bell curve to illustrate consumer behaviour with the uptake of new technology, such as EVs. Uptake in new technology is likely to hit a critical mass, with change in price, access or other intangible factors fostering a turning point in behaviour, leading to widespread consumer acceptance of an emergent technology (Parkhurst and Seedhouse, 2019). Diffusions of Innovations theory is a useful paradigm to understand wider behaviour surrounding EV technology, observable in Sierzchula et al (2014) where EV chargers were shown to be an explanatory variable in targeting consumer groups in policy implementation.

Another theory also brought into the fore is that of Social Practice Theory (Schatzki, 1996; Hargreaves, 2011). Social Practice Theory is ethnographically driven, suggesting that knowledge from the practice (or use of) of an emergent technology by social actors is distributed other sociological reasons than rational decisions for consumer trends (Spotswood, 2014); such as the driving of EVs being perceived through non-rational choices (Juttner, 2017). As such, social practice theory identifies that there are difficulties in overcoming social barriers to new technologies; with collective and social organisations of practices requiring change beyond financial or rational factors seen in Diffusions of Innovations (Schatzki, 1996). In the example of EVs, this includes the skills and practices associated with charging that would need to be relearnt, adapted or transferred from an ICV (Bunce et al, 2014). Social Practice also includes preconceptions already around EVs that block consumer use due to associated intangible risk; such as public perception or social impacts (Coffman et al, 2017; Parkhurst and Seedhouse, 2019).

A practical example of these theories in use in the EV literature is the finding that a high rollout of charging does not always correspond to a high level of consumer uptake (Hall and Lutsey, 2017b. Instead, public EV charging systems have been used more as a contingency across society (Morrissey et al, 2016; Lorentzen et al 2017) as consumers were more likely to charge at home, a significant problem for on-street charging (Wiederer and Philip, 2010). However, this view is contested by other research studies (Bakker et al, 2014); illustrating localised differences in incentivisation of EV uptake with different charging habits. In this field of theory, attitude-action gaps are also identified by Broadbent et al (2018), Bunce et al (2014) and Sierzchula et al (2014) where individuals who have replied to surveys in the past about EV use have often not been willing to follow this up with real-world action. In particular, the work by Broadbent et al (2018) is highly useful in synthesising wider theory into the real- world data surrounding policy instrumentation and uptake. Similar work is also seen in a much more dedicated context by Parkhurst and Seedhouse (2019), who provide a dedicated analysis into the field of EVs, MaaS and CAVs using both theories of Social Practice and Diffusions of Innovations. These wider papers showcase the relevance in understanding EV uptake through behaviours relating to behaviour, perception and other intangibles.

2.2. Case Studies of EV infrastructure

Moving towards a more targeted study of EVs in case studies, the literature studied also contains a diverse range of examples alongside wider global analyses of EV uptake and infrastructure development. Such literature has taken the form of reports/white papers or has been presented in dedicated journal articles covering case studies.

In the case of reports, a comprehensive and detailed overview of wider EV concerns has been developed by a wide range of policymakers, analysing EV uptake with effectiveness derived from quantitative sources and policy-based research. Analysis into both European and global EV uptake, alongside best practices by the

ICCT (Tietge et al, 2016; Hall et al, 2017; Hall and Lutsey, 2017) are useful to understand both the breadth in policy and quantitative data surrounding EVs. Of note is that the ICCT also recognises a need for direct fiscal and indirect behavioural incentives in order to support EV policies in cities, mirroring social practice theory. Complementing such insight, work by the C40 Cities (Wiederer and Phillip, 2010) provides a similar understanding with emphasis upon non-tangible benefits in urban areas but is less relevant due to the dated nature of the document and technological shifts since publication. Both sources provide no specific context of policy application and are more widely focussed. The latter issue is given a narrower city scope in work by The Nordic Eight (2012) and Nordregio (2017), which focusses upon urban sustainability in Scandinavian cities. This work also includes the incorporation of EVs and sustainable transport in cities such as Oslo and Torshavn respectively, representing a more direct case study of best practice by a report. The diffuse range and depth in examples provided by all the listed reports present a detailed showcase of quantitative literature surrounding EVs and their associated infrastructure in case studies.

Beyond this, journal-based case studies provide greater ethnographic detail involving local stakeholders and challenges. This includes Morrisey et al (2016), Bakker et al (2014) and Lorentzen et al (2017) reviewing examples of charging patterns in the Republic of Ireland, the Netherlands and Norway respectively, and with Frade et al (2011) and Rolim et al (2014) examining EV charging in Lisbon with user experiences of EV trials. Wolbertus and Van den Hoed (2019) provide further analysis of EV roll-out in the Netherlands, where corridor networks and more localised involvement of stakeholders is also analysed. This wide range of examples allows for a greater focus of details surrounding of EV to be made with respect to different spatial locations, albeit with such detail limiting the scope of the research towards singular contextual issues in EV uptake and infrastructure. When linked to a global focus by Broadbent et al (2018), a wider range of understanding behind EV usage and uptake across multiple case studies can be observed for best practice and development of EV networks.

Beyond a localised focus on case studies, other academic research has focussed on other aspects surrounding EV infrastructure. This includes theories of location for EV infrastructure in Greece (Efthymiou et al, 2017), traffic modelling for EVs (Scholte et al, 2012), evaluations of national EVs strategies (Madina et al, 2015), alongside wider research into EV environmental aspects (Hawkins et al, 2013; Bonges and Lusk, 2016). Once again, the listed articles are more focussed upon singular issues pertaining to either engineering, urban planning or policy design, rather than a holistic understanding of EV uptake and infrastructure. Nonetheless, such work is useful consider as a part of the wider literature involved in EVs.

2.3. Wider policy concerns

Another area of literature covered by the literature review is that of the wider policy concerns affecting EVs, particularly in the UK context. These include wider policy concerns from the UK's National Grid, alongside surrounding wider transport low-carbon transport policy from the UK government.

This review has identified the National Grid's Future Energy Scenarios (FES) paper as a highly useful document (National Grid, 2019) in relation to EVs and the GB electricity grid. The document highlights that with the increased use of electricity across the UK from EVs, there would be a profound impact upon the evening peak of electricity usage, influenced by impacts such as charger type, vehicle usage, parking facilities and consumer uptake of smart metering (National Grid, 2019). The FES also suggests routes for V2G, local generation storage and clean generation pathways that involve the use of EVs as part of a wider decentralised energy grid across the UK, a bottom-up shift towards that makes inclusivity and accessibility as key priorities for EV infrastructure in line with the DfT (2019) and Ofgem (2017). Whilst such a document has no direct influence in the way that EV technology progresses due to the National Grid not being a direct stakeholder in EVs, the insight provided from this document is useful in synthesising wider energy concerns for stakeholders involved in EVs. Supplementary research papers build upon this in case studies, such as in Sweden (Steen et al, 2012) and Ireland (Foley et al, 2013), where EVs are forecast to increasingly encroach upon peak usage of power use in the respective examples. However, this is contested by Richardson (2013) who instead suggests renewables will be more supported by EV charging techniques. These wider papers are useful to understand the implications of EVs upon the energy network from a technical perspective, but unlike the FES document, have a further niche of technical detail that is less relevant for this work.

At a national policy-level, reports concerning EVs have also been developed. This includes work by BEIS (2017), the DfT (2018) and the Future Cities Catapult (2018). EVs are illustrated in these works as a part of a UK-wide vision to reduce emissions and improve air quality, as well as devising methods to improve their accessibility. Such reports detail the provision for funding at local levels, the inclusion of best practices and case studies to improve access and uptake of EVs from other urban examples, as well as technological constraints involved in EV usage respectively. Such centralised documents are effective in displaying an overall direction in policy and best practice; yet provide a degree of ambiguity that is intentionally left for delivery at the local level (UK Parliament, 2019), a theme explored in the last section of this literature review.

2.4. Bristol and transport

Lastly, this section of the literature review focusses upon Bristol delivering policy surrounding EVs; the spatial area in which this work is primarily focussed. The Bristol theme of literature is divided into BCC reports and partnership/third party literature.

The literature in this field is inclusive of the reports developed so far by Bristol City Council (BCC), including the Bristol Local Plan (2011; 2019b), Bristol Resilience Strategy (2016) the Bristol One City Plan (2018a), the Bristol Transport Plan (2018b) and Bristol Climate Emergency (2019a). All of these illustrate the progress that has been made by the city to develop the city's sustainability into the future, with considerations taken across a wide range of sectors, partnerships and public actors. In particular, plans such as the One City Plan highlight an insight into delivering a holistic vision for Bristol until 2050, considerate of wider socio-economic and environmental developments across Bristol; whilst the Bristol Transport Plan and Local Plan provide mechanisms for EV infrastructure delivery that connect such a city-wide vision together through schemes such as Go Ultra Low West.

Whilst documents such as the Local Plan (BCC, 2019b) clearly outline EV targets, they are not developed with holistic considerations as well as they have been in other literature, such as case studies or policy reports (Hall et al, 2017; Broadbent et al, 2018).

These reports also connect to local partnership actors, such as the Joint Local Transport Plan (Travelwest, 2019), the Joint Transport Study (WofE, 2017a), Joint Spatial Plan (WofE, 2017b) and other work by Sustrans (2016), Prestwood et al (2017) and Barnes et al (2015). Cumulatively, these technical reports look at both the vision and the delivery of future technologies in Bristol to become a more sustainable city, including EV infrastructure and vehicle use. These reports present a holistic and strong emphasis on delivering a sustainable future in Bristol that involves multiple stakeholders and partner organisations across the West of England region, and the wider issues of connectivity across the WofE region. Such work also includes awareness of the "Rebound" effect and local limitations of Bristol, making awareness that private vehicles altogether need to be reduced the local scale (Travelwest, 2019). However, improving EV uptake is not given a dedicated focus in these planning documents, with these documents targeting wider concerns surrounding transportation rather than the socio-economic impacts of EV charging. Alongside the highly useful BCC reports, EV infrastructure at the local level is shown to be given some level of consideration, yet is not integrated into other holistic considerations in the city.

2.5. Summary

With a review of the wider literature, this work has considered a wide range of insights ranging from the fields of engineering, social science and urban planning insights, and inclusive of policy at the national and local level surrounding EV infrastructure. The literature review provides this work with a stand-off point to bridge the gap between reports published by national, local and other affiliated actors and academic research in delivering best approach for EV infrastructure that is both holistically considerate of wider sustainability concerns and is localised to Bristol.

3. Methods

In order to achieve the objectives and build upon the literature review, this work uses qualitative research methods. This includes the use of desk research analysis and semi- structured stakeholder interviews.

Desk research has been conducted to better understand the policy and academic background surrounding EV infrastructure systems in cities. This includes the study of reports published from national-level departments and local-scale publications, alongside academic journals and associated literature. Literature was then collated through the process of cross-tabulation with notes made on areas of overlap, then being used in order to produce the findings alongside supporting the discussion and recommendations of this work. By bringing together this research and localising the context to Bristol, the research was synthesised and used in order to generate new knowledge; that of a localised best approach with key principles and holistic recommendations and that did not exist in the wider literature.

In addition, a series of semi-structured interviews were undertaken between June and July 2019 with seven informants. The informants were interviewed as they represent a wide range of both private and public stakeholders involved in transport and sustainability across the city of Bristol. Semi-structured interviews were chosen as the method of research in order to best understand informant insights; with their semi-structured nature allowing for the conversation to progress beyond pre-prepared interview prompts. These prompts included questions surrounding the current implementation, potential developments and barriers of EV infrastructure in Bristol, tailored to each informant. Due to the ethical and wider implications of this work on the city of Bristol, the informants have been anonymised and are identified only by their job titles. This insight has been subsequently synthesised alongside the desk research of this work, in order to better localise the best approach recommended for Bristol from stakeholder knowledge.

4. Findings

This work finds that following the review of the literature and the inclusion of stakeholder insights, four main barriers exist in Bristol to the continued rollout of EV infrastructure and are areas the best approach will need to resolve. These are identified as Capital Cost, Range Anxiety and Behaviour, Power Supply, and On-Street Parking. Other case studies are also examined where appropriate, highlighting existing areas of best practice and potential scope to overcome the identified barrier. Owing to the diffuse nature of such barriers, there are significant overlaps associated with the challenges surrounding EVs.

4.1. Capital cost

The initial capital cost of an EV is identified in these findings as the most significant barrier to EV uptake both nationally and globally (Hall et al, 2017, POTP, TPSM, BIM). As of the time of this publication, EVs often cost several thousand pounds more than their ICV counterparts in the UK; even with a Plug-In Grant (Hall and Lutsey, 2017a). This is in part down due to the high price point of the high energy density batteries EVs utilise, as well as poor economies of scale associated with a currently small market-share holding production vehicle (UK Parliament,2019).

Furthermore, the initial capital cost is intertwined with the public perception of EVs that current battery range is not enough to replace an ICV in day to day use, additionally making EVs less financially viable (Bunce et al, 2014). Ownership as a result across multiple national contexts has seen consumers using EVs as a second car in order to avoid the perceived risk associated with “Range Anxiety”. This means that an EV is isolated to a small margin of individuals in society, further slowing EV uptake. This behaviour is in part explained by Diffusions of Innovations theory, wherein many early adopters of EVs are predominantly made up of innovators from other fields who are willing to accept the differences of an EV (Broadbent et al, 2018). Such innovators are on average wealthier, and often select EVs upon primarily environmental reasons over typically financially intuitive reasons, and thus mitigate for risk by also owning an ICV (Bunce et al, 2014). As a result, most consumers across national contexts have thus been unwilling to purchase EVs, unless there is significant subsidy for EVs and punitive measures against traditional ICVs as seen in Norway (Lorentzen et al,2017).

This collectively means that the continued development of EV infrastructure is economically difficult to justify without a paradigm shift in cost, remaining a barrier not just in Bristol but on a global scale. Moreover, overcoming the capital cost barrier is not possible at the local level due to limited funding to expand upon national grants (DfT, 2018, Cllr, TC). As such, the barrier of capital cost will need to be targeted by national-level policy and wider industry changes in battery price, rather than by cities (Cllr, ATP, TC). Nevertheless, overcoming other barriers in EV use would improve the economies of scale in EVs through further uptake, and thus would further mitigate for the barrier of capital cost within cities such as Bristol (Broadbent et al, 2018).

4.2. Behaviour and "Range Anxiety"

Another barrier to EV use and infrastructure is that of consumer behaviours and associated concerns of "Range Anxiety". The literature and informants suggest that consumers are unlikely to change to EVs from ICVs without strong non-tangible incentives for their ownership and use.

This barrier includes user concerns such as access to charging stations on longer journeys, the range from EVs, learning how to charge an EV, alongside different types of route planning that are associated with the use of an EV and concerns around charging times (ATP). Even if these concerns are not empirically tangible, this has led to many prospective owners perceiving EVs negatively due to the disruption EVs present to the practice of driving with few intangible benefits to compensate (Hargreaves, 2011; Bunce et al, 2014; Coffman et al, 2017; ATP; TC). This perception of "Range Anxiety" encourages more passive behaviour towards charging of an EV in order to avoid running out of charge and therefore disincentivises EV uptake, even for typical journeys still within the tolerances of an EV charge range (Bunce et al, 2014; Spotswood, 2014). As such, this finding suggests that consumers are less likely to uptake EVs in their current state, due to the disruptive behaviour associated with EVs.

In the Bristol context, behaviour is a barrier that unlike capital cost could be much more effectively targeted. This barrier will require strong mechanisms to not only disincentivise ICVs themselves but provide stronger intangible incentives towards using EVs and normalise the behaviour surrounding their use that would attract more consumers toward using an EV (Coffman et al, 2017; DfT, 2018, TPSM, TC, SASPO). This is as current EV experiences present disruptive, rather than socially acceptable changes for prospective EV owners (Bonges and Lusk, 2016; Juttner, 2017; TPSM). For example, Bristol has five different types of charging networks, each requiring a unique subscription and/or mobile application to utilise (Zapmap, 2019b, TC). Such schemes complicate access for EV consumers, further disincentivising the advocacy of their usage compared to the ICV refuelling network (Bunce et al, 2014). As such, developing EV infrastructure in Bristol will need to overcome such behavioural and accessibility challenges through non-financial incentives.

In response to such a barrier, examples of best practice in delivering non-financial incentives have been demonstrated in other cities. This includes schemes such as free HOV lane usage for EVs in Oslo, marketing campaigns by California, or highly visible public charging schemes such as in Amsterdam and Copenhagen (The Nordic Eight, 2012; Hall and Lutsey, 2017). These incentives primarily serve toward improving the public perception surrounding EVs through intangible, non-quantified benefits. Additionally, case studies in Lisbon show prospective users who have trialled an EV have found it to be easy to adapt towards; though this could be considered problematic given the prospective users already being innovators and being prone to action-attitude gaps (Rolim, 2014; Broadbent et al, 2018). Crucially, local EV incentives will need to be handled in such a way that is holistically considerate of Bristol's wider challenges. For example, allowing EVs to occupy HOV lanes when a policy shift is being encouraged away from private vehicles would be unsuitable in the long term (BCC, 2018b).

4.3. Power supply

Another barrier to EV infrastructure in Bristol is that of technical concern surrounding power supply. Such a barrier is not immediate to Bristol, yet in the long term could make EV charging more difficult to develop in the city. This is primarily in EV uptake having wider issues with the GB electricity grid, and localised problems with distribution networks.

The electricity requirements of a growing number of EVs will have a significant impact on the electricity grid as consumer uptake increases (Ofgem, 2017). The GB energy mix is transitioning towards low carbon generation technologies, particularly with strong growth in renewables and nuclear in the South West (National Grid, 2019). While a greener grid is a net positive for further supporting EVs to reduce their carbon footprint and support renewables themselves (Richardson, 2013), this means a greater strain will occur at times of peak load on the electricity network from more unpredictable forms of power generation (Foley et al, 2013). For example, during the evening peak for power supplies EVs are typically placed immediately on charge following the return of commuters and domestic evening uptake patterns (Morrisey et al, 2016). Whilst the impacts of this are uncertain given the National Grid (2019) are planning for such a scenario, in the long term this could have an impact upon EVs being able to reduce GHG emissions (Buekers et al, 2014).

Furthermore, Bristol's local power distribution networks will also be placed under strain, with sectors of local power cabling and substations being insufficient for the forecasted supply required to accommodate EV charging stations (SASPO, TC, POTP). Other UK cities such as London have already begun to experience challenges in retrofitting higher power cables and substations due to prohibitive logistical and economic costs, impacting upon the installation of EV chargers (TC). In a similar vein, large infrastructure hubs are faced with upgrading substations and power supplies, an additional financial burden that may also disincentivise further public charging at their sites (National Grid, 2019; SASPO). Such changes mean that future adoption of EVs will be significantly restricted by logistical means; not only creating a short-term barrier but a long-term concern for the use of EVs with public infrastructure (Steen et al, 2012).

In Bristol, the barrier of power supply is diffuse and technically complex to overcome. While future housing projects are being built with passive and active supply stemming from higher-capacity power lines, inclusive of smart metering, such considerations are more difficult to implement for retrofitting in existing streets (Efthymiou et al, 2017; TC, POTP). Possible policy solutions to the barrier of power supply will need to be considerate of changing EV charging profiles both through behavioural and technological means, being proactive rather than reactive in delivering sufficient power supply for a wider EV charging network (Ofgem, 2017; BCC, 2018b; 2019b; POTP).

4.4. On-street parking

Lastly, this work has found that the high concentration on-street parking in Bristol is a locally significant barrier to the rollout of EVs and associated infrastructure. This is a problem not unique to Bristol but is a key issue the city has faced in continuing the roll-out of EV charging and the associated uptake of EVs linked to their use.

Bristol uses an RPS (Residential Parking Scheme) across many of its central wards, including Clifton, Hotwells and Cotham; where there are high concentrations of on-street parking (BCC, 2011). The RPS restricts parking in core areas to residential use, with limited availability of paid on-street parking in the CPZ (Controlled Parking Zone). Such schemes strongly disincentivise visitor parking in Bristol; with the intention of further discouraging car use and congestion in central Bristol (BCC, 2018b; TPSM). However, such a scheme restricts EV usage in on-street parking sectors of Bristol due to issues surrounding parking and planning permission. The open nature of the RPS's on-street parking means that private vehicles are not fixed to a parking bay; a key pre-requisite for home charging (Hall and Lutsey, 2017a; TC). As such, a Bristolian on-street EV home charging site with a dedicated bay would compromise the number of available bays for parking, creating localised issues surrounding communal acceptance of an EV.

Furthermore, current on-street installations of EV home chargers in Bristol face challenges surrounding planning permission (TC). This includes approval by neighbours, considerations of charging station and leads with respect to cyclists and pedestrians, the impact upon power supply and conflicts between public and private access for on-street charging sites (TPSM). Even the ORCS subsidy from the DfT has not been enough to offset existing challenges that on-street charging faces, as from a policy perspective the financial and planning costs make on-street EV charging unfeasible to implement (Future Cities Catapult, 2018; TPSM). As a result, Bristol has been reluctant to install on-street charging points across the city which disincentivises EV uptake (Future Cities Catapult, 2018;POTP).

These collective problems in on-street charging in Bristol means that the rollout of EV charging has been spatially unequal across Bristol. At their current phase of deployment, EVs are commonly charged at home by consumers (Morrissey et al, 2016; Lorentzen et al, 2017). This trend means that access to dedicated L2 home charging stations is thus exclusive for those who have off-street parking in Bristol if on-street chargers are unsupported in the city (ATP). This leverages an additional cost for on-street parking EV users to either use slow L1 3-pin-type domestic charging with cables trailing from their homes, or expensive public L2/L3 EV charging points, thus removing the convenience, accessibility and financial benefits of EV charging respectively for on-street EV users (DfT, 2018; Future Cities Catapult, 2018; TC, TPSM). Whilst Bristol has moved towards schemes of easily accessible L3 rapid charging being rolled out across the city (BCC, 2018b), such policy in the short term cannot overcome existing barriers of accessibility to charging and spatial exclusion that disincentivises potential uptake of EVs by on-street users.

In response to such a barrier, Bristol could look at EV charging in cities which also have high concentrations of on-street parking. On-street EV charging schemes in Amsterdam, Oslo, Torshavn and Lisbon have had some success with community consideration for such schemes, considering that for the short-term, dedicated parking spaces for EV charging is a compromise worth implementing to encourage consumer uptake (Frade et al, 2011; The Nordic Eight, 2012; Bakker et al, 2014). In Oxford the use of lamp-post based charging points and pavement-based cable routing has been able to overcome problems with additional clutter from street furniture and minimised the impact on pedestrians and other road users respectively (DfT, 2018; Cllr). Whilst these may still drive the price of on-street charging facilities higher owing to additional planning concerns, such schemes illustrate it is technically possible to implement on-street charging to support willing EV consumers in on- street charging and deliver policy that is considerate of the wider community.

4.5. Summary

Such findings summarise a diverse and wide range of barriers that EVs and their associated infrastructure face in Bristol. The findings show that whilst some barriers such as capital cost or power supply are harder to tackle at a local level, being able to tackle barriers associated with consumer behaviour and issues associated with on-street parking are barriers that can be effectively targeted at the local level.

5. Discussion

Following from the findings related to barriers to EV infrastructure development in Bristol and delivery of the first research objective, this section seeks to discuss these findings in the light of Bristol's wider sustainability initiatives. This is in order to support the delivery of the second research objective, that of delivering a holistic best approach for EV infrastructure. In order to better frame this discussion, EVs and their associated infrastructure are discussed for their merits and costs through each theme of the Bristol One City Plan, in order to resolve a policy design for the best approach. In this discussion, EV infrastructure is illustrated to positively impact City Plan's themes of Environment, Health and Wellbeing, and Skills and Learning, overcoming multiple barriers and supporting the city's sustainability goals.

However, EV infrastructure will have a lesser impact upon on Homes and Communities, Connectivity, and Economy themes.

Unlike the One City Plan, this work's discussion frames the themes of Skills and Learning more towards the ideas of the knowledge economy, which has significant overlaps with the theme of Connectivity; whilst the theme of Connectivity itself is also used to cover wider themes surrounding transport in the Bristol region.

5.1. Environment

With regards to the theme of environment, EVs and associated EV infrastructure are expected to generate immediate short-term and long-term positives for the environment of Bristol and support a shift towards a low carbon city. EVs will support emissions reductions and air quality improvement schemes in sectors previously poorly targeted; with the delivery of policy in this theme needing to overcome barriers to EV take up most prominently in behaviour.

EVs are expected to reduce carbon emissions between 60%- 66% compared to an ICV, reducing (DfT, 2018), improving to 90% with further decarbonisation across the National Grid (2018). The wider impacts of immediately reducing CO2 emissions from a sector such as transport, in line with Bristol's climate emergency and wider literature can avoid further warming from climate change that will have both local and global implications. Whilst Bristol's efforts towards a zero-carbon city by 2030 may have a small global impact, the initiative taken towards EVs by Bristol alongside other global cities can make a disproportionate local difference in changing societal perceptions towards low carbon technologies owing to wider social practice theory (Rogers, 2010; Hargreaves,2011).

Examples of this emergent are visible in other case studies of rapidly growing EV uptake in Norway and the Netherlands, stemming from city efforts in Oslo and in the Randstad respectively (Bakker et al 2014; Lorentzen et al, 2017). Bristol's drive to reduce carbon can lead towards the risks associated with anthropogenic climate change being mitigated if the 2030 target is adhered to and supported through the uptake of EVs and other low carbon transport to reduce emissions. Whilst problems remain with wider Scope 2 emissions from the production of electricity for an EV (Buekers et al, 2014), limited particulate emissions stemming from road contact dust (BCC, 2018a), and wider life cycle/Scope 3 impacts on environment and health from battery production (Hawkins et al, 2013; Buekers et al, 2014, EVs and their infrastructure in Bristol are likely both in the short and long term to progressively improve the theme of Environment.

Owing to Bristol's pledge to become net carbon neutral by 2030, radical steps in policy in encouraging EV uptake will be needed to support the Environment theme in Bristol. This will mean that recommendations will need to factor in overcoming other existing barriers in behaviour that allows for drastic reductions in emissions from private transport and the uptake of EVs.

5.2. Economy

With regards to Economy, Bristol's adoption of EVs and associated infrastructure will have a mixed spectrum of effects. While benefits would arise from greater spending on infrastructure and industry integration of EVs into their fleets, problems would arise from EV charger spatial exclusion and issues surrounding fossil fuel taxes. The best approach would thus need to consider the business case for EVs and chargers themselves as a part of policy, combatting the wider barrier of capital cost identified in the findings and wider literature base.

EV infrastructure presents a new opportunity for both private and public actors to capitalise upon a new type of infrastructure and develop revenue streams from a market set to grow significantly in the coming decades (BIM). Development of EV infrastructure can help Bristol to stimulate jobs associated with the installation and maintenance of EV charging sites; a practice that may support EVs to become financially viable in the long term, akin to ICV fuelling stations (SASPO; POTP). As such, businesses and transport hubs are increasingly aware of the significance of using charging points on their sites and have been engaged by both local and national authorities to embrace EV use in their fleets to decrease their operational costs (BCC, 2018b; DfT, 2018; BIM; SASPO; POTP). Nonetheless, EV infrastructure also presents a series of problems to the theme of Economy, through costs such as the business case for EV chargers and road tax funding. EV charging in Bristol is currently concentrated towards the centre of Bristol and periphery routes, targeting areas of existing EV uptake and where there is a business case for EV chargers. In future uptake of EVs, this would mean that some communities would be spatially excluded from continuing developments in EV infrastructure if the market business case is driven only for existing demographic EV take up owing to the high cost of EVs themselves (Coffman et al, 2017; Cllr). This would thus reinforce, rather than overcome the barriers of on-street parking and capital cost. Additionally, EVs could have a significant impact upon the theme of Economy through the reduction in tax levies raised from typical ICV fuel taxes that EVs are currently exempt from (DfT, 2018). Stakeholders raised concerns that without a change in legislation, there will be a significant deficit for national and local government funding in road maintenance and Bristol's ambitious transport plans (ATP, TC, BIM). This would create uncertainty surrounding the price point of EV charging and continued government involvement in EV charging (TC, ATP, BIM). Whilst this is not one of the key barriers identified in the findings of this work, this is a challenge that combines with the barrier of capital cost in the wider theme of Economy to the long-term sustainability of EV infrastructure delivery schemes (Madina et al, 2015).

In connecting this theme towards recommendations, this work considers policy design will need to remain mindful that while the market is a useful tool to roll out EV charging and should be supported in the Bristol economy, this should not be at the cost of other themes and barriers (ATP). Policy should thus incentivise holistic developments that support local communities in Bristol to be truly sustainable.

5.3. Connectivity

With respect to the theme of connectivity, EVs and their associated infrastructure will also have a mixed impact, despite EVs being targeted directly by this theme of the One City Plan. While EVs will deliver a low carbon replacement for ICVs as a predominant transport mode, they will not improve connectivity in the city, spawning a negative "Rebound" effect. As such, this theme suggests that EVs will only be part of a solution towards a low carbon transport future in Bristol, with policy recommendations supporting a multi-modal shift away from private transport.

EVs and the associated rollout of infrastructure into Bristol's future will help shift private transport towards low carbon sources, a fundamental component in this theme in the One City Plan. With other disruptive transport changes forecast in this theme, including UAVs for deliveries, shared transport schemes such as MaaS and CAVs used in freight and transportation respectively, EVs will be an additional component in the future of Bristol's efficient and low carbon transport network (Scholte et al, 2012; Prestwood et al, 2017; WofE, 2017a). However, EVs are not viable as a method of improving connectivity alone, due to the "Rebound" paradox. This paradox highlights that the replacement of existing private ICVs with EVs would only undermine shifting private vehicle users towards public or active transportation, given that social practice of private vehicle usage in a city environment would not change. This would worsen connectivity in Bristol, as the city is forecast to experience an increase in commuter traffic (Sustrans, 2016; BCC, 2018b, TPSM, ATP, SASPO). As suggested by other stakeholders, the vision that Bristol has in delivering a more connected city is more dependent on other key focuses such as MaaS, public transport use and better internet access than EV infrastructure itself (WofE, 2017a; BCC, 2018b; ATP; Cllr). Recommendations from this theme should consider such a paradox, and how to both appease the uptake of EVs whilst simultaneously encouraging shifts toward active and public transport networks across the city. Whilst EVs may not improve connectivity across Bristol, EVs and their associated infrastructure will be a significant component in delivering low carbon transport in this theme with private transport remaining a predominant mode of travel (BCC, 2018b).

5.4. Homes and communities

In the theme of Home and Communities EVs and their infrastructure are also likely to have a mixed spectrum of implications. While EVs will support local communal transport in car- sharing schemes and local community power grids, the spatial exclusion associated on- street parking is likely to be a significant challenge. This theme influences policy to consider EV charging as a social good, inclusive of a long-term shift in society towards EVs.

In benefits, EV infrastructure is likely to improve the range of community transport choices individuals have and be involved as a part of MaaS in line with BCC (2018b) transport plans. This is as EV infrastructure can provide communities with an ability to locally recharge EVs in car-club schemes in a way that is not currently possible with ICVs, making shared vehicles much more accessible for shorter periods of time in a MaaS scheme (Travelwest, 2019; ATP). Furthermore, the advent of V2G and smart grids rolled out across homes in Bristol means that EVs will increasingly be more applicable in their use as a part of domestic energy systems, helping homes to become more self-sufficient in energy needs with forecast increases in energy efficiency and local renewables (Ofgem, 2017; Cllr). However, the barrier of spatial exclusion associated with on-street parking and Bristol's inequality in this theme, linked to challenges in the Economy theme would be reflected in the trends of EV charging. Communities in Bristol may find they are divided between ICVs owned by poorer citizens and left worse off by city shifts in policy, whilst those who can afford EVs are able to benefit (UK Parliament, 2019). As such, regressive policy in this vein may stifle uptake of EVs across Bristol's already poorer communities due to multidimensional factors associated with charging, widening inequality and in turn harming Bristol's work towards becoming a fairer city (Prestwood et al, 2017;TC).

With regards to EV policy, this theme suggests that EV infrastructure should not be a spatially exclusive means towards low carbon transport, but a social good that works for the wider community, mirroring BCC's other policy commitments (BCC, 2018a). As such, any policy design would need to consider innovators and adopters in the short term in communal benefits, yet consider wider uptake for communities that may be less suitable or able to adopt EV charging infrastructure in the long term.

5.5. Health and wellbeing

In Health and Wellbeing, EVs and their infrastructure will have a predominantly positive impact. Whilst EVs in this theme could disincentivise active transport and encounter barriers in on-street parking, the overwhelming improvement to air quality yielded from a shift away from ICVs is a benefit to Bristol's populace.

EVs will positively impact upon Health and Wellbeing, related towards the removal of NO2/SO2 and particulate emissions throughout the city centre and beyond throughout transport corridors (Barnes et al, 2015; Travelwest, 2017). The 300 premature deaths caused yearly by poor air quality can be reduced in

Bristol through ICV replacement by EVs, as well as improving the quality of life for asthma and other lung-related disease sufferers (Buekers et al, 2014; Sustrans, 2016; BCC, 2018b). In turn, this would co-facilitate the feedback loop of greater active transport uptake in less polluted streets that would reduce congestion and improve wellbeing across Bristol (Sustrans, 2016). The benefit upon health would also yield benefits to local healthcare services, reducing the costs spent on illnesses related to air pollution (BIM, TC, ATP). Whilst road dust from brakes and tyres would still be prevalent, this is likely to remain negligible compared to the overall reduction in other ICV related emissions (DfT, 2019). However, the outright replacement of ICVs with EVs could discourage the uptake of active transportation methods, if policy design is not considerate of supporting a shift away from private vehicles. Given that EVs will not solve the problem of congestion, active transport methods should remain a priority over EVs as they are able to improve a wider range of benefits at the community scale (WofE, 2017a). Additionally, EV chargers in of themselves may cause obstruction to cyclists and pedestrians, thus indirectly contributing to active transport being a less attractive option in the city (TC). Whilst such a problem is minor at current levels, in the long term this would become a larger issue with greater EV uptake.

As such, policy linked to this theme support that whilst EVs should be encouraged using EV infrastructure development by the city to improve air quality, this should not be at the cost of active transport. Recommendations in this vein would thus need to consider the impact of accessibility for active transport, whilst supporting an EV charging network to improve Bristol's wider standards of air quality.

5.6. Skills and learning

EVs and associated infrastructure will have a long-term positive impact on Skills and Learning. Whilst EVs have less impact upon this theme in the short term, Bristol's existing position in developing inductive charging and charging hubs can support a long-term positive feedback loop of receiving government support for R&D in EV technology. As such, the knowledge economy of Bristol can support EVs at the local scale to overcome barriers such as on-street parking, financial cost and power supply.

The positive impact of EVs upon this theme has been showcased in Bristol's participation through schemes such as the EU REPLICATE project or SourceWest, supporting EV rentals and L3 charging hubs across Bristol respectively (BCC, 2018b). Such schemes, alongside local businesses and transport groups being involved in EV charging showcase that Bristol is willing to be involved in more experimental schemes in order to obtain first-mover advantage in emergent transport technologies (Prestwood et al, 2017; BIM, ATP, TC). Dividends in this have been shown in the deployment of the 48A hybrid bus using inductive charging at the UWE Frenchay Campus in Filton, the rollout of diverse EV charging at Bristol Airport, or research by VENTURER at the University of Bristol (Travelwest, 2019; ATP, SASPO).

Continued experimental EV infrastructure rollout such as this would support Bristol's research institutions in a positive feedback loop from the benefits gained in local EV research and development, bringing co-produced tangible and intangible benefits to society and economy (Prestwood et al, 2017; Future Cities Catapult, 2018; Parkhurst and Seedhouse, 2019). However, the theme of Skills and Learning is unlikely to be impacted by EVs in the short term, as R&D surrounding EV infrastructure would not provide short term solutions but more long term and experimental developments that would more likely supplement already proven technologies in EVs (Tietge et al, 2016). Technology advances under EV infrastructure would still require diffusion throughout society and the wider knowledge economy, being more difficult to quantify with the exact return upon society and economy such technology would have (Rogers, 2010). EVs in this theme will thus have few short-term benefits in supporting Bristol's vision of sustainability, beyond experimental schemes and trials developed by the city's research universities and firms.

As a result, policy recommendations stemming from the discussion in this theme should remain inclusive of such advances in the knowledge economy of Bristol. Such policy would be mindful of futureproofing Bristol's EV charging network due to the positive knock-on effects on other themes, such as Connectivity and Economy.

5.7. Summary

This discussion summarises that EVs and their associated infrastructure will impact the Bristol One City Plan themes unequally. EVs and their infrastructure will support Bristol in improving the themes of Environment and Health and Wellbeing, as well as in the long-term in the theme of Skills and Learning. However, EVs have a more mixed impact upon the themes of Economy, Homes and Communities and Connectivity. The latter is surprising, given that there are more explicit objectives within the Bristol One City Plan towards EVs themselves in Connectivity. These themes used in this discussion thus provide a policy direction for a series of key principles which form the best approach. As such, this discussion is used to bridge the gap between wider issues surrounding sustainability and EV infrastructure work in delivering a holistically considerate EV infrastructure network as a part of the second research objective.

6. Recommendations / the best approach

Considerate of the wider findings and discussion of EV infrastructure with respect to the Bristol One City Plan, the best approach for EV Infrastructure is delivered here in line with the research aim and second objective. This is divided into four key principles, which provide an avenue for policy recommendations in future EV infrastructure planning. Many components of the principles and sub-recommendations overlap, illustrating further the co- benefits of pursuing two or more of these principles when developing EV infrastructure for Bristol. Whilst these principles synthesise best with specific themes of the One City Plan covered in the discussion, they are designed in mind as broadly supportive of all themes and in either limited or full application by a stakeholder. These recommendations are intended for use by not only BCC and wider Bristol research into EV infrastructure, but wider stakeholders involved in EV charging across Bristol.

6.1. Bristol City Council (BCC) as an enabler

This principle recommends that BCC should act as a keystone stakeholder, enabling, leading and promoting EV infrastructure through clear policy mechanisms (Hall et al, 2017; SASPO; TC; ATP; BIM; TPSM). With existing support for EVs by BCC being exemplified through Go Ultra Low West and SourceWest, BCC should build upon these initiatives to develop the social acceptance of EVs across Bristol in order to reduce transport emissions. Crucially, such a principle would need to be delivered with recommendations that understand long-term policy influence in creating stable conditions for businesses and private users alike to adopt EVs, including their feedback into such insights (BIM). This includes recommendations such as increased EV fleet uptake by BCC, improved planning documents for EV chargers, and increased consumer advocacy by BCC. This principle synthesises with the themes of Environment, Economy and Homes and Communities in particular.

This includes Bristol City Council acting as a leader in EV vehicles themselves, developing its own EV fleet more ambitiously than the One City Plan currently suggests in order to meet its 2030 net-zero GHG ambitions (BCC, 2018a). Shifting towards EVs and associated chargers in BCC operations itself would allow the Council to provide large-scale local experience of fleet EV use as a practical technology, as well as a publicly acceptable option that other local organisations, stakeholders and private users already have or are looking to incorporate into their own practices (Rogers, 2010; Spotswood, 2014; DfT, 2018; SASPO; TC; BIM). Simultaneously, this would help BCC reduce its own emissions total, supporting a push towards carbon neutrality as an organisation (BCC, 2018b). Whilst coming at a greater financial cost in transitioning away from ICVs at a faster rate with vehicle change and EV charger installation, the council's leadership would have a disproportionate social influence on other actors in Bristol to shift towards EVs and their associated infrastructure, helping to deliver a low carbon transport future.

Another policy recommendation for this principle is that of altering traditional planning legislation surrounding charging stations to improve uptake of EV charger installation (Hall and Lutsey, 2017; SASPO). This could take the form of a supplementary planning document containing best practice in developing an EV charging site, giving an effective mechanism to deliver both council-led and market-based charging points (TC). Such a document would need to be designed with stakeholder engagement in mind, and provide a proactive, rather than reactive planning approach to EV infrastructure for both private and public charging sites that increase EV uptake rather than disincentivises action (BIM, ATP, TC).

Lastly, the position of Bristol City Council's role as a lead stakeholder would be able to provide greater consumer advocacy for EVs through marketing and local champions of EVs (BIM, TPSM). Such a recommendation builds upon successful public outreach schemes such as Bristol Green Capital 2015, EU REPLICATE and Go Ultra Low West offering EV trials. Employing such a recommendation may allow the council to overcome the barrier of intangible behaviours, normalising a different technology such as EVs into the mainstream of consumer activity as a desirable choice through education and advocacy(TPSM).

6.2. An inclusive and accessible system

Echoing the sentiment of BCC's municipal energy and waste companies, Bristol should aim to be "in it for good"; delivering an EV charging system that is designed considerate of society (BCC, 2018a). This principle recommends that Bristol's EV infrastructure should be accessible to a wide range of stakeholders, should not impede other transport types, and be standardized in payment and charging methods to improve accessibility to EVs. This principle broadly synthesises with all One City Plan themes recommendations from the discussion.

For this principle, this work recommends EV infrastructure should be variegated and spatially available to all where possible through a range of both novel and established options. In the short term, barriers to EV charging to on-street charging would be resolved through the experimental rollout of L1/L2 EV chargers in lampposts and street furniture (DfT, 2018). This would be delivered through existing local schemes such as SourceWest with funding from the DfT ORCS, in order to provide EV charging coverage to spatially excluded areas (DfT, 2018). This would be delivered with the understanding that lamppost chargers would be limited in scale to mitigate for impact on parking availability across the Bristol RPS/CPZ zones, being targeted in such a way to alleviate spatial "black spots" of EV charging access (TC). Whilst on-street charging would be costly to install, such a scheme could help overcome Bristol's barrier of on-street parking in at least the emergent phase of EV uptake for home charging (Frade et al, 2011; DfT, 2018). In the long term, EV charging would be directed towards the continued rollout of public L2 hubs in car parks and other "destination" sites, alongside public L3 rapid charging hubs across key transport corridors and local centres in the city (POTP). Such schemes would build upon existing Go Ultra Low West policy and follow wider examples from the Netherlands and Denmark in delivering rapid- charging EV charging systems (Hall and Lutsey, 2017; Wolbertus and Van den Hoed, 2019). The long-term part of this strategy would thus promote the use of EVs in a similar style to ICVs, widening consumer participation and reducing the scale of disruption in an EV charging profile. While changing public charging patterns to become more akin to that of an ICV may prove unpopular to early adopters/innovators who may have expected EV charging to be readily available at home, such a recommendation would compromise between the barriers of Bristol's EV charging network and the future tipping point for EV uptake.

Furthermore, this principle recommends that street furniture associated with charging facilities be minimised or mitigated in order to avoid creating a further obstruction to pedestrians and cyclists alike. Wider design considerations surrounding trailing cables, using schemes alike the type employed in Oxford or local solutions could support to chargers to become non-obtrusive (DfT, 2018). Such guidance could be included in a supplementary planning document (6.1) that streamlines the planning of EV chargers to follow best practice. Such a move may further increase installation costs at existing public on-street chargers as a result of design cost, but would be an inclusive move supporting cyclists and pedestrians in Bristol whilst delivering EV charging across Bristol.

Lastly, this principle supports making EV charging more inclusive and accessible to more consumers through easier use and payment. Such initiatives have been mandated by the DfT (2018; 2019), but this will need to be enacted on a local scale through key stakeholders involved in EV charging in a proactive manner. This includes recommendations including the universal use of contactless or RF tag payment at all charging stations across all EV charging networks akin to Holland (Hall and Lutsey, 2017; Wolbertus and Van den Hoed, 2019), standardized charging station interfaces, the provision of clear instructions on how to charge an EV (Bakker et al, 2014), smart telemetry for charging points, as well as optimising chargers so that multiple vehicles could charge at once from one station (Bonges and Lusk, 2016). Such retrofitting, or inclusion in new design would come at a greater financial cost to both users and network suppliers. However, in the long-term, such a recommendation would facilitate consumer inclusivity into a public EV charging network and provide returns for suppliers in an open market environment akin to that of the standardisation of the existing fuel station network for ICVs (Broadbent et al, 2018).

6.3. Supporting multi-modal shifts

In a similar vein to other Bristol City Council and WofE reports, this study recommends that EV infrastructure supports multi-modal shifts for transport across Bristol, moving away from private vehicles and towards either active or public transport in the inner city. This principle would particularly synthesise with the recommendations made in the themes of Connectivity, Economy, and Health and Wellbeing.

One recommendation to support this principle would be the rollout of free EV parking and charging at key transport interchanges in Bristol, such as park and ride sites, bus termini or Bristol Airport. Coupled with free one-way public transport use, this could further draw down the use of private vehicles in the city centre (ATP; Cllr; TPSM). The implementation of free L1/L2 EV chargers would also overlap with the passive provision in electricity supply for other charging technologies used for electric buses, cycles, and other electrified mass transit options Bristol is currently considering (POTP). Fostering such overlaps would effectively capitalise upon the shift towards EVs, providing a positive incentive for individuals to travel into the Bristol via bus, train or other mass transit and in turn decreasing congestion from private vehicles (ATP). This would come with other co-benefits, such as reducing road wear, improving the economy and local quality of life for citizens and alleviating issues surrounding parking akin to Torshavn (The Nordic Eight, 2012). By making alternative transport choices more attractive, whilst simultaneously disincentivising the use of private transport in the city centre, EVs can be further supported whilst being kept away from Bristol's congestion black spots.

Funding and further policy mechanisms for such an approach of free parking and charging could be developed from a Congestion Charge, or a CAZ (Clean Air Zone) levy on ICVs in the short to medium term in Bristol city centre (Barnes et al, 2015; WofE, 2017a; Travelwest, 2019). Keeping non-EV traffic out by using these schemes would immediately improve connectivity through reducing congestion, improving air quality and reducing emissions in the city centre, but would not be a sustainable long-term policy to pursue if the uptake of EVs rapidly increases (ATP). Whilst EVs would still be prioritised over the use of ICVs across Bristol, their usage would be into the long term would need to be reduced in order to avoid the "Rebound" effect. To combat the "Rebound" effect, a more novel approach is suggested in the long term. By implementing a Road User Charge (Parkhurst and Seedhouse, 2019; ATP) on all private vehicles across the road network of Bristol, including EVs, a shift towards multi-modal transport can be incentivised through the disincentivising of private vehicle usage. This recommendation and the wider principle are strongly disruptive, but the implementation of multi-modal shifts accomplished by integrated EV charging would support Bristol's wider economy and communities, improving connectivity through reducing city- centre congestion in a manner seen in European cities such as Copenhagen (BCC, 2018b; Cllr; TPSM; TC). Such a disruptive shift will require significant improvement to public transport reliability, the rollout of mass transit and user awareness of the direction of such policy (Travelwest, 2019), but would support multiple themes of the One City Plan whilst encouraging EV uptake.

6.4. An adaptable and futureproof system

Lastly, this work suggests the principle that Bristol's EV infrastructure should be adaptable and futureproof, considerate of local intellectual capital. Such a consideration is less tangible to see in short-term returns compared to the other three principles of this best approach but would allow for Bristol to capitalise on research into EV infrastructure at the local level (Prestwood et al, 2017). This would include schemes such as smart metering to support the electricity grid and consumers, passive power planning and supporting local organisations to continue engagement with EV research. Such a principle particularly synthesises with the wider discussion recommendations in the themes of Economy, Homes and Community and Skills and Learning.

One recommendation under this principle would include the rollout of smart metering on all private and public EV charging points in Bristol to support the local distribution grid, a scheme currently under consultation by the government (DfT, 2019). Smart Metering would play a crucial role in future initiatives such as potential V2G and TOUT tariffs if implemented for EV chargers (National Grid, 2019). Preparing EV charging points early, even at an enhanced cost would thus be beneficial for the wider electricity grid and could provide consumers with a direct economic incentive to charge at non-peak times of day (Morrisey et al, 2016), making use of central government subsidies to support such a transition. Whilst some consumers may perceive the changing prices associated with fluctuating electricity costs as a disincentive for EV charging systems, the use of smart metering can futureproof EV charger uptake across Bristol inclusive of local renewable systems, whilst providing clear benefits to consumers who would use EVs as a part of a potential V2G system (National Grid, 2019).

Furthermore, this principle recommends that passive power provision for EV should also be considered across Bristol, in order to maintain futureproofing in EV charging installations.

The provision of passive systems across Bristol in new builds are positive steps (BCC, 2019b) yet would leave behind wards with older housing where EVs are increasing in uptake (POTP). Continued analysis into demands on the local electricity distribution network and construction disruption across the Bristol region by Go Ultra Low West will be thus required in advance of a potential tipping point in EVs, in order to target power supply upgrades through cost-benefit analysis (National Grid, 2019; SASPO; POTP). Additionally, allowing for passive EV capacity could support future emergent EV charging technologies, such as inductive charging and CAVs to be more viable if such technology becomes financially and technically feasible (ATP). Technologies such as these would have strongly disruptive benefits across society, economy and the energy system that would require pre-requisite planning to deliver (Parkhouse and Seedhouse, 2019). As such, futureproofing, whilst costly would provide EVs with a platform that is prepared for a future “tipping point” in EVs and reduce the long-term financial and logistical costs of future retrofitting.

Lastly, this principle recommends wider partnerships with Bristol’s research institutions to further research EV charging and CAVs. By developing Bristol’s homegrown intellectual capital with respect to EVs through dedicated support schemes, this would provide long-term knowledge and economic benefits to EVs in Bristol in a similar manner to how Bristol Robotics Lab or Engine Shed have provided in the technology and business sectors respectively (BEIS, 2017; BCC, 2018a; 2019b). A positive feedback loop for central government funding and support would also occur with such forward planning, similar to the manner in how schemes such as UWE’s 48A bus, EU REPLICATE and Go Ultra Low West have been successfully deployed in Bristol as emergent EV experiments (ATP; TC; TPSM; POTP). As such, supporting such schemes with a public partnership where applicable would support EV infrastructure developments at a local scale and support the development of a low carbon economy.

7. Conclusion

In conclusion, this work has been able to deliver the best approach for the development of EV infrastructure in Bristol, considerate of the One City Plan ambitions for Bristol to become “healthy, sustainable and fair” by 2050. This is alongside considerations of the Bristol Climate Emergency, with EVs being crucial in the rapid delivery of a low carbon transportation network in Bristol by 2030, and as such reflecting upon the implementation of infrastructure. Barriers to EV infrastructure have been identified in the findings as a part of the first research objective, and have been discussed with respect to the wider impacts of EVs and their infrastructure upon the Bristol One City Plan. This has allowed for the delivery of a series of holistic principles in EV infrastructure development, considerate of the wider concerns surrounding sustainability in Bristol and delivering the second research objective. As such, this work has delivered upon the wider aim of this work, by synthesising wider literature and insight in order to localise and develop EV infrastructure in Bristol using a holistic evidence-based approach.

7.1. Limitations

In limitations, there is an acknowledgement that due to this work pursuing more holistic key principles, it has not been possible to apply a quantitative lens to this work examining each in greater extended detail through GIS or statistical analysis. This work’s intentional breadth has meant that certain technical issues related to EVs are not fully covered here in comprehensive detail. In addition, more examples of case studies are likely to exist throughout the EV literature following the publication of this work, such as advancements in EV technology that may supersede the contemporary recommendations of this work. Lastly, given the more focussed and collaborative nature of this work, the recommendations made for Bristol may not be relevant in other cities or countries, as has been identified throughout the findings and discussion of this work; owing to financial, cultural, logistical or other local constraints.

7.2. Future work

As a project designed in collaboration with Bristol City Council and Bristol City Office, this work has been designed with the intent of being used in underpinning future changes to the Bristol One City Plan. This document is designed to provide a platform for iteration in the real-world development of EV infrastructure by BCC, pragmatic of existing and planned policy. Future work by BCC or others could use the principles made here as part of criteria locations for EV stations using GIS or statistical methods, (Efthymiou et al, 2017); allowing for the council and other actors to spatially document the best locations for EV infrastructure. Furthermore, further quantitative research into EVs and could further build upon the technical and social aspects of this work, reviewing the connections between EV charging and consumer opinions on a local scale.

References

- Bakker, S., Maat, K. and van Wee, B., 2014. Stakeholders interests, expectations, and strategies regarding the development and implementation of electric vehicles: The case of the Netherlands. Transportation Research Part A: Policy and Practice, 66, pp.52-64

- Barnes, J. Crawshaw, S., Parkhurst, G. , Toy, J. , Robinson, B. , Ricci, M. , Bartle, C. , Melia, S. , Carmichael, L. and Davis, A., 2015. The Bristol method: How to reduce traffic and its impacts. Documentation. Bristol European Green Capital, Bristol. Available from: http://eprints.uwe.ac.uk/27751[Accessed 28/8/19]

- Bonges III, H.A. and Lusk, A.C., 2016. Addressing electric vehicle (EV) sales and range anxiety through parking layout, policy and regulation. Transportation Research Part A: Policy and Practice, 83, pp.63-73.

- Bristol City Council, 2011. Bristol Local Plan 2011. Available at: https://www.bristol.gov.uk/documents/20182/34540/Core%20Strategy%20WEB%20PDF%20(low%20res%20with%20links)_0.pdf/f350d129-d39c-4d48-9451-1f84713a0ed8[Accessed 28/8/19]

- Bristol City Council, 2016. Bristol Resilience Strategy [Online] Available at: http://www.100resilientcities.org/wp-content/uploads/2017/07/Bristol_Strategy_PDF.compressed.pdf[Accessed 29/5/19]

- Bristol City Council, 2018a. Bristol One City Plan. Available at: https://www.bristolonecity.com/one-city-plan/[Accessed 28/8/19]

- Bristol City Council, 2018b. Bristol Transport Strategy. Available at: https://bristol.citizenspace.com/growth-regeneration/bristol-transport-strategy/user_uploads/bd10559---bristol-transport-strategy-2018_webv3-2.pdf[Accessed 28/8/19]

- Bristol City Council, 2019a. Climate Emergency-The Mayor's Response Available at: https://democracy.bristol.gov.uk/documents/s34127/Climate%20Emergency%20-%20The%20Mayors%20Response.pdf[Accessed 28/8/19]

- Bristol City Council, 2019b. Bristol Local Plan 2019. Draft Proposals and Development Allocations. Available at: https://www.bristol.gov.uk/documents/20182/34536/Local+Plan+Review+-+Draft+Policies+and+Development+Allocations+-+Web.pdf/2077eef6-c9ae-3582-e921-b5d846762645[Accessed 28/8/19]

- Broadbent, G.H., Drozdzewski, D. and Metternicht, G., 2018. Electric vehicle adoption: An analysis of best practice and pitfalls for policy making from experiences of Europe and the US. Geography Compass, 12(2), p.e12358.

- Buekers, J., Van Holderbeke, M., Bierkens, J. and Panis, L.I., 2014. Health and environmental benefits related to electric vehicle introduction in EU countries. Transportation Research Part D: Transport and Environment, 33, pp.26-38.

- Bunce, L., Harris, M. and Burgess, M., 2014. Charge up then charge out? Drivers' perceptions and experiences of electric vehicles in the UK. Transportation Research Part A: Policy and Practice, 59, pp.278-287.

- Coffman, M., Bernstein, P. and Wee, S., 2017. Electric vehicles revisited: a review of factors that affect adoption. Transport Reviews, 37(1), pp.79-93.

- Department for Business and Industrial Strategy (BEIS), 2017. Clean Growth Strategy. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/700496/clean-growth-strategy-correction-april-2018.pdf[Accessed 28/8/19]

- Department for Transport (DfT), 2018. The Road to Zero. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/739460/road-to-zero.pdf[Accessed 28/8/19]

- Department for Transport (DfT), 2019. Electric Vehicle Smart Charging Consultation. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/817107/electric-vehicle-smart-charging.pdf[Accessed 28/8/19]

- Efthymiou, D., Chrysostomou, K., Morfoulaki, M. and Aifantopoulou, G., 2017. Electric vehicles charging infrastructure location: a genetic algorithm approach. European Transport Research Review, 9(2), p.27.

- Foley, A., Tyther, B., Calnan, P. and Gallachóir, B.Ó., 2013. Impacts of electric vehicle charging under electricity market operations. Applied Energy, 101, pp.93-102.

- Frade, I., Ribeiro, A., Gonçalves, G. and Antunes, A.P., 2011. Optimal location of charging stations for electric vehicles in a neighborhood in Lisbon, Portugal. Transportation Research Record, 2252(1), pp.91-98.

- Future Cities Catapult, 2018. Electric Vehicles: Towards an Excellent User Experience. Available at: https://futurecities.catapult.org.uk/wp-content/uploads/2019/01/Electric_Vehicles-Report1.pdf[Accessed 28/8/19]

- Hall, D, Cui, H, Lutsey, N., 2017. Electric vehicle capitals of the world: What markets are leading the transition to electric? The International Council on Clean Transportation (ICCT): Washington, DC, USA. Available at: https://theicct.org/sites/default/files/publications/World-EV-capitals_ICCT-Briefing_08112017_vF.pdf[Accessed 28/8/19]

- Hall, D, Lutsey, N., 2017. Emerging best practices for electric vehicle charging infrastructure. The International Council on Clean Transportation (ICCT): Washington, DC, USA. Available at: https://theicct.org/sites/default/files/publications/EV-charging-best-practices_ICCT-white-paper_04102017_vF.pdf[Accessed 28/8/19]

- Hargreaves, T., 2011. Practice-ing behaviour change: Applying social practice theory to pro-environmental behaviour change. Journal of consumer culture, 11(1), pp.79-99.

- Hawkins, T.R., Singh, B., Majeau-Bettez, G. and Strømman, A.H., 2013. Comparative environmental life cycle assessment of conventional and electric vehicles. Journal of Industrial Ecology, 17(1), pp.53-64.

- Jüttner, W.R.C., 2017. An Introduction of Social Practice Theory in Environmental Policy- The Social Practice of Driving in The Netherlands. Bachelor thesis. University of Utrecht, Netherlands.

- Lorentzen, E., Haugneland, P., Bu, C. and Hauge, E., 2017, October. Charging infrastructure experiences in Norway-the worlds most advanced EV market. In EVS30 Symposium. Stuttgart, Germany, EN.

- Madina, C., Barlag, H., Coppola, G., Gomez, I., Rodriguez, R. and Zabala, E., 2015. Economic assessment of strategies to deploy publicly accessible charging infrastructure. World Electric Vehicle Journal, 7(4), pp.659-669.

- Morrissey, P., Weldon, P. and O'Mahony, M., 2016. Future standard and fast charging infrastructure planning: An analysis of electric vehicle charging behaviour. Energy Policy, 89, pp.257-270.

- National Grid, 2019. Future Energy Scenarios. Available at: http://fes.nationalgrid.com/media/1363/fes-interactive-version-final.pdf [Accessed 29/5/19]

- Nordregio, 2017. White Paper on Nordic Sustainable Cities. Available at: http://norden.diva-portal.org/smash/get/diva2:1292429/FULLTEXT03.pdf[Accessed 6/9/19]

- Ofgem, 2017. Upgrading our Energy System [Online] Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/633442/upgrading-our-energy-system-july-2017.pdf[Accessed 29/5/19]

- Parkhurst, G. and Seedhouse, A. (2019) Will the 'smart mobility' revolution matter? In: Docherty, I. and Shaw, J., eds. (2019) Transport Matters. Bristol: Policy Press

- Prestwood, E., Calvert, T., Clayton, W., Longhurst, J., Manchester, H., Parkhurst, G., Rosenberg, G., Taylor, C. and Townsend, I., 2017. Barriers to a better Bristol: Diagnosing city strategic sustainability challenges using systems, co-production and interdisciplinary approaches. WIT Transactions on Ecology and the Environment, 226, pp.285-296.

- Richardson, D.B., 2013. Electric vehicles and the electric grid: A review of modeling approaches, Impacts, and renewable energy integration. Renewable and Sustainable Energy Reviews, 19, pp.247-254.

- Rogers, E.M., 2010. Diffusion of innovations. Simon and Schuster.

- Rolim, C.C., Baptista, P.C., Farias, T.L. and Rodrigues, Ó., 2014. Electric vehicle adopters in Lisbon: motivation, utilization patterns and environmental impacts. European Journal of Transport and Infrastructure Research, 14(3), pp. 229-243.

- Schatzki, T. 1996. Social Practices: A Wittgensteinian Approach to Human Activity and the Social. Cambridge: Cambridge University Press

- Schlote, A, Crisostomi, E., Kirkland, S. and Shorten, R., 2012. Traffic modelling framework for electric vehicles. International Journal of Control, 85(7), pp.880-897.

- Spotswood, F, 2014. Using social practice theory to frame the contribution of social marketing in the multidisciplinary future of 'behaviour change'. In: ISM-Open One Day Social Marketing Conference: Broadening the Scope, Open University, Milton Keynes, UK, 29 September 2014. Available from: http://eprints.uwe.ac.uk/24615[Accessed 29/5/19]

- Steen, D, Carlson, O. and Bertling, L., 2012. Assessment of electric vehicle charging scenarios based on demographical data. IEEE Transactions on Smart Grid, 3(3), pp.1457- 1468.

- Sustrans, 2016. A Good Transport Plan for Bristol. Available at: https://bristolgreencapital.org/wp-content/uploads/2016/01/A-Good-Transport-Plan-for-Bristol-2016-PDF.pdf [Accessed 28/8/19]

- The Nordic Eight, 2012. Nordic Solutions for Sustainable Cities. Available at: https://www.oneplanetnetwork.org/sites/default/files/nordic_solutions_for_sustainable_cities.pdf [Accessed 6/9/19]

- Tietge, U, Mock, P, Lutsey, P, Campestrini, A. 2016. Comparison of Leading Electric Vehicle Policy and Demployment in Europe. The International Council on Clean Transportation (ICCT): Washington, DC, USA. Available at: https://theicct.org/sites/default/files/publications/ICCT_EVpolicies-Europe-201605.pdf[Accessed 29/5/19]

- Travelwest, 2019. Joint Local Transport Plan 4 (JLTP4). Available at: https://s3-eu-west-1.amazonaws.com/travelwest/wp-content/uploads/2015/05/Full-Draft-JLTP4.pdf[Accessed 29/5/19]

- UK Parliament, 2019. Electric vehicles and infrastructure. Available at: https://researchbriefings.parliament.uk/ResearchBriefing/Summary/CBP-7480
- West of England Combined Authority (WofE), 2017a. Joint Transport Study. Available at: https://www.jointplanningwofe.org.uk/gf2.ti/-/757442/31727173.1/PDF/-/JTS_Final_Report.pdf[Accessed 28/8/19]
- West of England Combined Authority (WofE), 2017b. Joint Spatial Plan. Available at: https://www.bristol.ac.uk/media-library/sites/estates/documents/West_of_England_Joint_Spatial_Plan Publication_Document_2017%20(5).pdf[Accessed 28/8/19]
- Wiederer, A. and Philip, R., 2010. Policy options for electric vehicle charging infrastructure in C40 cities.
- Wolbertus, R. and Van den Hoed, R., 2019. Electric Vehicle Fast Charging Needs in Cities and along Corridors. World Electric Vehicle Journal, 10(2), p.45.
- Zapmap, 2019a. Connector Speeds. Available at: https://www.zap-map.com/charge-points/connectors-speeds/[Accessed 28/8/19]
- Zapmap, 2019b. Statistics. Available at: https://www.zap-map.com/statistics/[Accessed 28/8/19]

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Appendix

Appendix A. Acknowledgements

I kindly acknowledge the support of James Snelgrove and David Ader at Bristol City Council/City Office, alongside that of Dr Sean Fox and Dr Sue Rodway-Dyer, who assisted in this dissertation work being developed as a partnership.

I am also very grateful to my anonymised informants, who were able to help support the insights provided in this work, and took their time out of their schedules to be interviewed. Their insight has been crucial to deliver the findings of this work and better understand the real-world application of EV infrastructure in public and private sectors.

Appendix B. Proposed project scope/TOR with Bristol City Council/City Office

Considerations for future electric transport systems in Bristol

Background and Aim

Electric Vehicles (EVs) will play a key role in Bristol's target for achieving carbon neutrality by 2030, particularly through private electric vehicles.

This is as a significant reduction in transport emissions (currently responsible for 25% of Bristol's total carbon emissions) will be required for the city to meet the 2030 target.

As such, suitable domestic and public electric charging infrastructure will be required for city residents and visitors to readily adopt EVs.

This project, in collaboration with Bristol City Council and Bristol One City Plan, looks to explore **how private electric vehicle infrastructure could be localised and developed in Bristol using a holistic, evidence based best practice approach.**

Research Question

What are the key aspects of a best approach in the development of EV infrastructure in Bristol?

Objectives

- Review existing barriers to EV infrastructure in Bristol.
- Develop a localized best approach devolved from the evidence base for potential EV infrastructure, considerate of Bristol One City Plan elements such as:
  - Environment (such as emissions reduction)
  - Transport and Connectivity (such as traffic flow & links to infrastructure)
  - Economy (such as economic return, areas of demand & who pays for EV infrastructure)
  - Health and Wellbeing (such as improving air quality)
  - Homes and Communities (such as inclusive access)
  - Learning and Skills (such as potential EV R&D in Bristol)

By developing all three objectives, this would create a best approach that future work, such as site suitability and/or GIS analysis for EV infrastructure could utilise.

Methodology

This project is expected to be undertaken with a majority of desk research. Interviews will be undertaken to understand the nuances of EV infrastructure, from sectors including energy, transport, academia among others on implementing an urban EV charging network in Bristol.

Methods of Analysis

1) Collate evidence of best practice and research from desk analysis using cross-tabulation
2) Undertake interviews, factoring in expert and stakeholder views on EV infrastructure development
3) Holistically integrate and localise a potential framework for Bristol

Appendix C. Consent form used in semi-structured interviews (blank)

University of BRISTOL

Consent Form for Interview

Project Title: Considerations for future electric transport systems in Bristol

Project Description:

This project, in collaboration with Bristol City Council and Bristol One City Plan, looks to explore how private electric vehicle (EV) infrastructure could be localised and developed in Bristol using a holistic, evidence based best practice approach. This project identifies that many considerations are required to develop a best approach for implementing EV infrastructure, such as inclusive access, links to other core infrastructure and traffic and transport flows.

Please initial the boxes below to confirm that you agree with each statement:	***Please Initial bo:***
I confirm that I understand the purpose of the interview.	☐
I understand that my participation is voluntary and that I am free to withdraw at any time. In addition, should I not wish to answer any particular question or questions, I am free to decline.	☐
I agree that although I will remain anonymised in any publication of the research findings, my role/position (e.g. Transport Academic/Planning Officer) may be used alongside any extracts of the interview. If necessary, my position can be further anonymised if I would be identified as a result.	☐
I would like to view a summary of the research findings once completed.	☐
I agree to take part in this interview.	☐

Name of Participant: Date: Signature:

Appendix D. Dissertation Partnership Scheme- project proposal

10. City Office/BCC (A – Electric transport)

Project Title: Considerations for future electric transport systems in Bristol

Background: The City Office is supporting the development and production of the Bristol One City Plan (www.bristolonecity.com). This plan outlines future ambitions for Bristol and highlights some key challenges. It also includes a sequenced timeline of targets from 2019 to 2050 which covers 6 core themes. There is an opportunity for MSc students from UoB to support the development of the One City Plan and to influence the delivery against this timeline through providing research which is aligned with the key targets listed in future years. Bristol is committed to developing its public infrastructure for electric vehicles to support the transition to a low carbon transport network and to meet with increasing demands, both from consumers and as public and private fleets. Key to the provision of this infrastructure is to develop a best practice and evidence-led approach to how and where this infrastructure should be developed, taking into account elements such as inclusive access, areas of demand, physical space and requirements, links to other core infrastructure, traffic/transport flowsetc.

Question: What are the key aspects of a best approach in the development of electrical vehicle infrastructure in Bristol? Please also consider the positive/negative impacts across areas of Environment, Transport and Connectivity, Economy, Health and Wellbeing, Homes and Communities, Learning and Skills.

Objective: This research can support Bristol City Council and other partners to understand best practice and key recommendations when considering how best to approach this topic. This means that this research can ensure that local leaders and policy makers are better informed on relevant best practices and local influencing factors, and therefore have an impact/influence on local activities and policies.

Methodology:

- Potentially: desk research, interviews, survey, review of internal documents, etc. For discussion

Appendix E. Ethics form

SCHOOL OF GEOGRAPHICAL SCIENCES

RESEARCH ETHICS MONITORING FORM, 2019

B: POSTGRADUATE STUDENTS

Research involving human subjects by all academic and related Staff and Students in the School of Geographical Sciences is subject to the standards set out in the Code of Practice on Research Ethics.

It is a requirement that prior to the commencement of all funded and non-funded research that this form be completed and submitted to the School's Research Ethics Committee (REC). The REC will be responsible for issuing certification that the research meets acceptable ethical standards and will, if necessary, require changes to the research methodology or reporting strategy.

A copy of the research proposal which details methods and reporting strategies must be attached. *Submissions without a copy of the research proposal will not be considered*.

The REC seeks to establish from the form that researchers have (i) thought purposefully about potential ethical issues raised by their proposed research; and (ii) identified appropriate responses to those issues.

Name: ……Konrad Wysocki… email: kw15343@my.bristol.ac.uk

Title of research project:

Considerations for future electric transport systems in Bristol

Source of funding (if any) None

				External/lay scrutiny required?
		YES	NO	Action
1.	Does your research involve living human subjects?	tick		If NO, go to Q.3, 11, 12, & '*Declaration'*
2.	Does your research involve ONLY the analysis of large, secondary and anonymised datasets?		tick	If YES, go to Q.3, 11, 12, & '*Declaration'*
3.	Do others hold copyright or other rights over the information you will use, or will they do so over information you collect?		tick	If YES please provide further details below
4.	Will you give your informants a written and/or verbal summary of your research and its uses?	tick		If NO, please provide further details below.
5.	Does your research involve covert surveillance (for example, participant observation)?		tick	If YES, please provide further details.
6.	Will your informants *automatically* be anonymised in your research?	tick		If NO, please provide further details below.
7.	Will you explicitly give *all* your informants the right to remain anonymous?	tick		If NO, please provide further details below.
8.	Will monitoring devices be used openly and only with the permission of informants?	tick		If NO, why not? – give details below.
9.	Have you considered the implications of your research intervention on informants?	tick		Please provide details below.
10.	Will data/information be encrypted/secured, and stored separately	tick		If NO, why not?

	from identification material to maintain confidentiality??			
11.	Will your informants be provided with a summary of your research findings?	tick		If NO, please provide further details.
12.	Will there be restrictions on your research being available through the university data archive (e.g. by the sponsoring authorities or from participants)?		tick	Please provide details below
13.	What other potential ethical issues arising from this research have you identified?			Please state below how they will be taken into consideration.

Further details: *please start paragraph(s) with the question-number to which they refer*.

Q6 – Anonymity will be in place for the interviews. I will however include a tick-box to state their role in the consent (i.e. academic, policy advisor) but not names of individuals/companies to avoid potential identification. A consent form will be used in order to provide full disclosure of this system, in order to avoid identification of the informant's provision of information.

Q9 – This project is being undertaken in conjunction with Bristol City Council, who may use this research going forward to investigate electric vehicle infrastructure in Bristol. Ethically, this means research implications may be used to steer electric vehicle policy on a city scale, and as such means this project should remain objective and unbiased, considering informant views fairly and anonymously.

Q11 – If requested by the informant on the consent form.

Continuation sheet YES/ NO (delete as applicable)

Declaration

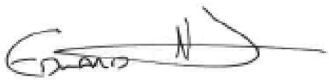
I have read the School's Code of Practice on Research Ethics and believe that my research complies fully with its precepts.

I will not deviate from the methodology or reporting strategy without further permission from the School's Research Ethics Committee.

Student

Signed. k.wysocki. Date 21/5/19

Supervisor



Signed Date 04/06/2019

Progress:

(please leave blank)

A	**Submission complete**	07/06/ 2019				
B	**Clarification requested**	11/06				
C	**Approval granted**	13/06				

MSc in Environmental Policy and Management Dissertation Synopsis 2018/19

Name:	**Konrad Wysocki**
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Staff member(s) consulted about this proposal:

Sue-Rodway Dyer, Ed Atkins

Proposed title:

Considerations for future electric transport systems in Bristol

Short summary of the topic (200-250 words):

Electric Vehicles (EVs) are increasingly being adopted across the globe, due to international efforts directed at reducing emissions from combustion engine-based transportation systems.

As such, EVs will play a key role in Bristol's target for achieving carbon neutrality by 2030, especially with regards to the ownership of private electric vehicles.

This is as a significant reduction in transport emissions (currently responsible for 25% of Bristol's total carbon emissions, the largest current contributor to emissions) will be required for the city to meet this target.

As such, suitable domestic and public electric charging infrastructure will be required for city residents and visitors to readily adopt EVs.

However, many technical, technological and societal implications arise from the use of EVs that are not yet well understood in the Bristol context. The holistic nature of these challenges means a best approach to develop EV infrastructure should remain considerate of such issues, some of which are well framed in the Bristol One City Plan. Other issues, such as who pays for infrastructure, inclusive access, areas of demand, physical space and requirements, links to other core infrastructure and traffic and transport flows are also of note.

This project, in collaboration with Bristol City Council and Bristol One City Plan, looks to explore **how private electric vehicle infrastructure could be localised and developed in Bristol using a holistic, evidence based best practice approach.**

Key research questions (100-300 words):

Research Question

What are the key aspects of a best approach in the development of EV infrastructure in Bristol?

Objectives

- Review existing strategy in EV infrastructure in Bristol.
- Identify existing areas/examples of best practice for EV infrastructure in other urban areas/cities

- Develop a localized best practice/best approach from the evidence base to adopt into future EV infrastructure for Bristol, holistically considerate of Bristol One City Plan elements, exploring potential sub-factors such as:
  - Environment
    - Reducing emissions
    - Physical space/adapter requirements for charging stations
  - Transport and Connectivity
    - Traffic/transport flows
    - Links to other core infrastructure (Park and Ride, Metrobus, Rail)
  - Economy (Financial)
    - Financial considerations/ "Who Pays"/costs of grants
    - Areas of demand
  - Health and Wellbeing (Human)
    - Improving air quality in Bristol
    - Inclusion/links to other active (Walk/Cycle) transportation methods
  - Homes and Communities (Social)
    - Inclusive access
    - Improving domestic uptake of EV charging infrastructure
  - Learning and Skills (Intellectual)
    - Developing local intellectual capital related to local EV technology
    - Inclusion of future unknowns in technology

Conceptual / theoretical context (100-300 words):

Bristol seeks to reduce its carbon emissions impact and reach the 2030 goal of achieving carbon neutrality in the city. As such electric transport will play a significant role in reducing transport emissions across all scopes.

As such, Bristol is committed to developing its domestic and public infrastructure for electric vehicles to support the transition to a low carbon transport network and to meet with increasing transport demands (Bristol One City Plan).

Similarly, the Travelwest JLT4 plan looks to integrate electric vehicles into this context, whilst other existing EVs are being brought to market, at a level that is increasingly attractive to private vehicle owners.

Key to the provision of such infrastructure in Bristol is to develop a best practice and evidence-led approach. This has been developed in other work, such as reviewing grid impacts (National Grid, 2019), modelling placement of charging stations (Efthymiou et al, 2017) or societal perceptions to EVs (Egbue et al, 2012). By having holistic considerations of multiple factors, such as the Bristol One City Plan tenets and other background issues EV infrastructure development can be developed in the manner that is best suited to the needs of the city.

Proposed methodology and sources (100-300 words):

Methodology

This dissertation is expected to be undertaken with a majority of desk research being used to direct this project. This would include the use of reports published by cities and EV charging companies, best practice documents, and other academic works. Interviews will be undertaken to understand nuances of localisation of infrastructure, from sectors including Bristol City Council, energy, transport hubs/companies and academic insight on implementing an urban EV charging network in Bristol.

Methods of Analysis

1) Collate evidence of best practice and EV infrastructure research from desk analysis using cross-tabulation
2) Undertake interviews with industry and academic sources
3) Holistically integrate and localise best practice for Bristol, considerate of the Bristol One City Plan and other considerations

Indicative secondary reading:

Naor, M., Bernardes, E.S., Druehl, C.T. and Shiftan, Y., 2015. Overcoming barriers to adoption of environmentally-friendly innovations through design and strategy: learning from the failure of an electric vehicle infrastructure firm. *International Journal of Operations & Production Management*, *35*(1), pp.26-59.

Morrissey, P., Weldon, P. and O'Mahony, M., 2016. Future standard and fast charging infrastructure planning: An analysis of electric vehicle charging behaviour. *Energy Policy*, *89*, pp.257-270.

Efthymiou, D., Chrysostomou, K., Morfoulaki, M. and Aifantopoulou, G., 2017. Electric vehicles charging infrastructure location: a genetic algorithm approach. *European Transport Research Review*, *9*(2), p.27.

Egbue, O. and Long, S., 2012. Barriers to widespread adoption of electric vehicles: An analysis of consumer attitudes and perceptions. *Energy policy*, *48*, pp.717-729.

Bristol City Council (BCC), 2018. Bristol One City Plan. Available at: https://www.bristolonecity.com/one-city-plan/ [Accessed 29/5/19]

Travelwest, 2019. Joint Local Transport Plan 4 (JLTP4). Available at: https://s3-eu-west-1.amazonaws.com/travelwest/wp-content/uploads/2015/05/Full-Draft-JLTP4.pdf [Accessed 29/5/19]

National Grid, 2019. Future Energy Scenarios (2019).. Available at: http://fes.nationalgrid.com/media/1363/fes-interactive-version-final.pdf [Accessed 29/5/19]

Details of any relevant external partnership:

Bristol City Council/City Office Partnership- 10

Please list 5 key words which best describe your dissertation:

1. **Electric Vehicles**
2. **Urban Infrastructure**
3. **Holistic**
4. **Best Practice**
5. **Evidence Based**