Public Recharging for Electric Vehicles –
The Business Model Challenge

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Abstract

The thesis investigates how to increase public electric vehicle (EV) recharging provision at the early-market stage when financial returns are poor. Mass adoption of EV is required to reach the UK's carbon emission reduction target, however the scarcity of public recharging infrastructure is seen as a major barrier to uptake. Longitudinal public recharging data required to make informed infrastructure investment and policy decisions is lacking. This research captures and analyses nine years of recharging data to address this gap.

The performance of North East England's (NE) recharging network was analysed and compared with a UK-wide network using recharging event, infrastructure cost and revenue data. The relationship between EV sales and public recharging was investigated using vehicle registration data, and future adoption and recharging demand forecasts were created for the NE region. Preference data was collected from drivers and stakeholders using questionnaires and workshops to investigate their requirements and wider objectives for public recharging.

The UK EV market is at the earliest Innovators stage in the Diffusion of Innovations cycle. Public recharging demand was found to be low in all real-world scenarios studied and introducing fees for recharging reduced demand further. Low recharging demand provides a poor financial return for recharging networks, which limits further investment. EV drivers reported a preference for rapid charging services, but with only a low willingness to pay. Stakeholders reported a range of dissimilar objectives governing their actions, including environmental and social benefits not captured within traditional financial models. Exploring broader non-financial measures to justify public recharging provision required diverse stakeholder analysis and qualitative research investigating stakeholders' perceptions of recharging infrastructure value. The research concludes that social and environmental value could be used to assist in recharging investment decisions to improve our environment now and for future generations, but further work is required to determine appropriate indicators.

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Glossary

Term	Meaning
AC	Alternating Current
Access Type	Those who are allowed to use a Charge Point
AEVA	Automated and Electric Vehicles Act
AFV	Alternative fuel vehicle
AQAP	Air Quality Action Plan
BE	Business Ecosystem
BEIS	UK government department for Business, Energy, Industry, Skills
BEV	Battery Electric Vehicle
BMS	Battery Management System
B2B	Business to business
B2C	Business to consumer
CATA	Check-all-that-apply (survey question type)
CCC	Committee on Climate Change
CCS	Combined Charging System, European automakers' standard
CHAdeMO	Abbreviation "CHArge de MOve", Japanese automakers' standard
Charge point	Supplies electrical energy to recharge a plug-in vehicle
Charge Point Type	Term defining the technical capability of a charge point (its power)
CMA	The Competition and Mergers Authority
CO_2	Carbon dioxide
CSO	Charging Service Operator – operates charge points
CSR	Corporate Social Responsibility
CYC	Charge Your Car

DC	Direct Current
DfT	Department for Transport
DNO	Distribution Network Operator
DVLA	Driver Vehicle Licensing Agency
EC	European Commission
EH	Electric Highway recharging estate
e-mobility	Electromobility
EMSP	Electromobility service provider – offers recharging services to EV drivers
Energy	Rate of delivery of power, measured in kWh
EU	European Union
EV	Electric Vehicle
EVFS	EV Filling Station – a quantity of at least four rapid chargers operated at a single location for use by EV drivers
EVSE	Electric Vehicle Supply Equipment
Fleet operator	Organisation running large quantity of vehicles for commercial purposes
Free-to-use	Charge points without fees charged for their use
GDHI	Gross disposable household income
GHG	Greenhouse gas emissions
Grid operator	DNO (Distribution Network Operator)
Home recharging	Recharging events carried out on private land which only the homeowner can access
HSE	Health and Safety Executive
ICE	Internal Combustion Engine
IEA	International Energy Agency

IPCC	International Panel on Climate Change
IR	Integrated Reporting
KPI	Key Performance Indicator
LA	Local Authority
LAQM	Local Air Quality Management (areas)
Legacy estates	Recharging infra installed by NEPIP & RCN and still operating
Location Type	Categories of places where charge points are located
MLP	Multi-level Perspective
MSA	Motorway Service Area
NE	North East
NE England	North East England
NECA	The North East Combined Authority
NECYC	The network of charge points operated by CYC in NE England
NEJTC	North East Joint Transport Committee
NEPIP	North East Plugged in Places project
NTS	National Travel Survey
Ofgem	The Office of Gas and Electricity Markets
ONS	Office for National Statistics
ORR	The Office of Road and Rail
PAYG	Pay-As-You-Go
PHEV	Plug-in Hybrid Electric Vehicle
PIV	Plug-in Electric Vehicle
Power	The amount of electrical energy transferred in one second, measured in Watts
Public chargers	Charge points intended for use by the general public

Public recharging	Recharging events carried out using public chargers
RCN	Rapid Charge Network project
Recharging data	Data recorded when electricity is put into a PIV battery
Recharging estate	A network of charge points
Recharging event	The act of putting electricity into a PIV battery
Recharging fees	The payments required for using a charge point
Recharging network operator	Operates a number of charge points within an area, providing customer support to drivers and charge point owners.
SAM	Sustainability Assessment Model
SNM	Strategic Niche Management
SOC	(Battery) state of charge
TBL	Triple Bottom Line
UK	United Kingdom
ULEV	Ultra Low Emission Vehicle
Workplace recharging	Recharging events performed on private land at workplaces which only employees can access
WTP	Willingness to pay
ZCF	Zero Carbon Futures

Chapter 1. Introduction

The purpose of this research was to investigate and identify the factors affecting the public recharging business model and to explore whether non-economic value could be used to justify increasing provision in this niche market. Recharging infrastructure is necessary for the adoption of electrically powered vehicles which reduce transport emissions, but the financial business case is currently poor. The study was conducted in a part-time capacity over a seven-year period from 2013 to 2019 whilst the UK electric vehicle (EV) and recharging markets were in their infancy. Consequently, this thesis reflects the landscape of the time and the data used to investigate the chosen research questions. EV adoption is continuing to grow but low demand remains a concern for the public recharging business case in 2020.

1.1 Background

It is well established that greenhouse gas (GHG) emissions are causing the average temperature of the earth to rise and that this global warming is causing irreversible harmful effects to ecosystems, coastlines, water, food and health across the world (IPCC, 2007). The UK therefore committed to reducing GHG emissions by at least 80% of 1990 levels by 2050, through its Climate Change Act (DECC, 2008). 2017 figures showed a 42% reduction in UK GHG emissions since 1990 (BEIS, 2019a), which gave the UK's Committee on Climate Change (CCC) the confidence to recommend a more ambitious target to end the UK's contribution to global warming completely by 2050 (CCC, 2019a). Consequently, in July 2019 the UK government tightened the Climate Change Act by introducing a new target of net zero GHG emissions by 2050 (BEIS, 2019b).

Greenhouse gases are atmospheric gases which absorb heat from the earth's surface and re-emit it into the atmosphere, effectively preventing a proportion of heat produced from escaping into space. The main GHGs of water vapour, carbon dioxide (CO_2), methane, nitrous oxides and ozone occur naturally in the atmosphere but human activities, particularly the burning of fossil fuels, are greatly contributing to the amount of atmospheric GHGs. These additional GHG concentrations are causing the temperature of the earth's atmosphere to rise beyond the level it would be without human industrial activities.

The transport sector produced the highest proportion of UK GHG emissions, 27% during 2017 (BEIS, 2019a). Carbon dioxide forms the majority of UK GHGs at 81% (BEIS, 2019a), and transport was responsible for 33% of the CO_2 total in 2017, largely caused by carbon-based petrol and diesel fuels used in road transport. Only a 2% reduction (BEIS, 2019a) in transport emissions has been achieved since 1990, largely due to over 50% increase in road vehicles licensed over that period which outweighs the improvements made in fuel efficiency. In contrast, the historically largest emitting sector, energy supply, has made a 60% reduction since 1990 (BEIS, 2019a) due to greater use of nuclear and renewables instead of coal for electricity generation. Consequently, the decarbonisation of road transport is a key focus for emissions reduction policy.

In 2016, road transport generated 91% of all UK domestic transport GHG emissions (DfT, ENV0201 (TSGB0306)), with cars and taxis contributing the largest proportion (61%) of this figure and recording only 3% GHG reduction since 1990. Internal combustion engine vehicles (ICE) using petroleum fuels (petrol or diesel) are currently the UK's dominant road transport technology, emitting carbon dioxide and other pollutants from their exhausts whilst driving as a bi-product of petroleum combustion. Car and taxi CO_2 emissions have almost doubled since 1990 whilst light goods vehicle CO_2 emissions have more than tripled in the same period (DfT, ENV0202 (TSGB0307)), but these increases are largely due to the increased quantity of vehicles and the distance they travel.

The number of licensed road vehicles in the UK continues to rise, with almost 39.4 million vehicles registered at the end of 2018 (DfT, VEH0104), representing a 60% increase from the 1990 reference position (DfT, TSGB 9.1). Cars accounted for 82.5% of the 2018 total, with an additional 10.5% contributed by light goods vehicles, commonly referred to as vans (DfT, VEH0101). The annual distance travelled has also risen to the highest value ever recorded, 327 billion vehicle miles in 2017, a 28% increase on 1990 figures (DfT, TRA0101). 78% of this travel took place by car and 15% by van (DfT, 2018e). The increases in vehicle volume and distance travelled produce additional exhaust emissions, most notably CO_2, adding further GHG to the atmosphere.

Road transport is therefore a major consideration in UK emissions reduction policy. However, transport is a key industrial sector, enabler of economic prosperity (Eddington, 2006) and a quality of life indicator, so it is important that the sector continues to grow whilst dealing with the competing challenge of reducing GHGs, as reflected in the UK government's Clean Growth Strategy (HM Government, 2017). Many European countries have introduced policy measures aimed at reducing transport emissions under the sustainable transport agenda, described as the ability to meet today's transportation needs without compromising the ability of future generations to meet theirs (Richardson, 2005). Reducing the carbon emissions of new road vehicles is a key component of sustainable transport strategies.

1.2 The Role of Electric Vehicles

Multiple vehicle technologies are being developed to reduce emissions from new road vehicles as set out in the UK's Technology Roadmaps (Automotive Council UK, 2017). Conventional ICE technology developments have increased fuel efficiency, helping to reduce new car emissions by 30% between 2003 and 2016 (DfT, VEH0150). However, average CO_2 emissions for newly registered cars subsequently rose to 122.3 gCO_2/km in 2017, reversing this downward trend as consumers moved from diesel to petrol vehicle purchases with higher CO_2 emissions (SMMT, 2018) in response to the Volkswagen "Dieselgate" scandal[1]. The CCC has stressed that this progress lags behind their indicators and called for more effective policies, incentives and more ambitious targets (CCC, 2018b). It is widely accepted that ICE technology alone cannot achieve the UK's required reduction in transport emissions, but that a combination of electric vehicles (EVs), more efficient freight movement and switches to more

[1] The Environmental Protection Agency (EPA) found that automotive manufacturers used "defeat devices" or software in diesel engines to detect when they were being tested, changing the performance accordingly to improve emissions results.

sustainable modes of transport such as walking, cycling and public transport are all necessary (CCC, 2018b).

Electromobility (e-mobility) is an all-encompassing term that includes all vehicles with an electrically powered drivetrain which delivers power to the wheels. Two categories of electrically powered vehicles exist currently: battery electric vehicles (BEVs); and hybrid vehicles. BEVs are propelled by an electric motor, which is powered by a battery, have no combustion engine and therefore zero exhaust emissions, making them an attractive solution for transport emission reduction policies because they produce neither CO_2 nor air pollutant emissions from the exhaust. Hybrid vehicles, however, take many forms: some use multiple power sources; whilst others simply use petroleum fuel more efficiently, so all hybrids produce some exhaust emissions. The most carbon efficient hybrids combine an ICE with a battery and electric motor, either of which can drive the wheels dependent upon speed and battery charge, and the combination of power sources used whilst driving dictates the amount of exhaust emissions produced.

Three distinct terms for electrically powered vehicles are intentionally used throughout this thesis to suit different contexts: Ultra Low Emission Vehicle (ULEV) used in UK policy; Plug-in electric vehicle (PIV) which creates demand for recharging services; and the generic title electric vehicle (EV) which the general public recognises. The term Plug-in electric vehicle (PIV) is used globally to refer to any vehicle which can be plugged into an external electricity supply to recharge its battery, including all BEV and plug-in hybrid (PHEV) variants. PIV sales statistics are reported across the world and can therefore be used to compare vehicle uptake progress between countries.

UK policy uses the term Ultra Low Emission Vehicle (ULEV) to refer to any motor vehicle emitting extremely low levels of CO_2, currently defined as 75gCO_2/km driven or less, which includes both BEVs and some hybrid vehicles. In 2016, the UK government added a zero emission range to the criteria used for ULEV purchase incentives (OLEV, 2016) to drive the adoption of cleaner electric over hybrid vehicles. ULEV sales in the UK continue to grow year on year reaching 200,295 by the end of 2018, but this represents only 0.5% of total licensed vehicles (DfT, VEH0104; DfT, VEH0130), signalling the need for significant acceleration in adoption. In terms of new vehicle sales, only 2.14% were ULEVs in the UK in 2018 (DfT, VEH0150), falling far short of the CCC's target which will be discussed further in Chapter 5.

The UK government's stated objective is to achieve a fully de-carbonised new car and van fleet by 2040 and for almost all cars and vans on UK roads to be zero emission by 2050 (OLEV, 2013). This target was re-emphasised in the Clean Growth Strategy (HM Government, October 2017) and Road to Zero strategy (HM Government, 2018b). In 2013 the UK's Committee on Climate Change (CCC) commissioned an investigation into the scale of ULEV uptake required to achieve the UK's legally binding emission reduction targets. The resulting report "Pathways to High Penetration of Electric Vehicles" (Element Energy, 2013) provided targets that ULEVs should represent at least 9% of all new car sales in the UK by 2020, reaching 60% by 2030. However, both the National Infrastructure Commission and CCC have called for the ban on ICE sales to be accelerated to 2030 (NIC, 2018; CCC, 2019b). The government subsequently brought the ban forward to 2035 in February 2020 and widened it to include all hybrid vehicles.

1.3 The Need for Recharging Infrastructure

The UK government believes that recharging facilities are necessary in public places to both encourage and enable PIV uptake (OLEV, 2013; HM Government, 2018b). Whilst incentivising public bodies to provide recharging since 2010 (OLEV, 2013), it is also keen to attract private investment into the market. Therefore, credible business models are required to attract private investors. However, by 2016 the UK's PIV market was still at the Innovators stage of diffusion (Rogers, 2003) with uptake below 2.5% (DfT, VEH0130), where public benefit is thought to outweigh private value to the investor (Sierzchula *et al.*, 2014) and demand was insufficient to attract charging infrastructure investment on a purely financial basis. However, it is vital that plug-in electric vehicles (PIVs) achieve sufficient early adopters to establish a market niche (Geels, 2002), which explains why governments provide vehicle incentives to increase recharging demand.

In many countries PIVs have been the major manifestation of ULEVs, and the UK has been active in PIV development, demonstration, roll-out and the introduction of supporting recharging infrastructure since 2010 (Hübner *et al.*, 2013a; Herron and Wardle, 2015). All PIVs create demand for recharging services. The PIV's on-board battery, which stores electrical energy, is recharged by connecting the vehicle to an external electricity supply, most commonly to the electricity transmission network (the grid). Electric Vehicle Supply Equipment (EVSE) is a collective term used to refer to all equipment installed to deliver energy from the grid to a PIV, including power sockets, plugs, conductors, controllers, etc.

All PIVs require EVSE to recharge their batteries. However, the vehicle not the EVSE dictates how quickly power is drawn from the grid, using its bespoke battery management system (BMS) to ensure safe and reliable battery operation. PIVs therefore require recharging equipment that matches vehicle requirements, in suitable locations, which is available at appropriate times of the day or night to recharge their batteries in an acceptable duration. Consumer preferences and habits also have a large role to play in recharging behaviour. The current recharging durations and the availability of recharging facilities are perceived as limitations of PIV (DfT, 2016), as detriments to freedom of movement and vehicle utility. Different types of recharging equipment are now available to suit different recharging use cases at homes, in workplaces and in public places.

EVSE is also referred to as Recharging Infrastructure. The UK's 2009 national infrastructure report emphasised the importance of recharging infrastructure in reducing transport emissions (CST, 2009). The Institute of Civil Engineers defines infrastructure as "the physical assets underpinning the UK's networks for transport, energy generation and distribution, electronic communications, solid waste management, water distribution and waste water treatment" (Rhodes, 2015), which suggests that recharging equipment is an asset fulfilling both societal and economic functions, enabling the movement of goods and people whilst improving quality of life.

There is much debate about who should provide recharging infrastructure, and public and private organisations have therefore implemented a variety of solutions in the UK and across Europe. There are many stakeholders interested in recharging infrastructure, for many different reasons, making it a complicated marketplace with often conflicting objectives and an unclear business case.

Public recharging infrastructure comprises charge points sited in locations accessible by the general public. The UK government believes that public recharging infrastructure is necessary to encourage and enable the uptake of PIV, however there is no national strategic roll-out plan to achieve this. The UK's Office for Low Emission Vehicles[2] (OLEV) has incentivised public bodies to provide EVSE since 2011 (OLEV, 2013) but is keen to see private initiatives entering the marketplace, so credible business models are required to attract private investors. However, since PIV adoption is currently low there is little demand for public EVSE. Additionally, vehicle technologies are still developing as manufacturers strive to provide PIV at an acceptable price with an equivalent perception of utility to ICE vehicles. Therefore, there is a high likelihood of ongoing technological change, coupled with low demand, making investors' expected levels of financial return unlikely.

This is a classic Chicken and Egg conundrum (Serradilla *et al.*, 2017): which should come first, the vehicles or the recharging infrastructure? Consumers continue to state that a lack of public recharging facilities is a barrier to purchasing an EV (DfT, 2016). Drivers want the comfort of knowing they can recharge if and when required, even if they subsequently don't often use the public EVSE provided to meet those perceived needs (Franke and Krems, 2013a; Hübner *et al.*, 2013a). Moreover, recharging infrastructure falls outside of the EV manufacturers' traditional area of activity, creating an ongoing debate about who is responsible for public EVSE provision and ownership. Investors require some certainty about return before entering the recharging infrastructure market, which is difficult to provide in this nascent market.

[2] A government body jointly run by the Department for Transport (DfT) and Department for Business (BEIS) which oversees both the challenges related to the use and adoption on PIVs and the industrial investment opportunities for developing an electro-mobility industry and supply chain

1.4 Statement of the Problem

Unless a significant increase in ULEV adoption takes place, the UK is unlikely to achieve its carbon emission reduction targets. ULEVs' range on a single battery charge is currently lower than ICE vehicles, which consumers perceive as a reduction in vehicle utility. Consequently, visible and widespread public recharging infrastructure is required to reassure consumers that they can meet their personal mobility goals using ULEVs (Bakker *et al.*, 2014). Furthermore, a failure to maintain and expand the availability of recharging infrastructure represents a significant barrier to widespread ULEV adoption (Achtnicht *et al.*, 2012). Given the low level of UK ULEV adoption to date and the continuing development of ULEV technologies and recharging behaviour, the financial business case for the provision of public recharging infrastructure does not meet the return requirements of potential investors. Consequently, there is a need to investigate other ways to justify increasing the provision of public recharging infrastructure.

Traditional business planning calls for evidence of the likely financial return within a standard timeframe to drive investment decisions. However, in the nascent PIV market at the beginning of a transition path this is difficult to provide with any assurance due to uncertainties about user acceptance, trajectories for driving and recharging behaviour change and continuing technological innovations. The surrounding landscape is also subject to great uncertainty such as oil and electricity prices, alternative transport solutions, Brexit and future UK regulations which may all impact the recharging market. Therefore, justification beyond purely financial return may be required to encourage private investors to provide public recharging infrastructure until PIV adoption matures.

The UK government's zero emission fleet objective is driven by both emission reduction targets and the desire to maximise UK business opportunities in the ULEV sector**,** so the ULEV market must develop rapidly beyond its current niche status to achieve this goal. Radical innovations in technology, user practices, supporting infrastructure and functionality are still required to increase ULEV adoption, which is difficult to achieve when faced with the challenges of the existing well-developed and improving ICE market. Recharging behaviour is not yet normalised because ULEV and recharging technologies are still developing so the characteristics of 2040 recharging demand are currently unknown (rate of recharge, where and when), making forecasting the trajectory of future public recharging demand difficult. ULEV adoption is also limited by vehicle manufacturers' production and supply chain constraints, and their long capacity planning timeframes may not be responsive enough to meet ULEV targets. All of which creates uncertainty for potential investors in recharging infrastructure. In its Road to Zero Strategy the UK government states: "We want to encourage and leverage private sector investment to build and operate a thriving, self-sustaining public network" (HM Government, 2018b). Yet the CCC responded that "relying on the private sector to effect the shift to zero emission vehicles by 2040 is risky" (CCC, 2018a).

There is a risk that the UK's existing public recharging infrastructure, provided largely with financial support from national and local government, will become obsolete within the next five years unless it is maintained and upgraded. The RAC Foundation's recent report recommended that "charge point unreliability … needs to be addressed if the network is to remain credible" and stated that "the current (charge point) network is unattractive to use and is unsuitable for encouraging the next wave of EV customers" (Dermott, 2017). Hence further investment is required in both new and existing recharging networks.

1.5 Research Approach

The early experience of recharging infrastructure roll-out in North East England and a lack of continuing investment in the regional infrastructure has provided the motivation behind this research. Previous research suggests there are a wide variety of stakeholders interested in low-carbon transport solutions (Bakker *et al.*, 2014; Lu *et al.*, 2014), but that the financial business case for investment in recharging infrastructure is poor due to limited ULEV uptake and early adopter recharging behaviour (Schroeder and Traber, 2012; Madina *et al.*, 2016). However, low-carbon transport solutions also provide environmental and social benefits which are not accounted for in the financial business case for recharging infrastructure. Therefore, alternative accounting approaches which reflect the value of non-financial benefits may be useful to encourage infrastructure investment until ULEV adoption provides enough recharging demand to support an acceptable financial return.

When this research began in 2013, data regarding recharging infrastructure cost and use was largely missing from the literature, hindering the development of economic models to encourage investment in public recharging infrastructure and limiting policy decisions. Previous research suggested that the views of a diverse stakeholder group are required to make effective policy decisions leading to successful sustainability transitions (van de Kerkhof and Wieczorek, 2005). Access to all three inputs is available in North East England (NE) due to its formative recharging experience since 2010, providing the ability to investigate the public recharging business case using longitudinal empirical data and to engage with stakeholders to investigate how wider benefits may assist in developing public recharging infrastructure business models.

Furthermore, Newcastle University and ZCF delivered the Rapid Charge Network (RCN) project together between 2013 and 2015 as described in section 3.8.2, and the author collaborated on the design of PIV driver surveys and the RCN business model. The RCN survey data was subsequently analyzed by the author for this thesis to generate the UK drivers' perception results reported and discussed in section 4.2.1. The RCN business model was tested for this thesis by the author, using recharging data gathered beyond the RCN project as discussed in section 7.5, and was then adapted to investigate fast charger profitability as reported in section 7.6.

Finally, ZCF's work on recharging strategies with local authorities and PIV ecosystem businesses provided the opportunity to test many of the ideas in this thesis. The 2019 NE PIV driver survey questions designed by the author for the client NECA were derived from the 2016 survey delivered for this thesis, enabling a comparison to be made between 2019 and 2016 results to inform the discussion on changing behaviour and attitudes reported in section 4.2.2.

1.6 Research Aims

The limited availability of public recharging infrastructure is cited as a barrier to ULEV adoption, however the justification for public recharging provision currently suffers from a lack of information regarding demand, recharging behaviour, costs and value. Consequently, this research has two aims and the hypotheses and objectives designed to address them were defined following the literature review and are presented in Chapter 3.

Aim 1: To identify the demand and supply determinants for continuing and increasing recharging infrastructure provision in public places.

Aim 2: To explore stakeholders' views about the wider value of recharging infrastructure to inform the development of new business models.

1.7 Contribution to knowledge

There is a knowledge gap in understanding the parameters on which a business case can be built for public recharging infrastructure. This study will provide insight into the supply of and demand for public recharging infrastructure in two different scenarios: a regional recharging network combining different types of recharging infrastructure and locations; and a national network of rapid chargers at in-transit locations. An improved understanding of public recharging deployment and operation costs and drivers' willingness to pay for public recharging will also be provided to inform the financial business case. The findings will inform private investors, local and national governments about the demand for public recharging infrastructure and the wider benefits of provision. This research is intended to help both public and private sector organisations develop business models which justify providing appropriate public recharging infrastructure. It may also assist public bodies to develop policies which encourage further private sector investment in public recharging infrastructure.

1.8 Structure of the Thesis

This study seeks to identify the factors affecting recharging provision and use in public places and the implications for the recharging business case. Seven more chapters follow. Chapter 2 provides a review of literature concerning the role of e-mobility within Sustainable Transport, the function of recharging infrastructure in the recharging ecosystem and recharging business models. The Diffusion of Innovations theory, socio-technical transitions and stakeholder frameworks are identified as the basis of this research. The knowledge gaps highlighted in public recharging business models provided two hypotheses and the objectives designed for study are described in Chapter 3, with the chosen research methodology. The two UK recharging projects used as case studies are also described in Chapter 3. Chapter 4 identifies stakeholders in the public recharging business ecosystem, then presents the results of consultations with three key stakeholder groups regarding their roles, motivations and recharging requirements. Chapter 5 presents the results of a PIV adoption study investigating demand for recharging infrastructure and discusses the implications for public recharging in NE England. Chapter 6 discusses the results of a longitudinal study of public recharging behaviour in NE England, compares regional and national rapid recharging behaviour and investigates the implications of recharging fees. Chapter 7 uses financial data from the two case studies with the recharging behaviour results from Chapter 6 and drivers' willingness-to-pay data to investigate the financial business model for public recharging infrastructure. Finally, stakeholders' views about the wider value of recharging are reported to initiate further work to develop an alternative business model considering environmental and social as well as economic value.

Chapter 2. Literature Review

The goals of this literature review are to investigate the role of e-mobility as a mode of Sustainable Transport, to explore the function of recharging infrastructure within e-mobility and to explore recharging business models. The review was conducted to inform the aims, objectives and methodology of this seven-year part-time study, so this chapter focusses on research and theory available up to 2016. However, recharging technology and policy have continued to develop since then so section 2.8 provides a summary of the recharging ecosystem up to 2019. The Diffusion of Innovations theory and socio-technical transitions are relevant to the adoption of e-mobility and successful transitions rely on understanding stakeholders' interests, so this literature review identifies stakeholders with recharging interests. Public recharging business models are presented, identifying some financial challenges for public recharging provision. Finally, to explain recharging in context, the policy, vehicle adoption and recharging technologies driving the market are summarised in the UK's recharging ecosystem. Figure 2.1 illustrates the structure of this chapter and the links between topics.

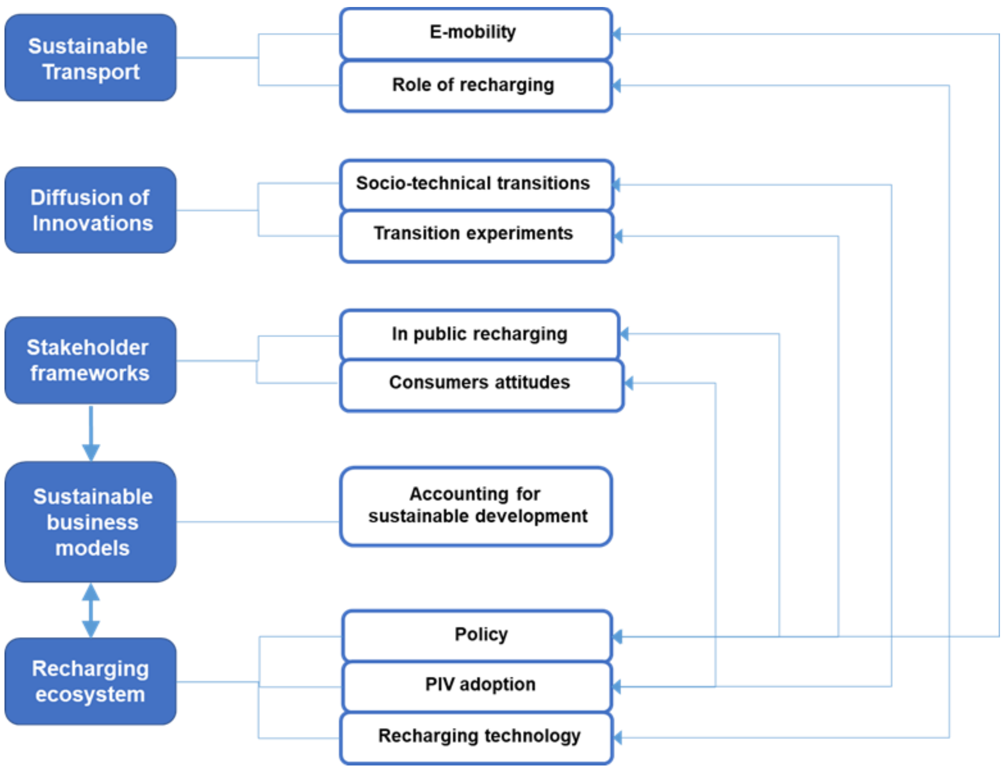

Figure 2.1 – Summary of literature review

2.1 Sustainable Transport Systems

Transport systems move people, goods, materials or information around with the aid of a vehicle (Gudmundsson and Hojer, 1996). Transport systems are complex and contain physical components: vehicles; propulsion sources; and infrastructure, interacting with institutional and social actors, affecting the system both internally and externally. Based on Brundtland's description of sustainability (WCED, 1987), sustainable transport systems have the ability to meet today's transportation needs without compromising the ability of future generations to meet theirs (Richardson, 2005).

The UK's transport sector continues to grow because it is a key enabler of economic prosperity and a quality of life indicator (Eddington, 2006), but the dominant ICE vehicles produce harmful emissions. Road transport accounts for the majority (93%) of UK transport GHG emissions (DfT, 2017b), with cars accounting for 83% of road vehicles (DfT, VEH0101). Cars are the most desirable mode of road transport due to perceived convenience, status and flexibility over public transport solutions (DfT, 2015). Therefore, it is increasingly important to reduce road vehicle emissions to achieve the co-benefits of cleaner air for public health, the economy and the environment according to the UK's Clean Growth Strategy (HM Government, 2017).

The value of transport systems is defined in two ways (Jones, 1987): *Mobility* – the power to overcome restrictions to free movement in a given social context; and *Accessibility* – the ease of physical movement. It is generally agreed that a systems approach is required to assess the performance of transport systems, using indicators which account for the complex behaviours and interactions of the system to assess all the positive and negative impacts (Gudmundsson and Hojer, 1996; Richardson, 2005). There is much debate about which indicators to use, how, and what influence they have on transport decisions and actions, so frameworks are proposed to identify indicators which can assist with decision-making in the relevant context (Gudmundsson and Sorensen, 2013).

To provide mobility and accessibility without dwindling natural resources, the UK government has concluded that decarbonisation of all new car and van sales is required (DfT, 2017a). Road Traffic Forecasts (DfT, 2018d) predict continuing traffic growth to 2050 driven by increasing population and vehicle running cost changes, but also stress uncertainty about future travel behaviours due to changing transport technology. One scenario suggests that 95% of all miles travelled could be zero emission by 2050 if all new cars and vans sold are zero emission by 2040 (DfT, 2018d), but disadvantages of doubling traffic levels and increasing congestion are also identified.

2.1.1 *E-mobility*

E-mobility is a mode of sustainable transport using electrically propelled vehicles which emit lower exhaust emissions than ICE vehicles. UK policy uses the term Ultra Low Emission Vehicle (ULEV) to refer to any motor vehicle emitting extremely low levels of CO_2, currently defined as 75gCO_2/km driven or less, which includes e-mobility solutions. ULEV innovation has begun to contribute to UK decarbonisation, but an acceleration in the speed of transition to e-mobility is required to meet the UK's emission reduction targets (CCC, 2018b).

E-mobility performance indicators are required to inform future transport plans and stakeholder support is needed to design suitable indicators (Bannister, 2008). ULEVs, their recharging infrastructure and stakeholders including drivers and the wider community are all components of the e-mobility system, so a holistic approach is required to understand their interactions and behaviours. Quantitative data is available on UK vehicle registrations and emissions, but little data is currently available on ULEV use and recharging behaviour, making successful sustainable transport strategy development very difficult (Hickman *et al.*, 2013). Furthermore, location-specific priorities and circumstances are reported to be very important for successful local sustainable transport planning (Hickman *et al.*, 2013; Government Office for Science, 2019) but the available data may not be suitable for local planning needs. For example, emissions are not reported at local authority (LA) level, yet transport emissions are particularly an urban problem. Therefore, meaningful local area performance indicators are required to support urban planning decisions, such as local area emissions data and ULEV use data which are not currently publicly available.

An analysis of European National Travel Survey (NTS) data suggested that daily car distance travelled and time parked suited the range and recharging capabilities of ULEVs (Pasaoglu *et al.*, 2014), however debate exists about whether ULEV driving behaviour differs from that of ICE vehicles because of current ULEV constraints (Tal *et al.*, 2013; Jakobsson *et al.*, 2016). Consequently ULEV-specific travel data is required because current ICE data may not be representative. ULEV data regarding urban trip distances, routes and recharging behaviour will be needed to inform urban area traffic management plans, as well as long-distance trip data to inform national recharging network planning. Finally, because long-term strategies are required to achieve decarbonisation, reliable information on the expected timeframe for technological developments in ULEV range, emissions and recharging capabilities is also required to inform likely future user behaviour and to set appropriate e-mobility indicators.

2.1.2 *The role of recharging infrastructure*

Infrastructure is a key enabler of economic prosperity which can also address social and environmental challenges, including climate change mitigation (Foxon *et al.*, 2015). Recharging infrastructure is required to supply electricity to ULEVs, so it affects both mobility and accessibility within the e-mobility transport system, which in turn contributes to emission reduction objectives. Previous studies have demonstrated that consumers require the proliferation of public recharging facilities to provide the reassurance required to change from ICE to electrically powered vehicles (Axsen and Kurani, 2013; Caperello *et al.*, 2013; Franke and Krems, 2013b; Bailey *et al.*, 2015). However, there are no forecasts available for local area volume of recharging infrastructure required to enable mass adoption of ULEVs. Some researchers suggest that large-scale deployment of public recharging facilities is not required because most drivers can recharge at home (Gnann and Plotz, 2013), whilst others believe it is necessary to convince consumers to convert to PIVs (Graham-Rowe *et al.*, 2012; Franke and Krems, 2013a; Bailey *et al.*, 2015). One study concluded that a national public recharging infrastructure equating to 15–20% of existing fuel stations would be necessary for ULEV adoption, however greater consideration of recharging duration, frequency and infrastructure ownership is needed for volume modelling, especially at local area level (Gnann and Plötz, 2015).

2.2 Diffusion of Innovations Theory

E-mobility is a technological innovation seeking to break into a transport system dominated by ICE technology with defined user practices and plentiful refuelling infrastructure. Technological innovations have occurred throughout history as new technologies develop, first co-existing with existing technologies before eventually supplanting the previously dominant technology. Transport examples include automobiles replacing horse-drawn vehicles and steamships replacing sailing boats.

The Diffusion of Innovations Theory (Rogers, 2003) explains the rate at which new technologies are adopted by society. Rogers describes diffusion as the process by which a new technology is communicated through the social system over time. Human capital is a fundamental requirement of the diffusion process and wide adoption is considered necessary to maintain a self-sustaining technological innovation. Potential adopters evaluate a new technology on its relative merit when compared with existing technology, tools and practices. But assessing interactive factors including functionality, stability, complexity, compatibility, testability and scalability for a new technology is a difficult task. Therefore, consumers value a new technology differently, either positively or negatively depending upon their existing behaviour, habits, social standing, knowledge and understanding (Rogers, 2003). Some consumers judge ULEV price (Sierzchula *et al.*, 2014), range limitations and recharging practices (Carley *et al.*, 2013; Hübner *et al.*, 2013a) as inferior to the existing ICE regime, and therefore disruptive to existing tasks or behaviour, which creates adoption risks.

The Diffusion of Innovations theory maps categories of adopters along the technology diffusion curve shown in Figure 2.2. The blue line indicates consumer categories adopting the new technology, growing its market share over time shown in yellow. Innovator adopters are willing to take risks and have the financial means and social standing to adopt new technologies which may ultimately fail. Early adopters then act as opinion leaders, choosing to adopt new technologies to maintain their leading position within highly developed communication channels and the early majority are influenced to take on the new technology through communication with early adopters. Whereas late majority adopters are sceptical about the new technology, have little contact with early adopters and lower financial liquidity, so they delay adoption until after the average person. Laggards are the last to adopt, tending to dislike change.

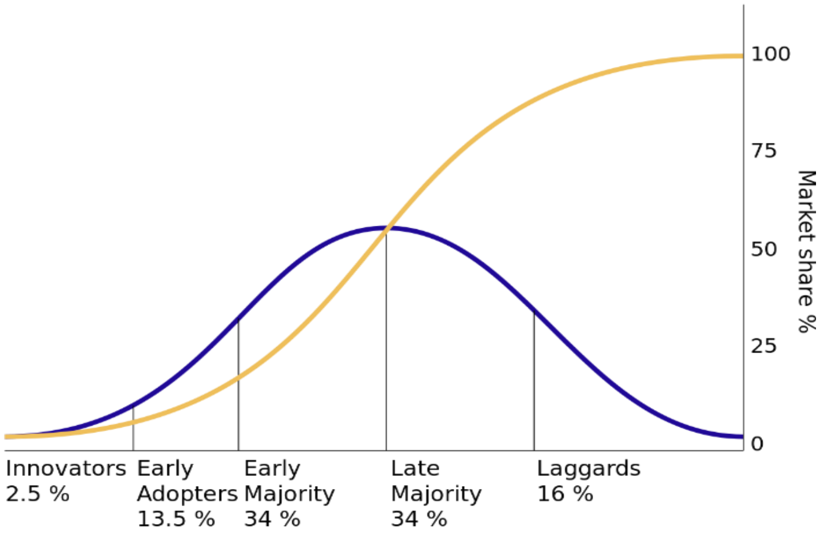

Figure 2.2 – Rogers' diffusion of innovations curve

Several factors can influence the speed of diffusion of a new technology, such as social networks, support from existing adopters, wide-scale demonstration and information programmes, and incentives. At the Innovators stage most potential investors consider markets insufficiently developed to provide an acceptable return on investment (Ngwakwe, 2012) so the UK government has provided incentives since 2010, described in section 2.8.2. But because this is a complex adaptive environment, incentives can also have unintended consequences which distort the marketplace, presenting government with the dilemma of how and when to change or cease intervention (Langbroek *et al.*, 2016).

2.3 The Socio-Technical Transition of Electric Vehicles

Technological transitions are complex, co-evolutionary processes involving many stakeholders which can take decades to unfold, along many different pathways which may or may not succeed (Geels, 2012). It is recommended that stakeholders' opinions should be used to consider transitions where comparable data does not exist (Collantes, 2007), adding a social dimension to the technological factors in traditional innovation frameworks. Socio-technical transitions theory describes how technological innovations occur and are incorporated into society, considering how user practices, regulations, infrastructure, industrial networks and culture are affected (Markard *et al.*, 2012). Most socio-technical transitions research considers the system as a configuration of technology, policy, markets, consumer practices, infrastructure, cultural meaning and scientific knowledge (Kemp *et al.*, 1998; Elzen *et al.*, 2004; Smith, 2007). The transition from ICE to e-mobility affects technology, infrastructure, user practices, policy and markets so it should be considered as a socio-technical transition.

Sustainable development has attracted much social science attention and multiple conceptual transition frameworks have consequently developed (Markard *et al.*, 2012). The Strategic Niche Management (SNM) approach was proposed to foster innovative solutions by creating new niches in protective environments to expedite transitions to new regimes (Kemp *et al.*, 1998). The Milton Keynes Plugged in Places programme was used as a case study to assess early-market EV transitions using the SNM approach (Valdez Juarez, 2015). The study found that financial incentives and infrastructure deployment had limited impact on the choices made by organisational EV users, but that potential adopters invested significant effort to learn and embed appropriate behaviours and collaboratively create new competitive structures around them.

The Multi-level Perspective (MLP) (Geels, 2002) was developed to understand changes in socio-technical systems between three functional levels: the regime or dominant position; the niche level where innovations can develop with some protection; and the landscape or social, political and economic context in which the stakeholders interact. The MLP explains how transitions can evolve following many different pathways depending upon timing and the interactions between levels (Geels and Schot, 2007). However, criticism of the MLP approach calls for greater attention to elements of practice including know-how, activities, meaning, ideas and understanding which interact across the MLP levels in feedback loops changing real-life practices over time (Shove and Walker, 2010). Hence because transitions continue to evolve over time, longitudinal studies are required. To evaluate the effectiveness of policies for sustainable transport transitions, social scientists propose using diverse theoretical perspectives, including both traditional qualitative and novel practice theories to understand the agency of stakeholders in complex and unstable systems (Schwanen *et al.*, 2011).

ULEV adoption in the UK is currently at the niche level in the MLP approach where radical innovation in technology, user practices, supporting infrastructure and functionality can occur with some protection from free market pressures (Geels, 2012). ICE transport with its refuelling infrastructure and routine practices represents the current regime and mass ULEV adoption would represent the onset of a new regime. Public concern and political pressures for environmental protection and sustainability are driving technological innovation in transport, however these are still weak drivers in comparison to the inertia within the dominant ICE regime (Geels, 2012). Consequently many governments are using policy instruments to affect the landscape in which its stakeholders act, by providing some protection from the existing ICE regime, but the effectiveness of the current pathways has been questioned (Lieven, 2015; Mazura *et al.*, 2015; Langbroek *et al.*, 2016; Berkeley *et al.*, 2017).

The ENEVATE project studied the early e-mobility evolution in terms of the MLP (ENEVATE, 2013), identifying multiple niche businesses operating in a regulated and incentive-driven market, including some failed enterprises such as Betterplace and Think. However, they also commented that governments were still evaluating the most effective methods of protection to ensure rapid e-mobility growth. A comparison of UK Reconfiguration and German Transformation ULEV transition pathways (Mazura *et al.*, 2015) using common transition typologies (Geels and Schot, 2007) indicated that whilst both governments had the same goals, emission reduction and industrial preservation and development, very different routes were pursued, highlighting the importance of stakeholders and the power they hold in sustainable transition pathways. However, further longitudinal research is required to understand whether either pathway achieves the desired outcome by the deadline.

2.4 UK Socio-Technical E-mobility Experiments

Socio-Technical Transition experiments are used to test innovations in a real-world environment on a small scale (Ceschin, 2014), enabling stakeholder interaction to improve an innovation and investigate the most favourable conditions for its success across the socio-technical environment. However, Ceschin cautions that a series of linked incremental experiments are required to bring about major change. This section presents the results of UK ULEV experiments which studied driving and recharging behaviour before and after the deployment of public recharging infrastructure.

The Smart Move trials were conducted between 2010–2011 (Carroll, 2010; Walsh *et al.*, 2010; Carroll, 2011), in which Smart and iMiev PIV models were trialled by fleet operators prior to widespread roll-out of public recharging infrastructure. The majority of participants found that PIVs were appropriate for return to base journeys, without need for public recharging. However, the trial also identified that opportunity-recharging could increase range and therefore PIV utilisation, improving economic outcomes, which public recharging solutions could support. High levels of range anxiety were evident, with only 7% of journeys beginning at less than 50% state of charge (SOC) and driver behaviour being modified during journeys to conserve energy once SOC reached 50% (Walsh *et al.*, 2010). However, public rapid recharging facilities were reported to alleviate range anxiety. The TSB-funded Ultra Low Carbon Demonstrator Programme with 135 private drivers (Carroll *et al.*, 2013; Bunce *et al.*, 2014) relied heavily on home recharging in advance of widespread public recharging roll-out. Users reported that recharging at home was simple and convenient and 85% subsequently preferred it to petrol station refuelling. 55% of drivers said they recharged whenever the opportunity arose whilst 49% recharged regularly overnight at home or during the day at work. Perceived need for public recharging infrastructure fell from 89% to 73% after the trial, which is unsurprising given the high availability of home recharging facilities and low public recharging facilities. These results broadly agree with those of the MINI-E trials in Germany (Franke and Krems, 2013a) and the US (Woodjack *et al.*, January 2012,), which all reported users' increasing confidence through experience and higher satisfaction in terms of recharging behaviour, mostly using home recharging.

Contrastingly, the SwitchEV project trialled 44 EVs over two years, in parallel with the roll-out of widespread public and workplace recharging infrastructure described in section 3.8.1. SwitchEV vehicles were recharged most frequently in work locations, followed by public and then home locations, and peak afternoon recharging and overnight recharging were the least popular times (Robinson *et al.*, 2013). However, drivers reported that workplace and public chargers were “free” since the £100 annual membership included free parking and electricity, so recharging at home was considered an unwarranted cost. The availability of widespread public recharging facilities with spare capacity and no time restrictions caused on-peak electricity demand in the case of SwitchEV, generating a risk for grid operators if replicated by mass ULEV adoption. However, the UK’s CABLED project (Bruce *et al.*, May 2012) successfully used financial incentives to encourage off-peak recharging overnight.

2.5 Stakeholder Frameworks

Stakeholders are the people or groups who can affect or are affected by an organisation’s activities, either positively or negatively, intentionally or unintentionally. Multiple stakeholders can affect a company’s business either by contributing to value creation or by having their well-being affected by the company’s activities (Freeman, 1984). Stakeholder Theory introduces the need to consider wider groups such as employees, customers, suppliers, competitors, governments, communities and trade associations in addition to the economic benefits required when making business plans. Freeman classified stakeholders by ownership, economic dependence and social interest which was later refined to consider the strength of a stakeholder’s relationship in terms of power, legitimacy and urgency (Clarkson, 1995). However, stakeholders’ roles can also change as a market evolves (Wittmayer *et al.*, 2017).

Stakeholders have an important role in sustainability transitions. Early transition management work identified that stakeholders from diverse backgrounds and opinions are required to generate the learning and innovation necessary for successful transitions (van de Kerkhof and Wieczorek, 2005). More recent literature proposes that stakeholder agency is fundamental to successful transitions which are explicit consequences of people’s actions (Farla *et al.*, 2012; Markard *et al.*, 2012; Avelino and Wittmayer, 2016), so transition frameworks need to focus on actors’ value-driven agency to understand the necessary conditions for successful transformations (de Haan and Rotmans, 2018). To identify stakeholders that are willing to participate in sustainable transitions, their interests and expectations for that transition must first be understood (Bakker, 2014). However, the agency and dynamics of stakeholder power relationships also fluctuate during transitions (Fischer and Newig, 2016), so it is important to understand how they act in relation to each other within the transition arena (Avelino and Wittmayer, 2016). This implies that understanding stakeholders' changing values, interests and actions will be necessary to make a successful transition to e-mobility.

Multiple typologies have been proposed for actors' roles in sustainability transitions based on sectors, governance and MLP transformation levels (niche, regime, landscape) where actors can feature in multiple categories concurrently and move between them (Fischer and Newig, 2016; de Haan and Rotmans, 2018). The multiplicity and importance of intermediary roles is also a growing research area (Fischer and Newig, 2016; Kivimaa *et al.*, 2019). Several studies have examined the dynamics of stakeholder activity in sustainable transport transitions. A study of German stakeholders' expectations for hydrogen vehicle transition found that vehicle manufacturers' actions were based on future regime expectations which kept changing as new actors and technologies entered the niche and were assessed differently by competitors. The German government acted on longer term social and environmental objectives which did not protect German industry in the short term (Budde *et al.*, 2012). By contrast, when the Chinese government acted as the key intermediary, or ecosystem orchestrator, it was found to have nurtured the Chinese EV industry through the emerging and diversifying stages of the EV business ecosystem lifecycle (Lu *et al.*, 2014; Shang *et al.*, 2015). Both incumbent and new actors in the Netherlands EV niche demonstrated a desire to learn by testing pathways and then influencing development direction towards their own objectives (Bakker *et al.*, 2014). Hence the e-mobility transition involves a diverse group of dissimilar stakeholder interests, with varying levels of power, acting in potentially opposing ways which may change over time, making this a complex business ecosystem.

The results of a distributed energy storage system transition study using stakeholder frameworks and socio-technical transition techniques identified a supply position similar to the current PIV market value (Grunewald *et al.*, 2012) containing overlaps between multiple regimes and incumbent stakeholders unwilling to fund capital. Complementary demand-side value studies were proposed to further the understanding of stakeholders' interests in sustainability transitions, which presents methodological opportunities for this research.

2.5.1 *Stakeholders in public recharging*

Studies investigating Dutch stakeholders in the e-mobility market found that the different expectations of national and local government, electricity providers, grid operators, oil companies, car manufacturers and recharging suppliers affected their attitudes towards financial return and consequently their actions (Bakker *et al.*, 2014). E-mobility was described as an evolving socio-technical system where the conflicts between stakeholders' interests coupled with the stability of the dominant ICE market produced an uncertain development path. It is generally agreed that many diverse organisations must cooperate to enable and accelerate behaviour changes, within a framework of stable supportive policies, regulation and taxes, to enable wider ULEV investment and innovations so the niche can grow (Bakker *et al.*, 2014; ACEA, 2016).

The existing literature emphasises that recharging is a service differing from the product offering of the ICE market, requiring new stakeholders to perform new roles, providing services outside of the traditional vehicle business model (Kley *et al.*, 2011; San Roman *et al.*, 2011; Williander and Stalstad, 2015). New roles in the recharging market have been identified for Distribution Network Operators (DNOs) as recharging infrastructure owners and for electricity suppliers as operators (San Roman *et al.*, 2011). Consequently the roles, responsibilities and interfaces between stakeholders must first be defined to understand and maximise the value propositions of each.

2.5.2 *Consumers' attitudes to recharging*

Many PIV demonstration studies have concluded that consumers prefer to recharge at home overnight or at work during the day, suggesting little need for public recharging infrastructure (Skippon and Garwood, 2011; Morrissey *et al.*, 2016; California Air Resources Board, 2017). However, the need for public recharging remains a source of contention with the counter argument that failure to expand the public recharging network will curtail PIV adoption (Achtnicht *et al.*, 2012; Caperello *et al.*, 2013; Figenbaum and Kolbenstvedt, 2016). Perceived charger abundance was found to have a significant relationship with PIV interest (Bailey *et al.*, 2015).

Consumer feedback suggests that PIV price (Sierzchula *et al.*, 2014) and performance compare negatively with existing ICE technology (Egbue and Long, 2012; Carley *et al.*, 2013). Consumers indicated that battery range limitations and recharging time were significant deterrents to PIV adoption and the UK's SwitchEV trial confirmed this even after six months of PIV use (Hübner *et al.*, 2013a). The UK government's 2016 investigation into consumers' attitudes to EV (DfT, 2016) found that only 5% of respondents were thinking about buying an EV and that the biggest adoption barriers were lack of recharging facilities and limited range on a single recharge. More specifically, respondents mentioned insufficient chargers in their local area and poor knowledge about wider recharging locations as major barriers, so recharging solutions are required to address these perceived barriers.

PIV studies in the UK (Graham-Rowe *et al.*, 2012) and US (Egbue and Long, 2012; Krause *et al.*, 2013) found that cost rather than sustainability drove vehicle purchasing decisions and that drivers prioritised personal mobility above environmental benefits. Respondents desired PIVs to match or exceed current ICE standards before adopting, citing both utilitarian goals (distance, travel time, effort) and positive affective experiences (autonomy, independence, personal space) as determinants of driving pleasure. Consumers tend to resist new or unproven technologies (Egbue and Long, 2012), so awareness programmes addressing consumers' concerns coupled with incentive information are proposed to increase consumer acceptance and ultimately PIV adoption (Krause *et al.*, 2013; Bühler *et al.*, 2014; Bailey *et al.*, 2015). Therefore, policy decisions must address consumers' lack of knowledge and their perceptions of poor PIV utility and insufficient recharging facilities for an e-mobility transition to occur.

2.6 Infrastructure Business Models

Business models describe how value is created, delivered and captured (Osterwalder and Pigneur, 2010; Zott *et al.*, 2011). The traditional view of profit maximisation has been criticised for ignoring wider motivations and temporal effects (Elkington, 1997), so the business model construct has developed to include narratives explaining wide motivations alongside their value creation methods (Zott *et al.*, 2011; Boons and Lüdeke-Freund, 2013). The International Integrated Reporting Council therefore defines a business model as "the organisation's chosen system of inputs, business activities, outputs and outcomes that aims to create value over the short, medium and long term" (IIRC, 2013a).

Infrastructure fulfils a necessary public good requirement for users with a long and complex lifecycle and, due to high up-front capital cost and economies of scale, often operates under monopoly conditions ultimately providing complex financial and non-financial value (Bryson *et al.*, 2014). Therefore, infrastructure solutions require business models which combine large up-front investment with long-term revenue, involve diverse private and public actors and measure complex value. The iBUILD project consequently defined infrastructure business models as "the system of physical artefacts, agents, inputs, activities and outcomes that aim to create, deliver and capture economic, social and environmental values over the whole infrastructure life cycle" (Dawson, 2013).

A successful sustainable business model combines: value propositions; value creation methods through suppliers and customers; and a revenue distribution model which provides value for all actors in the system (Boons *et al.*, 2013). Hence the business challenge of sustainability is to maximise and balance shareholder value with stakeholder welfare (Schaltegger *et al.*, 2012). Four elements have been identified in business models for sustainable products: the implementation of socio-technical experiments; building a broad network of actors; defining a shared vision and values; allowing continuous learning and adaptation (Ceschin, 2013). Consequently, stakeholders must be identified and engaged in business model development, ranging from economic actors to government and citizens who are likely to have different definitions of a product's value, not necessarily measured in economic terms.

2.6.1 *Business models for recharging infrastructure*

New business models are required for e-mobility solutions (Bohnsack *et al.*, 2015; Williander and Stalstad, 2015) because of the differences between PIV and ICE ecosystems, including vehicle capabilities, recharging infrastructure, costs, legislation, suppliers, consumers and their learned behaviours. E-mobility represents a wider value proposition than ICE because it has a public good purpose to reduce environmental degradation as well as an economic benefit, which reflects on its recharging infrastructure. However, the elements of value are weighted differently by each stakeholder, with different potential methods of measurement not always in financial terms. For example, lower emissions are an advantage of PIV over ICE, supporting local air quality and emission reduction policy which the local authority will value, but drivers may not recognise. Valuation differences also occur within stakeholder groups depending upon individuals' circumstances and preferences, for example consumers with the convenience to park and recharge at home may assign higher value to PIV than those without.

Therefore, business models for the holistic e-mobility system are envisaged to promote the wider value proposition, including environmental and social considerations in addition to traditional financial concerns (Bohnsack *et al.*, 2014). However, consumers have limited willingness to pay for services providing societal rather than private value (Williander and Stalstad, 2015). Consequently methods are required to measure and interpret appropriate value indicators considering all stakeholders' viewpoints, but how to convert them into sources of economic value requires further consideration (Bohnsack *et al.*, 2014). Frameworks of sustainability key performance indicators (KPIs) reflecting economic, governance, social, ethical and environmental factors could help businesses to innovate and increase productivity to create value (Rezaee, 2016).

The attractiveness of public recharging to potential investors has been questioned because of high up-front costs and unpredictable demand growth (Kley *et al.*, 2011; Schroeder and Traber, 2012; Madina *et al.*, 2016). Rapid chargers are proposed for public recharging due to their fast recharging rate and convenience to consumers (Element Energy, 2013). However, views on the viability of rapid charging investment vary from positive outcomes based on estimated costs (Markkula *et al.*, 2013) to conclusions raising caution over high risk uncertainties (Schroeder and Traber, 2012; Hug, 2015) and more recently economic feasibility in certain locations, for example along the German autobahn (Jochem *et al.*, 2016). Much of the debate stems from the use of estimated costs and limited recharging data, so analysis of authentic infrastructure cost and longitudinal recharging data is required to test these hypothetical conclusions.

Incentives to control external factors which could influence the viability of recharging business models have also been reported. Free-to-use public recharging is offered by local authorities and private businesses to encourage use during the early diffusion of e-mobility, e.g. NE England, Amsterdam, Ecotricity, Lidl, however this is not expected to continue as PIV adoption increases (Delnooz and Six, 2015). A range of pre- and post-payment methods based on duration and electricity are being trialled by different stakeholders (Delnooz and Six, 2015) but their long-term effectiveness is yet to be studied, providing scope for this thesis. However, previous research indicated that pricing could change recharging behaviour (Schey *et al.*, 2012), manage public infrastructure use and availability (Caperello *et al.*, 2013) and peak time energy demands (Azadfar *et al.*, 2015). Free parking offers were found to necessitate time-based recharging fees due to the higher relative value of parking over energy (Delnooz and Six, 2015). Changes in vehicle ownership and use patterns to shared mobility solutions could also present new business model opportunities for public recharging operators to increase utilisation, such as free-floating car share services (Williander and Stalstad, 2015). A study of theoretical pricing levels for recharging in multi-occupancy dwellings investigated whether drivers' willingness to pay could provide sufficient financial return for capital cost recovery (Williams and DeShazo, 2015), providing a potential method for this thesis.

A study of the evolving e-mobility market in China using the business ecosystem approach (Moore, 1993) identified the government as a business ecosystem orchestrator promoting several different recharging business models in parallel (Shang *et al.*, 2015). New competing business models emerged at the embryonic stage of the ecosystem, then evolved following interaction between actors to produce a dominant business model as the market matured.

It has recently been predicted that viable recharging business models are likely by the early 2020s (Platform for Electromobility, 2018) because the UK will share 90% of European PIV sales with only ten other countries. However, the report also recognises the hesitance of private stakeholders to invest before then and suggests that DNOs may need to provide public recharging facilities for a fixed period in locations where the market will not invest. The "Powering Ahead" report (PWC, 2018) identified four emerging supplier business models spanning recharging market segments (destination, transit, workplace and home). The Portfolio supplier operates across segments and roles to maximise its revenue potential; The Specialist operates in one segment using their technical and stakeholder capabilities; The Network Optimiser seeks secondary revenues arising from recharging such as grid optimisation services; The Energy Supplier seeks to ultimately secure additional electricity sales. These propositions should be reviewed as the market develops and new roles and services are created.

2.7 Accounting for Sustainable Development

Sustainable development refers to activities which achieve economic and social development goals without depleting the natural resource stocks required to sustain future generations (WCED, 1987). In business practice, financial and management accounting processes collect and analyse data about an organisation's performance against its stated objectives to inform effective decision-making, suggesting that appropriate data could be used to make decisions regarding public recharging provision.

Since capital drives wealth both today and in the future, sustainability must consider whether we are simply living off our capital or depleting it and consequently limiting the ability of future generations to meet their needs. The sustainability of natural capital is particularly relevant in transport where the existing ICE regime uses finite natural carbon fuel resources and generates harmful waste emissions. It may therefore be advantageous to evaluate the provision of public recharging infrastructure in terms of its capitals. The wealth creation process is traditionally described as the combination of three capital inputs: land, labour and produced capital, to create goods and services which are then consumed or invested to create wealth. However, a more sophisticated four-capital model was proposed to incorporate sustainability, by adding social capital, broadening land and labour definitions, and adding feedback loops (Ekins, 1992). Additionally, the idea of sustainability gaps between current and sustainable activities was introduced. Critical capital which cannot be substituted was then added and thresholds proposed beyond which assessing financial consequences makes no sense, for example on moral grounds (O'Connor, 2006).

Early sustainability accounting work applied the capital maintenance accounting principle to natural capital (Gray, 1994), but complexities of defining and costing, and susceptibility to interpretation, influence and challenge were highlighted (Bebbington and Gray, 2001). Gray has defined the hypothetical cost of sustainability as “the amount an organisation would have had to spend if it had been sustainable”, but cautioned that this financial approach would eliminate all profit (Gray *et al.*, 2014a). Alternatively, measuring sustainability in a wider sense by considering social and environmental as well as economic impacts can help companies to make more effective decisions about future activities (Bebbington *et al.*, 2007). The Sustainability Assessment Model (SAM) developed with BP (Bebbington *et al.*, 2007) provided a sustainability signature for a project’s activities, measuring the accumulated changes in different forms of capital: economic, environmental, resource and social impact. To define which stakeholders are relevant to any sustainability account, the environment must first be explored, considering the legitimacy, power and equity of those affected both now and in the future (Bebbington and Larrinaga, 2014). Therefore, the public recharging environment must first be defined in order to then engage with relevant stakeholders.

Because sustainable development is a very broad concept, indicators are required to measure performance towards its multiple objectives at both the macro- and micro-economic level (Lamberton, 2005). Consequently sustainability accounting frameworks are proposed to inform decision-making (Lamberton, 2005) using traditional financial indicators to measure economic aspects, plus non-financial indicators such as narratives to capture social and environmental performance (Bebbington *et al.*, 2007; Gray and Laughlin, 2012; Ngwakwe, 2012), whilst acknowledging the difficulties of indicator interpretation, prioritisation and mis-representation.

Multiple approaches have been proposed to account for sustainable development. The Triple Bottom Line (TBL) method (Elkington, 1997) introduced the concept of reporting an organisation’s economic, social and environmental impacts in line with sustainable development goals using separate accounts. TBL is generally understood as the impact on people, planet and profit of the way we use resources, but businesses are unlikely to view these components equally, instead preferencing economic factors (Gray *et al.*, 2014b). Many authors caution against monetising ecological and social factors because it risks overstating financial importance and is susceptible to power, ideological influence and subjectivity (Bebbington *et al.*, 2007). Decisions about what to monetise therefore depend upon the multiplicity of stakeholders' perspectives on the subject of any account. The Global Reporting Initiative (GRI)[3] subsequently provided a framework of financial and non-financial sustainability indicators which businesses could use with TBL foundations to voluntarily report.

The International Integrated Reporting Framework (IR) is intended to advance the understanding of value creation and capital interdependencies over time, resulting in more productive capital allocation to drive financial stability and sustainability (IIRC, 2013b). The IR framework considers six capitals: financial, manufactured, intellectual, human, social and relationship, and natural capital as stocks of value which are increased, decreased or transformed through the activities of the organisation. Whilst IR has been criticised for its financial capital and investor focus (Milne and Gray, 2013), Adams believes IR could help business leaders to better align profit maximisation with the well-being of society and the environment by demonstrating that "value for society" brings "value to investors" (Adams, 2015). IR stresses that value is influenced by the external environment, is dependent upon various resources and is created through relationships with stakeholders. However, further work is required to explore how businesses define value and how stakeholders' views are taken into consideration (Adams, 2017). Since recharging infrastructure business needs financial investment, with financial returns likely only in the long term, defining its value using the IR framework may be a useful development.

However, sustainability is a global concept, with ecological and social objectives which are unlikely to coincide with a business' dominant economic goals (Gray, 2010; Milne

[3] Further information can be found at https://www2.globalreporting.org/standards/g4/Pages/default.aspx

and Gray, 2013), raising questions about how far individual organisations can contribute to sustainability. Therefore, research is required to establish whether sustainability accounting approaches could assist in developing sustainable business models for the provision of public recharging infrastructure.

2.8 The Recharging Ecosystem

The recharging ecosystem contains plug-in vehicles and their users, recharging infrastructure and its suppliers, policies, incentives and legislation. Both technology and stakeholder practices interact with the environment around them, as illustrated in Figure 2.3. This section reviews the policies, vehicle and recharging technologies involved, to complement the information collected on stakeholders in the previous sections.

Figure 2.3 – Recharging ecosystem

Many European countries have introduced road transport policy measures to reduce emissions, including encouraging e-mobility, but legislation may also be required to enforce the necessary travel behaviour change. There are many e-mobility policy options in use and growing literature discussing their effectiveness and transferability (Davies *et al.*, 2016) including: direct vehicle subsidies aimed at private consumers and/or businesses (Gnann *et al.*, 2015); car-sharing or multi-modal transport schemes; regulatory measures such as free parking or priority lane use; awareness-raising programmes and support for recharging provision (Lieven, 2015). A mixture of policy actions is likely to be most successful in encouraging e-mobility but the choice of measures will differ depending upon the funder's influence and objectives (Bakker and Trip, 2013).

2.8.1 *European Commission policy and legislation*

The European Commission (EC) introduced vehicle legislation to achieve its target of 60% reduction in CO_2 emissions from transport by 2050, requiring new car fleet sales to emit no more than 95gCO_2/km by 2021 with financial penalties for non-conformance (European Parliament, 2009). This represents a 40% reduction since 2007 and presents a major challenge to car manufacturers from the UK's 2017 average 121.2gCO_2/km (DfT, VEH0150). In addition, the Clean Power for Transport policy (EC, 2013) seeks to break Europe's dependence on oil for transport, requiring a single market for alternative transport fuels in Europe. The Alternative Fuels Infrastructure Directive (EC, 2014) requires member states to adopt national policy frameworks for the development of alternative fuels and their infrastructure. By 2017 only 35% of the 2020 recharging infrastructure target had been met (IEA, 2018), however this was deemed sufficient to meet the EU's recommendation of one charge point per ten PIVs due to a lower than expected rate of PIV adoption (Platform for Electromobility, 2018). By 2017 the UK had met its 2020 recharging infrastructure target and was consequently criticised for its relatively low targets in comparison to similar member states. These EC regulations are driving ULEV activity in the UK. For the purpose of this research, it is assumed that the UK will adopt equivalent legislation after Brexit to facilitate the legally binding emission reduction targets in the UK Climate Change Act.

2.8.2 *UK policy and legislation*

The UK originally targeted a reduction in greenhouse gas (GHG) emissions to 50% of 1990 levels by 2025 (CCC, 2008) and 80% by 2050 (DECC, 2008). The transport sector was the biggest GHG contributor in 2017 and has made the lowest contribution to emission reduction since 1990 (BEIS, 2019a), so maximising the uptake of low emission vehicles is one of the UK's primary strategies (OLEV, 2013). UK transport policy takes a technologically neutral approach to emissions reduction, using the term Ultra Low Emission Vehicle (ULEV) to refer to any vehicle emitting less than 75gCO_2 per km driven. UK ULEV policy aims to: develop buoyant ULEV markets; create a network of supporting infrastructure; create world-class skills and facilities to develop and manufacture ULEV technologies; develop a smarter electricity grid to maximise the benefits to vehicle owners and the electricity system.

The UK's Committee on Climate Change (CCC) targeted the ULEV market to reach a 9% share of new vehicle sales by 2020 and 60% by 2030 (CCC, 2015), based on its commissioned report "Pathways to High Penetration of Electric Vehicles" (Element Energy, 2013). In 2017 the UK government announced plans to end the sale of conventional petrol and diesel cars and vans by 2040 (DEFRA and DfT, 2017), with the intention that almost all cars and vans on UK roads should be zero emission by 2050. However, the CCC's 2019 progress report recommended a more aggressive 2050 net-zero GHG emission target (CCC, 2019a) and phasing out ICE cars and vans by 2035, which was adopted into law in June 2019 (BEIS, 2019b). The CCC also called for expanded recharging infrastructure, policies generating long-term certainty, high public engagement, skills, access to capital and aligned incentives to accelerate ULEV growth.

ULEV is a new market where technology and customer acceptance are developing in parallel, in competition with the embedded Internal Combustion Engine (ICE) market with its highly developed infrastructure and wide customer acceptance. According to Technological Transitions theory (Geels, 2002) new markets such as ULEV need investment to achieve sufficient early adopters to establish a market niche which can eventually challenge the existing ICE regime. Therefore, the UK government has provided incentives since 2010 to encourage demand (OLEV, 2010; OLEV, 2011; OLEV, 2012): subsidies for cars, vans and public fleets; grants for recharging infrastructure in homes, public places and workplaces (OLEV, 2019); favourable tax incentives including zero road tax and company car tax benefits. However, most public recharging infrastructure incentives are directed at local authorities, resulting in an uneven spread of public recharging facilities across the country. The UK's incentive approach has therefore been criticised as regressive for its risk of social exclusion based on both geography and wealth (Wells. P, 2012).

In 2016, following almost five years of £5,000 subsidy for eligible ULEVs, the UK government implemented reduced incentives graded by environmental performance based on: CO_2 emissions, zero emission range, and ULEV price with a cap of £60,000 to address wealth exclusion criticisms (OLEV, 2016). Subsequently, in 2018 the car incentive was reduced to £3,500 for only those ULEVs with emissions below 50 gCO_2/km and at least 70 miles electric range (OLEV, 2018), effectively excluding most PHEV models from subsidies. Studies on the impact of consumer financial incentives on PIV adoption have found that availability of recharging infrastructure was the strongest predictor of PIV adoption (Sierzchula *et al.*, 2014; Lieven, 2015), whilst others report vehicle financial incentives to be the most effective protective measure (Yixi Xue *et al.*, 2016). These findings support the UK government's combined incentive approach for vehicles and infrastructure.

The UK government had resisted introducing recharging infrastructure legislation until 2017 when the Automated and Electric Vehicles Act (HM Government, 2018a) introduced new powers to accelerate recharging infrastructure provision where the market is not providing fast enough. The act includes mandating recharging provision at motorway service stations and large petrol stations, and the need for smart recharging equipment which can interact with the UK's electrical grid at times of peak demand.

2.8.3 *Policy experience of other countries*

Most ULEV policy examples concentrate on vehicle incentives, however Norway has a more progressive approach, using “the polluter pays” taxation on high emission cars to finance ULEV incentives since the early 1990s (Haugneland *et al.*, 2016). Norway’s 12-year consistent national policy (Norwegian Ministry of Transport and Communications, 2016) targets 100% PIV sales by 2025 and addresses ULEV price, capability limitations and recharging requirements, succeeding in reducing average transport CO_2 emissions to a record low of 100g/km by 2015 (Steinbacher *et al.*, 2018) and achieving early majority ULEV adopter stage at 46% of new car sales by 2018 (EAFO). Notably, Norway is one of the wealthiest countries in the world, with high renewable energy generation, low population density, high land availability and electrical grid capacity for recharging (Steinbacher *et al.*, 2018), which together create ideal territory for sustainable road transport. Norway’s high vehicle purchase and road taxes enabled the government to offer valuable financial incentives for PIV adoption and the lack of ICE manufacturers in its economy avoided the UK’s conflict between national economic, employment and environmental objectives. By contrast, the UK’s population density and car population is over ten times greater than Norway’s (EAFO) and GDP per capita and renewable energy generation are much lower. However, the UK could learn from Norway’s use of long-term PIV promotion and policy certainty, country-wide public recharging deployment, use of bus lanes and design of financial incentives.

An alternative policy approach suggests that higher social benefit could be achieved using variable incentives targeted at geographic areas and consumers with higher likely net benefit (Skerlos and Winebrake, 2010), for example lower income consumers in high renewable energy generation areas could increase emission benefits at the same or lower cost than a fixed price national incentive. The US incentive structure was used to illustrate how incentives towards R&D, infrastructure and vehicle tax show market bias and proposed instead to direct incentives at early adopters who appreciate ULEV benefits and are therefore willing to trade off its limitations (Green *et al.*, 2014). A more recent study identified that infrastructure subsidy effectiveness varied by ULEV type and in different country circumstances (Harrison and Thiel, 2017). This aligns with findings that wider stakeholders affect policy decisions, because the roles and relative importance of vehicle manufacturers and renewable energy generation affect a country’s economy (Bakker *et al.*, 2014). Interplay is evident between government policy and firms’ ULEV strategies (Bohnsack *et al.*, 2015), such as California’s actions driving US national policy, Norway’s experience informing other countries and Nissan’s infrastructure investments in the UK where its European manufacturing plant is located. These alternative policy discussions lead to the consideration of co-benefits, for example incentivising consumers with renewable electricity generation at home to convert to ULEV or encouraging drivers to use green electricity suppliers to recharge could increase emission reduction impacts. These findings suggest that targeted incentives could improve the impact of limited government financial resources.

The Dutch experience highlighted some unintended consequences of incentive policy. The Netherlands achieved 9.9% ULEV adoption in 2015, a small geographic area suited to ULEV range, with an active environmental focus, renewable electricity generation and relatively high gasoline prices. Dutch incentives included zero registration fees and road tax, additional subsidies for ULEV taxi and delivery vans, free ULEV parking and free recharging in public places. However, in 2015 vehicle incentives were cut to favour zero emission vehicles over hybrids, causing a large fall in hybrid and consequently ULEV sales. Additionally, grid operators installed most of the Dutch public recharging infrastructure to learn about recharging behaviour whilst retaining control over grid loading issues (Bakker, 2014). However, the regulator halted this in 2013 and private actors did not take over, so the responsibility fell to local authorities which constrained continuing public provision (Bakker, 2014).

Denmark’s experience also cautioned against too radical an approach to incentive reduction, with its plentiful renewable energy, high taxes, vehicle and gasoline prices. Danish incentives originally offered ULEV zero new vehicle tax, but from 2016 ULEV taxes were increased whilst ICE taxes were reduced, causing ULEV sales to fall by 70% between 2015 and 2016. Danish recharging incentives were originally limited to home chargers and partial connection rebates for public provision, although public recharging tax rebates were introduced in 2016 to encourage infrastructure provision.

This brief review has identified that differences between countries’ circumstances can affect their chosen policy route. Factors such as renewable energy generation, national vehicle production, vehicle tax regimes, petrol/diesel prices, travel modes and distance travelled affect governments' objectives, illustrating the complex e-mobility system. It appears that governments are struggling to identify how to generate the speed of ULEV transition required to meet their emission reduction goals.

2.8.4 *PIV adoption*

Recharging demand is generated by PIVs needing to plug into an electricity supply to recharge their batteries, so understanding PIV adoption will be critical to this study. UK PIV sales began in 2010, reaching 129,094 by 2017 (DfT, VEH0131), which represented only 1.68% of new vehicle registrations (DfT, VEH0150) at the first innovators stage in the Diffusion of Innovations cycle. PIV adoption lags behind both the CCC's 2020 target (Element Energy, 2013) and the European leader Norway's 39.19% in 2017 (EAFO).

PIV technology continues to develop using higher capacity batteries to increase the driving range between charges and reduce drivers' range anxiety, which may change recharging behaviour (frequency, energy, locations) as a result. Recharging flexibility may be key to future PIV adoption because giving drivers choice about where, how and when they recharge may make the necessary behaviour change more acceptable (Axsen and Kurani, 2013; Caperello *et al.*, 2013; Bailey *et al.*, 2015). Hence, appropriate recharging infrastructure is necessary to meet the needs of both existing PIV owners and to encourage ICE drivers to convert to PIV, but reliable PIV adoption forecasts are required to guide infrastructure provision.

Many organisations provide adoption forecasts to suit certain stakeholders' interests, however the independent International Energy Agency (IEA) has predicted that PIV sales will reach 26% by 2030 in Europe (IEA, 2019). By comparison, Deloitte predicts that PIVs will comprise 10% of the automotive market by 2024, with cost parity between ICE and PIV reached by 2022 (Deloitte, 2019). In terms of UK forecasts, the National Grid's Future Energy Two Degrees Scenario suggested one million PIVs by early 2020s (National Grid, 2017), whereas analysis of EU PIV adoption targets against GDP has suggested a 5% market share by early 2020s (Platform for Electromobility, 2018).

The continuing need for public recharging infrastructure incentives is, however, a subject of debate. The Platform for Electromobility suggests a 5% PIV market share means infrastructure incentives will no longer be required, conflicting with an earlier finding that infrastructure incentives correlated with PIV sales at between 5%–25% market share (Harrison and Thiel, 2017). Data regarding UK stakeholders' attitudes to e-mobility incentives would therefore be useful to inform both policy and business direction.

2.8.5 ***Recharging technology***

The PIV defines the rate at which the battery draws power from a charge point, using bespoke battery management systems and recharging protocols. Electric Vehicle Supply Equipment (EVSE) is the collective term for all the equipment required to deliver energy from the grid to a PIV using a charging cable, through which the PIV communicates with the charge point. Most UK PIV models available in 2019 draw maximum 7kW AC power for fast recharging and up to 50 kW DC power for quicker rapid recharging solutions (*Electric Vehicle Database*), but new larger battery premium PIVs entering the market have high-power recharging capabilities of up to 350kW DC.

Many specifications of charge points are available, differentiated by power output, communication protocol, quantity and type of recharging outlets. In the early UK recharging market in 2010, only slow 3kW AC charge points were available, fitted with a UK domestic socket for a 3-pin plug, meeting early PIVs' recharging capabilities. However, safety concerns over long plug-in durations and lack of communication capability drove the development of the now standard Type 2 AC connector and socket. Fast 7kW AC single-phase and 22kW three-phase charge points developed when PIVs launched with 7kW on-board chargers and evolved with multiple outlets and power sharing capabilities. The development of rapid chargers followed, driven by Japanese PIV manufacturers, to provide a quicker recharging experience by delivering power at up to 50kW DC through a tethered CHAdeMO connector. Rapid chargers were designed to recharge a 24 kWh PIV from flat to deliver 80% state of charge (SOC) in 30 minutes. French and German automakers subsequently produced CCS DC and 43kW AC rapid recharging connectors resulting in the development of multi-standard rapid chargers, similar to the ICE regime's petrol and diesel pump scenario. However, this increased infrastructure cost and not all PIVs can rapid charge because lower-cost slow or fast recharging capabilities are adequate for most hybrids' small batteries. In 2014 the EC (EC, 2014) regulated that all rapid chargers must provide at least one CCS outlet with other specifications as optional extras, and the CCS connector dominates the announced PIV for the UK in 2022 (*Electric Vehicle Database*). The roll-out of 350kW DC high-power chargers using CCS connectors began with IONITY[4] in 2019 to target recharging times comparable with ICE refuelling, though very few high-cost PIVs currently have this capability. However, high-power CHAdeMO connector development is also underway[5] which is critical to the UK economy because the UK's Nissan plant only manufactures PIVs with CHAdeMO technology.

The EC recommends a target of one public charger for every ten PIVs (EC, 2014), but this figure must vary widely at local level depending upon drivers' needs, recharging locations and charger type (Platform for Electromobility, 2018). The charger's power rating and therefore rate of recharge dictates suitable locations for different types of charger. Slow and fast chargers are suited to locations where customers park for a long duration, for example at homes, workplaces, car parks and residential streets referred to as Destinations. Rapid chargers are suited to locations where drivers wish to stop for a short period and then continue their journey, called Transit locations.

The availability of sufficient power from the grid where drivers wish to recharge is also a key constraint to public recharging provision (Azadfar *et al.*, 2015). Urban locations often lack spare power capacity so new electrical connections must be purchased from the grid operator, adding cost, complexity and delay to the deployment of recharging facilities.

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[4] Further information can be found at https://ionity.eu/

[5] Further information can be found at https://www.chademo.com/category/high-power-category/

2.9 Summary of Literature Review Findings

The first goal of this chapter was to provide an overview of the literature regarding e-mobility as a mode of sustainable transport and the role of recharging infrastructure and its stakeholders within the recharging business model. This literature review has confirmed the need to reduce transport emissions in the UK. Political pressures for environmental protection and sustainability are therefore driving technical innovations in the transport sector. E-mobility is one form of sustainable transport system and its recharging infrastructure clearly affects both mobility and accessibility. Transition from ICE vehicles to e-mobility for road users could greatly reduce transport emissions, so the UK government is using policy and legislation to increase PIV adoption and recharging provision, but in spite of this PIV adoption remains below targets and behind European leaders to date. However, there is much debate about appropriate policy methods and timeframes required to make the e-mobility transition. UK policy focusses on national ULEV impact, but e-mobility indicators are missing at a local level to understand impact and to inform urban planning and transport solutions. Local policy needs to consider how to change consumer behaviour to enable PIV adoption which maximises emission reduction without worsening congestion. Longitudinal data for public recharging behaviour and empirical infrastructure costs for deployment and operation are largely missing from the literature to date, especially at a local level. Lack of data limits the development of economic models to encourage private investment in recharging infrastructure and informed policy decisions.

UK PIV adoption has only reached the first Innovators phase in the Diffusion of Innovations cycle (Rogers, 2003), where mainstream consumers consider limitations in range and recharging capabilities as disruptive to routine tasks and are therefore unwilling to adopt. Adoption must reach the Early Adopter phase by 2020 and Late Majority phase by 2030 to achieve the CCC's targets. Therefore, by 2030 the majority of consumers must believe that e-mobility technology at least matches or exceeds ICE technology to be willing to change their established ICE travel and recharging behaviour.

The PIV industry is currently at the niche level in the Multi-Level Perspective of Socio-technical Transitions theory (Geels, 2002), where it is partially protected from the dominant ICE industry whilst it develops. Radical and accelerated innovations in technology, user practices and supporting infrastructure will be required to make a regime change happen from ICE to e-mobility. Most consumers resist new technologies, so consumer awareness-raising programmes are proposed to improve consumer acceptance to accelerate PIV adoption. However, the long-term effects of PIV socio-technical experiments are not yet recorded in terms of consumer acceptance, PIV adoption and emissions reduction.

The availability of recharging infrastructure is reported as a strong predictor of PIV adoption. Socio-technical experiments investigating PIV drivers' recharging behaviour in different environments found that drivers preferred to recharge at home overnight or at work, but most of these studies had little or no access to public recharging infrastructure. By comparison, the SwitchEV trial benefitted from widely available public and home recharging facilities and found much greater use of public recharging, although heavily subsidised. However, most trial participants continued to cite recharging limitations as a barrier even after trials, so infrastructure solutions are required to address these concerns. Some governments are using public recharging infrastructure incentives as a complementary approach to direct vehicle subsidies, but no evidence was found to confirm whether the availability of public recharging infrastructure actually increased PIV adoption rates. Recharging technology development is continuing, driven by PIV manufacturers, with the aim of overcoming consumers' range anxiety, resulting in a variety of public recharging solutions to suit different needs in a variety of locations.

It is widely agreed that stakeholder involvement is necessary for successful socio-technical transitions and the growth of new industries. The diversity of e-mobility stakeholders and motivations increases complexity but can also help to develop successful transition paths, encouraged by governments. Early studies suggested that public recharging infrastructure should be owned and funded by national DNOs, however evidence of different ownership and operational models is required for comparative study. The recharging stakeholder literature review concluded that the cooperation of many stakeholders plus supportive government policies will be essential for the e-mobility market to grow to targeted levels in the desired timeframe.

Financial justification for public recharging provision is still uncertain due to risks surrounding PIV adoption and therefore demand for public charging services. The ultimate goal of transport emissions reduction is related to ecological and social objectives, which do not necessarily coincide with an individual business' goals. A sustainable accounting approach considering wider benefits in addition to economic value may therefore be appropriate to encourage investment in public recharging infrastructure. Considering the social, environmental, ethical and governance impacts as well as economic impacts of their investment may help companies to make effective decisions about public recharging provision. Literature states that measuring business-level sustainability is valuable, but it requires holistic indicators and precise measurement techniques which capture the wider value proposition across the value chain. Both financial and non-financial data is proposed, combining narratives of social and environmental impact with financial indicators. Therefore, clear definitions of each objective and performance indicator are required which are equally relevant to each stakeholder involved. Understanding the views of each stakeholder and then maximising the value to each is key to achieving a successful business model for recharging. However, there is no evidence of the inclusion of wider environmental and social value in recharging infrastructure business models at present.

The second goal of this literature review was to inform the aims, objectives and methodology of this research. Stakeholder surveys are widely reported to gather preference data related to e-mobility, particularly amongst drivers although most were participating in time-limited PIV trials. Preference data from experienced long-term PIV drivers is therefore required to update recharging preferences and the understanding of PIV travel and recharging behaviour. Focus groups were used to gather more complex data from wider e-mobility stakeholders including government, electricity providers, DNOs and manufacturers regarding their motivations and actions (Bakker *et al.*, 2014), so this method could be used to investigate recharging value at the local level to feed into the wider business model. Furthermore, supply-side studies using stakeholder frameworks were reported (Grunewald *et al.*, 2012) to investigate the energy storage sustainable technology market, so a similar method could be applied to study the demand and supply characteristics of the PIV market. Finally, drivers' willingness-to-pay data could be used to investigate the recharging financial business model (Williams and DeShazo, 2015). Chapter 3 presents the chosen research methodology.

Chapter 3. Hypotheses, Objectives and Methodology

The purpose of this chapter is to present the hypotheses, objectives and research methodology used to investigate the public recharging business model challenge. This chapter describes the interdisciplinary mixed methods research approach chosen, which incorporates a longitudinal quantitative study of public recharging data with a qualitative study of stakeholders' roles in and requirements for public recharging. The methodology, data, study participants, collection procedures and analysis methods are explained for each element of the study, alongside the case studies used to inform the research outputs.

Chapter 2 reviewed and identified knowledge gaps in the public recharging business case, in particular regarding public recharging behaviour beyond free-to-use trials and infrastructure costs. Gaps were also identified in the understanding of stakeholders' motivations for participating in the recharging market and their perceptions of value beyond purely financial aspects. First, the hypotheses and objectives designed to investigate the two research aims introduced in Chapter 1 and to address the knowledge gaps identified in Chapter 2 are explained. Then follows a description of the methodology used to facilitate the data collection and analysis of each element of the study: stakeholders; vehicle recharging demand; public recharging characteristics; and public recharging business models. Finally, the case studies used to provide real-world data are explained to complete the chapter.

3.1 Research Aim 1

Chapter 2 identified that UK ULEV adoption by 2017 was far below the CCC's targets and that limited availability of public recharging infrastructure was cited as one reason for low ULEV adoption. Literature (Kley *et al.*, 2011; Schroeder and Traber, 2012; Hug, 2015) also indicated that financial justification for public recharging infrastructure provision was uncertain for two reasons: a lack of real-world demand and cost information; and the continuing development of PIV and recharging technology, which means that user recharging behaviour is still evolving. These findings drive the first aim of this research as set out in Chapter 1:

AIM 1: To identify the demand and supply determinants for continuing and increasing recharging infrastructure provision in public places.

AIM 1: To identify the demand and supply determinants for continuing and increasing recharging infrastructure provision in public places
HYPOTHESIS 1: Majority of recharging will take place at home or at work, with little demand for public recharging facilities. **Objectives** A. Determine Drivers' requirements for public recharging services B. Identify trends in vehicle adoption and implications for future recharging demand C. Define historical use of public recharging infrastructure
HYPOTHESIS 2: Revenue generated by public charge point owners is not sufficient to match their total financial investment. **Objectives** D. Determine Charger owners' motivations for public recharging investment E. Identify recharging costs, fees and constraints for deployment and operation

Table 3.1 – Aim 1 hypotheses and objectives

Two working hypotheses were developed with corresponding research objectives to address Aim 1 as shown in Table 3.1. Chapter 2 identified consumer preferences for home and work recharging which suggest there may be little demand for public recharging, leading to the first hypothesis. Literature also suggested that there was no feasible financial business model for public recharging infrastructure provision, leading to the second hypothesis. Table 3.2 indicates where the methodology and results for each objective can be found in this thesis.

AIM 1: To identify the demand and supply determinants for continuing and increasing recharging infrastructure provision in public places				
HYPOTHESIS 1: Majority of recharging will take place at home or at work, with little demand for public recharging facilities.				
Objectives	**Research Methods**	**Section**	**Data**	**Results**
A. Drivers' requirements	Quantitative Surveys	3.4.1	Primary	Ch.4
	Qualitative focus groups	3.4.3	Primary	Ch.4
B. Vehicle adoption	Quantitative analysis	3.5.1	Secondary	Ch.5
Recharging capabilities	Qualitative content analysis	3.5.2	Secondary	Ch.5
Vehicle use	Quantitative analysis	3.5.3	Secondary	Ch.5
C. Public recharging infrastructure use	Quantitative statistical analysis	3.6	Primary	Ch.6
HYPOTHESIS 2: Revenue generated by public charge point owners is not sufficient to match their total financial investment.				
Objectives	**Research Methods**	**Section**	**Data**	**Results**
D. Charger owners' motivations	Quantitative Surveys	3.4.2	Primary	Ch.4
	Qualitative focus groups	3.4.3	Primary	Ch.4
E. Recharging costs, fees & constraints	Quantitative case study analysis	3.7	Secondary	Ch.7

Table 3.2 – Aim 1 summary

3.2 Research Aim 2

Although ULEV policy is driven by emission reduction goals, the literature summarised in Chapter 2 provided no evidence of the use of environmental or social benefits in the business model for public recharging infrastructure. This omission leads to the second aim of this research:

AIM 2: To explore stakeholders' views about the wider value of recharging infrastructure to inform the development of new business models.

Aim 2 requires an inductive research approach to draw inferences from observations which can then be used to inform hypotheses for further research. This is an interpretivist approach common in social science research which does not have its own hypothesis. Informed by literature regarding stakeholders and sustainable business models, two objectives were devised to address this aim summarised in Table 3.3. The study required data regarding stakeholders' objectives for recharging provision and their perceptions of value. Stakeholder engagement activities were required to gather data to investigate how stakeholders define non-financial value resulting from public recharging services. Table 3.3 also summarises where the methodology and results for each can be found in this thesis.

AIM 2: Explore stakeholders' views about the wider value of recharging infrastructure to inform development of new business models				
Objectives				
A. Determine stakeholders' opinions on wider value of public recharging infrastructure				
B. Identify the use of wider value in alternative business models				
Objectives	**Research Methods**	**Section**	**Data**	**Results**
A. Wider value of public recharging	Quantitative Surveys	3.4.2	Primary	Ch.4
	Qualitative focus groups	3.4.3	Primary	Ch.7
B. Use in alternative business models	Quantitative Surveys	3.4.2	Primary	Ch.4
	Qualitative focus groups	3.4.3	Primary	Ch.7

Table 3.3 – Aim 2 summary

3.3 Research Approach

This section explains the research approaches chosen to address the aims, hypotheses and objectives set out in sections 3.1 and 3.2. The following sections then describe each method, the study participants, data collection and analysis procedures and introduce the case studies used.

A number of methods were reviewed and the most appropriate deployed to collect and analyse the various data required to underpin this research. The need for ULEV adoption is driven by policies shaped by environmental and social objectives, but user acceptance and behaviour change are required to transition to e-mobility. It is generally agreed that public recharging solutions are currently limited by technology constraints and low demand, resulting in a poor financial business case. Therefore, a combination of engineering, economic and sociological factors are likely to affect the recharging business case. Literature was reviewed from transport, energy, economics, ecology, sustainable development, geography, technological forecasting and social change sources, confirming that many stakeholders have interests in the complex recharging business and multiple disciplines have provided financial, environmental and societal insights. Hence an independent engineering, sociological or economic research approach was unlikely to provide sufficient data to address the research aims. Consequently, an interdisciplinary research approach was employed to collect and analyse transport, business and social science data.

Both quantitative and qualitative approaches were required to achieve the research aims so a mixed methods approach was developed using a triangulation method combining complementary data sources, theories and methods. This is described as a convergent parallel design of mixed methods research, in which the quantitative and qualitative data have equal priority and the resulting analyses can be combined to form an integrated output (Bryman, 2016).

Literature (Walsh *et al.*, 2010; Franke and Krems, 2013a; Bunce *et al.*, 2014; Ceschin, 2014) identified socio-technical experiments as a method used to collect both qualitative and quantitative data on recharging behaviour. Two experimental recharging projects managed by the author at Zero Carbon Futures were therefore used as case studies for this research, the North East Plugged in Places (NEPIP) and Rapid Charge Network (RCN) projects described in section 3.8. Data generated by those projects, supplemented by additional data collected specifically for this research, enabled a longitudinal study addressing the research aims.

Both primary and secondary data were collected and analysed to meet the research objectives. Primary data was gathered using questionnaires and focus groups designed specifically for this research. Recharging events, infrastructure cost and revenue data obtained from the case studies and subsequent data collection were also considered as primary data, since raw datasets were collected and analysed specifically for this thesis. Secondary data included vehicle registration, travel statistics, charge point and vehicle recharging characteristics taken from government publications, vehicle manufacturers' and recharging operators' websites, academic and industry publications.

3.3.1 *Hypothesis 1*

HYPOTHESIS 1: *The majority of recharging will take place at home or at work, with little demand for public recharging facilities.*

The demand study used to address hypothesis 1 combined quantitative and qualitative research techniques in a mixed methods approach which is summarised in Figure 3.1. PIV adoption and travel data were required to investigate the volume of demand for public recharging services. Secondary data was available in national datasets summarising vehicle registrations and recharging infrastructure locations and the analysis methods used are described in section 3.5. Secondary data was obtained from websites describing vehicle recharging systems in order to correctly interpret the recharging data. Recharging event data was required to investigate the volume, energy, temporal and spatial characteristics of real-world public recharging infrastructure use. However, public recharging use data was not publicly available, so new primary data had to be collected for this research as described in section 3.6.

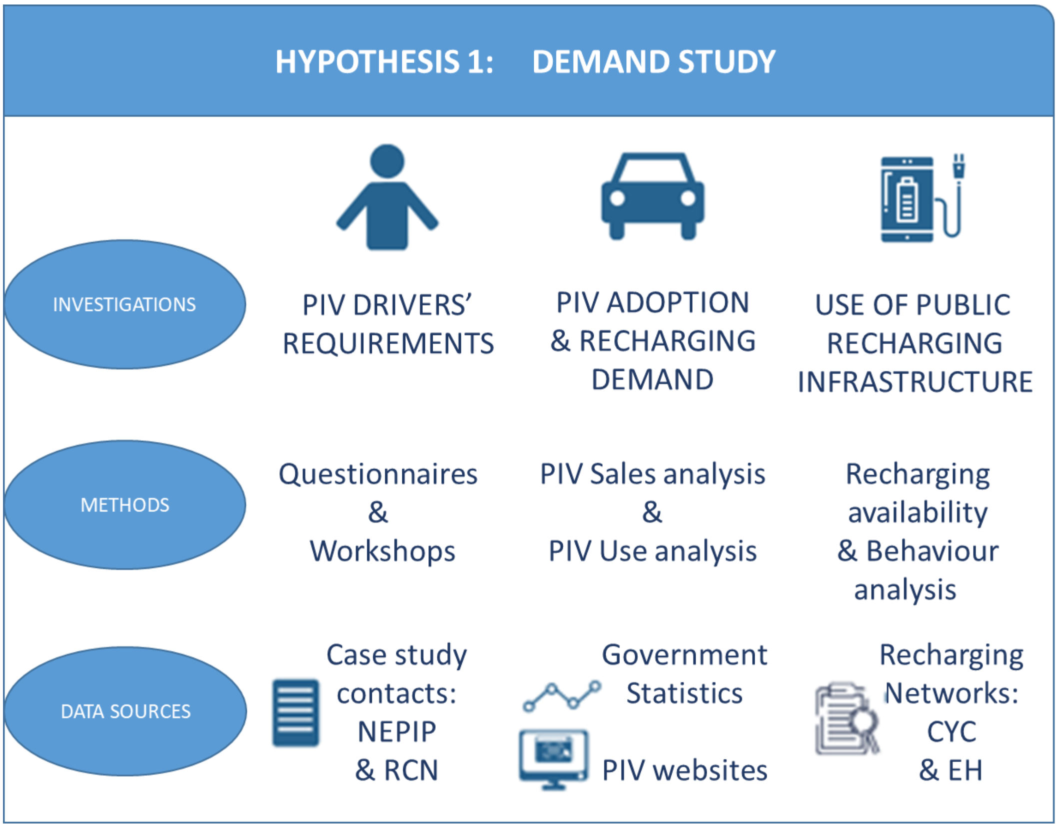


Figure 3.1 – Recharging demand study method

Furthermore, since the UK ULEV market was only at the first stage of diffusion, the recharging data available for quantitative analysis only represented early adopter behaviour. Therefore, qualitative data capturing drivers' recharging behaviour and preferences was collected to supplement the empirical recharging data collected, as described in section 3.4.1.

3.3.2 *Hypothesis 2*

HYPOTHESIS 2: *Revenue generated by public charge point owners is not sufficient to match their total financial investment.*

The supply study used to test hypothesis 2 employed both qualitative and quantitative methods which are summarised in Figure 3.2. Financial data regarding public recharging infrastructure deployment, operating costs and revenue were required to investigate the financial business case, however this sensitive commercial information is unavailable in the public domain. Consequently, empirical case study financial data was collected as described in section 3.7.1.

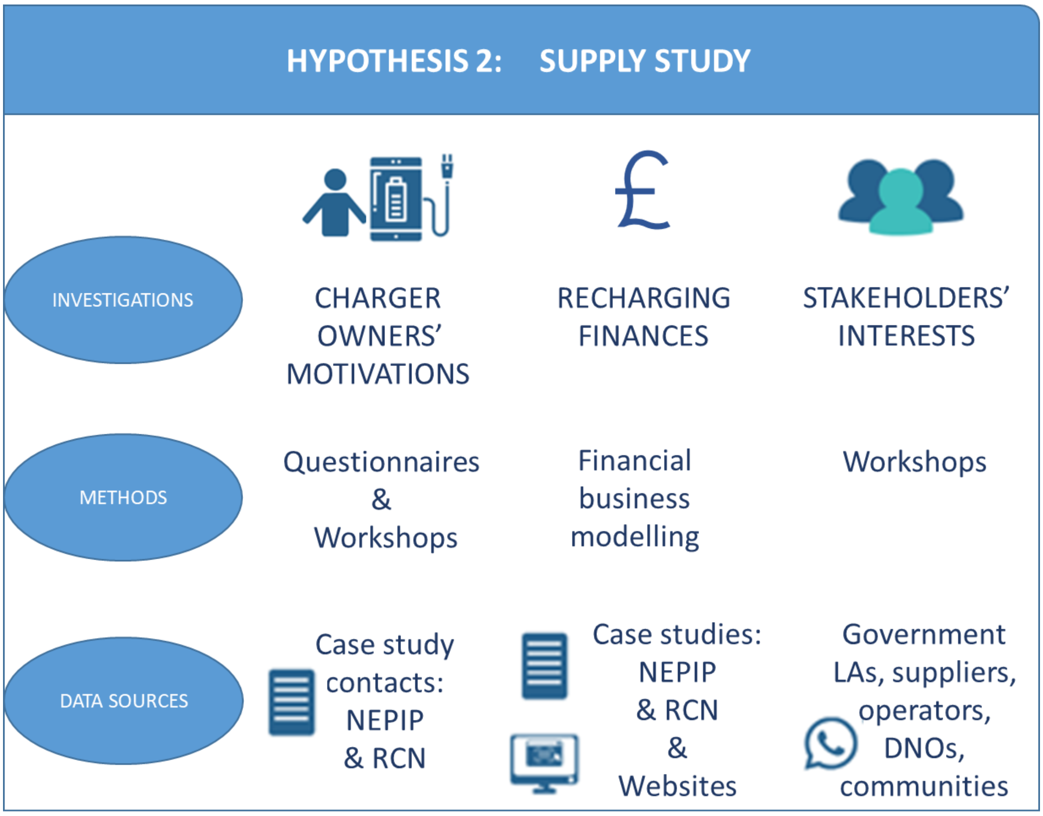


Figure 3.2 – Recharging supply study method

Qualitative feedback from charge point owners regarding their reasons for public recharging provision was also required to provide information on both financial and wider objectives, as described in section 3.4.2. Finally, the case studies and contacts available through ZCF enabled an investigation of diverse stakeholders' interests in public recharging as described in section 3.4.3.

3.3.3 *Aim 2*

AIM 2: To explore stakeholders' views about the wider value of recharging infrastructure to inform the development of new business models.

To address aim 2, data was required to understand how stakeholders defined the value of recharging infrastructure. Literature provided little information regarding stakeholders' definitions of value beyond financial return, so qualitative research was required to determine stakeholders' perceptions and interpretation of wider recharging infrastructure value. Reports and personal experience at ZCF indicated a growing range of stakeholders with interests in recharging, suggesting that significant engagement activity would be required to collect primary data for this research. The engagement methods chosen are described in sections 3.4.3 and 3.7.2. Business models for other sustainable development activities may also provide information regarding wider definitions of value, which could be assessed for translation into the recharging sector.

3.4 Stakeholder Research

Stakeholder analysis was performed to determine groups which directly influence supply and demand for public recharging services and those indirectly affected by it. Literature supplemented by the author's recharging work at Zero Carbon Futures was used to create a recharging stakeholders' framework identifying customers, suppliers and actors with wider involvement, referred to as intermediaries (Kivimaa *et al.*, 2019). Following Shang et al.'s (Shang *et al.*, 2015) use of Moore's Business Ecosystem approach (Moore, 1993) to describe recharging systems, this method was used to identify the actors in each group and to investigate their interests and influence. One stakeholder group from each of the supply and demand categories was then selected for further research based on their agency and the access to likely respondents.

3.4.1 *PIV drivers' attitudes to recharging*

Data was required to determine drivers' perceptions of and requirements for public recharging services. Chapter 2 indicated that home was the favoured recharging location, followed by work and then public places (Hardman *et al.*, 2018), however regional differences in housing stock and travel behaviour may affect drivers' recharging behaviour, so public recharging requirements may differ at the regional level. Future changes in PIV and recharging technology are also likely to affect future recharging behaviour.

Some secondary data regarding PIV drivers' preferences was identified in government and industry reports (DfT, 2016; AA, 2018), however neither source focussed on recharging preferences at a regional level, nor considered the type, location, frequency, energy and pricing preferences of drivers. Therefore, primary recharging preference data was collected from PIV drivers in NE England for consideration alongside the regional recharging event dataset described in section 3.6. Preference data collected by the RCN case study described in section 3.8.2 was also analysed alongside the rapid charging data collected.

Literature (Bunce *et al.*, 2014; Bryman, 2016) indicated that questionnaires, interviews and focus groups are good methods for collecting perception data. The RCN project conducted three self-administered questionnaires with national PIV drivers in 2015, attached in Appendices A, B and C. Each questionnaire contained between 35 and 41 questions designed to inform the RCN project's research aims and to inform this thesis. Questions covered PIV purchasing decisions, PIV travel, recharging behaviour and experiences, and willingness to pay for rapid recharging and additional services. The design process considered questions asked in previous PIV surveys, but few questions were available regarding recharging behaviour and willingness to pay. Each questionnaire was designed using Survey Monkey and promoted on the RCN website and by PIV manufacturers to reach UK PIV drivers.

Subsequently, in 2016, a self-administered questionnaire was designed to determine NE drivers' opinions on public recharging and their requirements for the future, attached in Appendix D. The benefits of this low-cost method of collecting data include speed, convenience for respondents and lack of interviewer variability. The 46 questions were designed to be easy to respond to in under 30 minutes with limited variability, to ease coding and analysis. The questionnaire contained four sections: current recharging behaviour; recharging preferences; willingness to pay for public recharging; and personal data. A mixture of horizontal and vertical closed questions were presented in each section to enable quantitative analysis. Most recharging behaviour questions required frequency responses using a four-point Likert scale (often, sometimes, seldom, never), supplemented by factual questions about recharging experiences. Evaluation questions were used to elicit preference data using a three-point Likert scale (very important, important, not important), a common method for investigating attitudes. The final section contained personal factual questions regarding PIV use, access to parking, age and gender. Where all possible answers could not be predicted, an “Other” response category was included requiring text explanation from the respondent, however these proved difficult to analyse. Another limitation proved to be the use of “Check-all-that-apply” (CATA) questions which added complexity to the analysis, so simpler forced choice questions would be preferable in future research.

The questionnaire was created using the Survey Monkey online tool and piloted with four colleagues who drove PIVs, resulting in simplification to improve understanding, consistency and speed of response. The questionnaire was distributed via email to 300 NE PIV drivers with a covering letter, using contact details from the NEPIP case study. The author’s previous contacts with these drivers led to a low risk assessment of a poor response rate which could cause biased results, however reminders were required to achieve a 60% response rate. Responses were collected from Survey Monkey over a four-week period and were analysed using Excel.

In 2019 ZCF conducted a further survey of NE PIV drivers’ perceptions of the region’s public recharging infrastructure for the NE Joint Transport Committee (NEJTC), attached in Appendix F. NEJTC was responsible for the region’s EV strategy on behalf of the seven LAs who owned most of the NECYC estate studied. A questionnaire containing 30 questions designed using Survey Monkey was distributed using local authority and ZCF social media channels. 91 responses were received and compared with the data collected in 2016 to investigate changes in EV drivers' behaviour and perceptions of public recharging requirements.

3.4.2 *Charge point owners' attitudes to recharging*

Data was required to investigate charge point owners' experiences of providing public chargers and their attitudes towards continuing provision, so a self-administered questionnaire was delivered in 2015. 42 closed questions were designed regarding use, performance, demand and the business case for NE charge point owners to complete in under 30 minutes with limited variability, attached in Appendix E. The majority of questions were informant factual questions in which the respondent was asked to report on behalf of his or her organisation. However, some questions about beliefs were included to ascertain respondents' impressions about future demand for and growth of public recharging facilities. The questions were piloted with two LA colleagues from the NEPIP case study, using a qualitative interview to test and modify the fixed choice responses proposed. Most questions provided multiple-choice responses, informed by the early results of the NEPIP recharging data analysis, however some questions received low responses suggesting excessive complexity or assuming too much knowledge. The few open questions requiring text responses elicited few but wide-ranging responses which proved difficult to analyse.

The questionnaire was created using Survey Monkey and distributed via email to 118 charge point owners involved in the NEPIP project, plus each of the six regional Plugged in Places projects and two commercial operators, ESB ecars and Ecotricity's Electric Highway. The risk of a poor response was assessed as low due to the author's previous contact with the target group, however only 38% provided responses over a five-week period. The data was subsequently analysed using Excel.

3.4.3 *Wider stakeholders' attitudes to recharging*

Data was required regarding wider stakeholders' interests and actions concerning public recharging so focus groups were used to gather information on their objectives and perceived barriers to success. Focus groups are interactive sessions which allow participants to explore a topic in some depth, discuss their views and respond to others' comments, providing an efficient method of eliciting a variety of views from knowledgeable participants (Bryman, 2016).

This research was used as a case study within the iBUILD Project (Infrastructure BUsiness models, valuation and Innovation for Local Delivery) (Newcastle University), which investigated the features of infrastructure solutions and proposed an analytical framework to explain how infrastructure business models are constructed and delivered (Bryson et al., 2014). iBUILD provided the opportunity to conduct stakeholder workshops addressing the research aims so diverse participants with relevant recharging experience identified in the stakeholder framework were invited to take part in focus group activities, using contacts established in the author's work at ZCF. Most participants had an established relationship with the author who acted as facilitator and with other participants, enabling relaxed and productive discussions. However, each focus group contained some dominant voices and occasionally strayed from the point, so the facilitator sought to encourage everyone to speak whilst refocussing attention when necessary.

The first stakeholder workshop entitled "Making the business case for public recharging infrastructure" was delivered at the iBUILD project launch event in 2014 and the agenda is provided in Appendix G. Following focus group good practice, the debate was structured around two broad questions to encourage discussion.

Q1. How can we make a business case for public charging infrastructure stack up?
Q2. What costs and benefits should we take into account when making a business case for public EV charging infrastructure?

The debate was designed with audience participation and the session was recorded and transcribed to enable analysis. The six panel members first presented their own varied perspectives: a recharging network operator; city council sustainability and transport officers; a transport and energy advisor; the energy regulator Ofgem; and a drivers' representative. The audience were then encouraged to ask questions generating further discussion. The audience contained a diverse range of approximately 30 stakeholders including: council staff; academics; energy suppliers; and DNOs, who were encouraged to ask questions and voice their own opinions.

In March 2017 the author designed and delivered a second focus group session to collect data from e-mobility stakeholders regarding alternative solutions to residential recharging needs, in line with the extended business model canvas developed by iBUILD (Foxon *et al.*, 2015). The workshop was titled:

> *Are EV Filling Stations a logical answer for mass adoption of EV and the lack of parking & charging at homes?*

The agenda is provided in Appendix H. A total of 23 experienced recharging stakeholders were invited, representing: PIV drivers with varying recharging needs; recharging network operators; EV dealership; energy provider; grid operator; energy storage developer; financing specialist; academia; smart cities advisors; and local and national government. Whilst this is higher than the recommended six to ten focus group participants (Morgan, 1998), more were intentionally invited to allow for non-attendance and 16 finally participated. To mitigate the risk of group effects caused by reticent or dominant participants, two smaller groups of eight were created for workshop discussion and data capture, with the support of an iBUILD facilitator. Due to the complexity of the workshop transcriptions of the discussions were not made, but participants recorded their contributions at each stage on post-it notes for analysis.

During ZCF's commission to support development of the London Mayor's EV Infrastructure Delivery Plan (TfL, 2019), the author designed and delivered three large stakeholder workshops regarding Londoners' recharging requirements, challenges and opportunities. Each half-day workshop contained three focus group activities interspersed with contextual presentations intended to drive discussion. The first workshop was designed to ascertain EV users' driving and recharging behaviour in London. The second activity focussed on the challenges and solutions for deployment of recharging infrastructure in London, and the final session discussed market models and financing methods. Each workshop attracted between 59 and 95 participants, who were split into groups of approximately ten for focus group discussions led by a facilitator drawn from TfL and ZCF staff. The findings were used to inform London's Delivery Plan and the research aims of this thesis.

3.5 Vehicle Demand for Recharging Services

PIV adoption drives demand for recharging facilities because all PIVs must be plugged into an electricity source to recharge. Chapter 2 identified that PIV models have different recharging requirements, so the quantity and type of PIV registered in an area, coupled with drivers' recharging behaviour, dictates the demand for public recharging. Drivers' patterns of PIV use (distance, frequency, destinations), alongside their recharging behaviour, informs where recharging infrastructure is required and how it will be used. Consequently, data was required covering PIV registrations, technology and use to interpret historic public recharging behaviour and to infer future recharging requirements.

3.5.1 *Vehicle adoption*

Data were required to quantify PIV ownership in NE England and secondary PIV registration data was available from multiple sources: UK Department for Transport (DfT); UK Society of Motor Manufacturers and Traders (SMMT); European Automobile Manufacturer's Association (ACEA); and European Alternative Fuels Observatory (EAFO). However, only DfT's Vehicle Licensing Statistics contained publicly available PIV data at the regional level required for this study. Vehicle Licensing Statistics data were limited because each vehicle was linked to its registration address, which may be a company head office rather than the primary user's address, causing misrepresentations of regional PIV adoption. Further complications were also experienced with this dataset: different vehicle and region definitions between datasets; different update frequency at regional and national levels; and inconsistent update timing.

Data summarising registered vehicles at national, regional and local authority levels was consequently collected from the DfT's Vehicle Licensing Statistics. Data regarding total vehicle registrations was extracted (DfT, VEH0104; DfT, VEH0105) with ULEV and PIV data (DfT, VEH0130; DfT, VEH0131; DfT, VEH0132; DfT, VEH0170) for analysis using Excel to investigate adoption and growth.

Chapter 2 identified the CCC's targets for UK ULEV adoption (Element Energy, 2013) but PIV targets required for recharging demand forecasting and regional targets against which to monitor performance were both lacking. Therefore, a comparison of ULEV and PIV registrations was performed using Excel at national and regional level using DfT vehicle licensing statistics (DfT, VEH0131; DfT, VEH0132). Regional and national total vehicle ownership figures (DfT, VEH0104) were compared to create proportional ULEV targets for NE England. New vehicle registration figures were subsequently collected quarterly from DfT's Vehicle Licensing Statistics to monitor progress towards the region's calculated targets.

Excel was used to track the growth in vehicle registrations at national and NE England LA level from 2011 to 2018 and trend line forecasting techniques were deployed using Excel to estimate likely PIV adoption in the future. The best-fit trendline was found to be a second order polynomial curve reflecting quarterly fluctuations in new registrations. However, modelling is only a valid approach where the underlying conditions are likely to remain the same and both battery technology and PIV availability are likely to change beyond 2025, so only the CCC's 2020 and 2025 target dates were modelled. The same forecasting approach was adopted for all vehicle registration analyses.

A comparison of PIV adoption between UK regions was also conducted to assess relative performance, so data were collected regarding population density (ONS, 2017), wealth (ONS, 2018), housing stock (NOMIS) and mileage data (DfT, TRA89) for analysis. Average annual car mileage was calculated for each region by dividing total cars registered by total annual car mileage reported.

3.5.2 *Vehicle recharging capabilities*

Data regarding the recharging capabilities of PIVs was required to understand the historic demand for public recharging. The PIV's battery capacity and energy efficiency dictate its theoretical range per recharge, which in turn affects the frequency of recharging and the energy required. Driving style, terrain and environmental conditions also affect real-world range (Neaimeh *et al.*, 2013) but real-world figures are rarely reported. Hence changes in PIV capabilities could affect public recharging behaviour and demand. On-line sources (*Electric Vehicle Database*) and vehicle manufacturers' websites were used to identify PIV recharging characteristics and to investigate plans for future technology changes, but firm delivery dates for new model releases and technology changes were unavailable and are beyond the scope of this research.

Secondary data on UK ULEV model sales was collected quarterly from DfT's Vehicle Licensing Statistics (DfT, VEH0170), from which a PIV models subset was extracted. However, this dataset was incomplete, only containing data for the ten most popular models sold and without any regional data. Alternative PIV sales data sources were identified including SMMT and ACEA but PIV registration data by model and region was not publicly available.

3.5.3 *Vehicle use*

Data concerning PIV drivers' trip lengths and frequency was required to inform likely demand for recharging. Secondary data was collected from DfT's national road traffic statistics regarding average road distance travelled per year by mode and by local authority (DfT, TRA89). Total annual car mileage data was extracted for each LA and divided by the total number of licensed cars (DfT, VEH0105) to gain an average annual car mileage for each LA area. Although this dataset was not specific to PIV drivers, it provided adequate data for this study.

To calculate the total annual energy required by PIVs in the NE area, PIV energy efficiency data (*Electric Vehicle Database*) was multiplied by the average car mileage (DfT, TRA89) and PIV registration figures for each LA (DfT, VEH0131). Using the PIV forecasts described in section 3.5.1, future recharging energy requirements were then estimated for the region, enabling estimates to be made for the NE's public recharging energy requirement in 2020 and 2025. Trip destination data would be useful to highlight specific locations where recharging infrastructure is required, but this detail is outside the scope of this thesis.

3.6 Public Recharging Characteristics

To define the historical use of public recharging infrastructure, data was required concerning the composition of the recharging estate, the volume, frequency, energy delivered, type of charger, time of use and location of recharging events.

3.6.1 *Availability of public recharging infrastructure*

To understand the characteristics of charger use, data was required indicating the charger type, its location and operating terms (e.g. access, operator and fee), called static availability data. Primary datasets from the NEPIP and RCN projects were examined to extract availability data for the two case studies. Complementary UK data identifying charger type, locations and operating terms is available on individual network operators' websites, UK-wide recharging maps e.g. Zap-Map[6] and in the National Chargepoint Registry (NCR)[7]. Neither network operators nor Zap-Map provide public access to their datasets, making data collection a time-consuming transcription task. By comparison, the NCR data is freely available, is intended for developer and researcher use and can be downloaded in .csv format for analysis. The NCR has some limitations: it does not provide live status data, but this is not required for this research; it only contains publicly-funded chargers, but this includes most UK chargers and OLEV also encourages private providers to register chargers, so it provides adequate data for this research. The recent Automated and Electric Vehicles Act (HM Government, 2018a) may require the registration of all public access chargers in the future, improving the dataset. Consequently, the NCR dataset was chosen as the best source of secondary UK charger availability data to complement the case study data.

NCR data confirmed that the Charge Your Car (CYC) network operated the majority of NE England's recharging estate, identifying who to approach for recharging event data. The NCR also identified that Ecotricity operated a much wider network than the RCN case study, providing a greater opportunity for data collection and recharging event analysis.

[6] Zap-Map is available at https://www.zap-map.com/live/

[7] The National Chargepoint Registry can be downloaded from http://www.national-charge-point-registry.uk/

3.6.2 *Use of public recharging infrastructure*

To define the characteristics of public charger use, recharging event data was required which was not publicly available due to early-market commercial sensitivities. However, the author's role in the two case study projects NEPIP and RCN, described in section 3.8, enabled access to early recharging datasets. The NEPIP project provided unexamined datasets containing primary recharging event data for NE England from 2010 to 2013, the most comprehensive dataset of its type at the time. The network operator CYC also gave permission to collect additional primary recharging data for the period 2013 to 2018, creating a large nine-year NE England population dataset of 497,469 recharging events referred to as NECYC. Ecotricity, operator of the Electric Highway (EH) national recharging estate, provided recharging data for 94 publicly-funded rapid chargers installed between 2013 and 2015, including RCN project data. Data for the entire national EH network was subsequently provided from August 2016 to September 2017, creating a large population of 363,751 EH rapid recharging events. Recharging data collected beyond the case studies contained additional variables, which enabled a study of the implications of vehicle type and fees on recharging demand.

Excel was initially used for recharging data analysis, identifying the independent categorical variables: charger type; location type; access type; and ownership; as well as two dependent numerical variables: charge event energy and duration. But by the third year of data collection, it became apparent that Excel was no longer a suitable tool for recharging data analysis due to the growing size of the dataset and the need for statistical analysis. Two alternative tools were investigated for continuing recharging data analysis. SPSS software is widely used in social science research to edit and analyse data and provides predefined statistical tests through a menu-based interface. As an alternative, the open-source R package was already in use by university researchers on the RCN project. R was found to be a more flexible, free-to-use tool, integrating easily with the existing datasets created in Excel. The ability to cleanse high volumes of data and to test out ideas using clear plotting and visualisation commands made R ideal for the growing recharging dataset. The R-Studio tool with its many tested and verified commands and online advice also provided an opportunity to develop transferable programming skills for later use. Consequently, the R software package was chosen to complete the analysis of recharging data. The coding methods and analysis techniques used are described in the following sections.

Inconsistencies were identified in both datasets, including date and time format errors, energy data omissions and erroneous records with energy readings outside of PIV recharging capabilities, requiring significant data cleansing. The duration of each recharging event was calculated using the start and end dates and times recorded. A duration filter was applied using DfT's methodology (DfT, 2018a; DfT, 2018b), removing extreme durations below three minutes and above one week which do not represent PIV recharging capabilities and could skew the analysis unnecessarily. Adopting this filter enabled comparison with DfT reports on 2017 UK recharging data.

The cleansed datasets were then categorised ready for analysis. Using the charger model data each recharging event was assigned a charge point type according to UK terminology (UK EVSE): slow, fast, rapid, and a power level (3,7,22 or 50 kW). Using the start date provided, appropriate days, months and years were assigned to enable a review of the spread of recharging events over time. NECYC location types were assigned using the first digit of the unique identification code designed by the NEPIP project to indicate: Commercial places; Public on- and off-street places; Workplaces and Transit locations. However, the NEPIP coding philosophy was found to be inconsistent, so CYC's website (*Charge Your Car Limited*) was used to confirm location types for chargers where necessary. The NECYC charger owner (host) was identified from the group field in the dataset and then categorised into five company types: Academia, Council, Government, Private and Third Sector for analysis. All EH recharging events were delivered by rapid chargers at transit locations. The private company Ecotricity owned all EH chargers, however the chargers were sited and therefore "hosted" by private site owners under operating agreements. EH charger identification coding changed between the first and second periods of data, so a cross-matching exercise was performed to standardise unique identifiers ready for analysis. Finally, test and duplicate recharging events were identified and removed, and the remaining population dataset was analysed using the R-Studio tool to provide a detailed account of recharging behaviour.

The first stage of analysis quantified the density of each recharging estate in terms of unique charge points recording data each year by each independent variable: location; access; charge point type; and ownership. Next, an analysis of recharging events was performed to quantify the volume of recharging activity delivered each year by each independent variable. To identify peak demand periods bar charts summarising recharging events and energy by day were produced, and a line graph of start times was plotted to identify trends during the day. Line graphs were also plotted by month to visualise the trends in recharging events and energy delivered over the study period.

As the income generating features in the recharging business model, the dependent variables energy and duration of recharging events were then investigated in more detail using population statistics. Boxplots were created to understand the distribution, variability and centre of the recharging event energy and duration data by location, access and charge point type. Line graphs were plotted to inspect the trends in average recharging event energy and duration over the study period. Both mean and median time series were generated but extreme duration data skewed the results, so the median was chosen as the best representation of the central location. The annual utilisation of each recharging estate was calculated by dividing the total recharging events by the number of unique charge points for each category: location, access and charger type.

Statistical tests were performed to identify the significance of differences between the dependent variables, energy and duration, caused by the independent variables: charger type; location type; and access type. Firstly, the population statistics were inspected for each dependent variable and a sample containing December 2018 data was created to investigate normality using the Shapiro-Wilk test. Having concluded that the data was not normally distributed, non-parametric tests were identified to investigate significance. The Wilcoxon-Mann-Whitney U-test was performed for each independent variable to investigate whether the populations were identical, and the Kruskal-Wallis test was used to compare means since each independent variable had more than two groups.

The correlation between the two dependent variables, energy delivered and duration of recharging events, was inspected using scatterplots for each independent variable:

location; access; and charger type. Initial inspection identified that the datasets contained some impossible recharging events, with very high energy but very low duration readings. Therefore, a rate of recharge calculation was performed on all recharging events to identify and remove impossible events which exceeded the maximum charger power. The correlation coefficient was then calculated for the relationship between energy and duration for the variables: charger; location; and access type. Histograms were also produced to inspect the distribution of energy delivered per recharging event because this is an important aspect of recharging business modelling and energy network capacity planning.

Analysis of variance (ANOVA) tests were performed to determine whether the independent variables – charger, location, and access type – acted in combination with each other to affect the mean energy delivered. Although normally distributed data is usually required for ANOVA testing, the sample size was sufficiently large to assume normality according to the Central Limit Theorem. Since rapid chargers had a one-to-one relationship with the Transit access and location variables, rapid charge events were removed from the data creating a subset of slow and fast charge events. Two-way ANOVA tests were then conducted using R on the two remaining levels of charger type (slow, fast) with two levels of access type (All Public, workplace), and then with the four remaining levels of location type (commercial, on-street, off-street and workplace).

An analysis of unique users and PIV models using each recharging estate was performed from 2013 since user identification and vehicle model data were missing from earlier records. Using the PIV model field, each record was assigned a Powertrain type (BEV, PHEV) and bar charts were produced for each independent variable to visualise comparative frequency of use. Subsets of BEV and PHEV recharging events were then created to examine the energy and duration distribution, variability and centres for each powertrain with each independent variable.

Further data subsets were created to compare NECYC and EH use in the free-to-use period and to determine the effect of fees on EH use. EH subset 1 contained 91,116 free-to-use recharging events delivered before 2016, whilst subset 2 contained 154,363 events delivered between Aug 2016 and Oct 2017 with fees in place. Two further EH subsets were created to compare behaviour under the two different fees identified within subset 2. In total 106,313 events were studied with Fee 1 applied: a £6 fixed price charged for up to 30 minutes duration between 1st August 2016 and 25th June 2017. 47,980 events with Fee 2 were studied: a £3 fixed connection fee plus 17p per kWh of electricity received, applied after 25th June 2017.

3.7 Public Recharging Business Models

3.7.1 *Costs and fees*

Cost and use data were required to determine whether the capital investment in recharging infrastructure, with its associated operating costs, can be recovered over a reasonable time to make a return on capital which is sufficiently attractive for a prospective investor.

Capital cost data was collected from the two case studies providing a large dataset of empirical data for over 1,000 chargers covering a range of equipment types, installed in a variety of locations over a five-year period up to 2015. Capital cost data covered chargers, warranty and delivery, ancillary equipment, civil and electrical works and commissioning activity accumulated and analysed by charger type and location type using Excel. However, this cost data represents the early e-mobility market, which limits the validity of the results because equipment prices are likely to change as demand and capability grows and grid supply costs will increase when sites with inadequate power supply are exploited in the future.

Operating costs include electricity, site rent/lease, back office, customer support, planned and unplanned maintenance costs. Minimal operating cost data was available for analysis from either project due to commercial sensitivities, so operating cost data was sought from charge point owners using the research methods described in section 3.4.2.

To determine the revenue available from recharging infrastructure, information was required about the fees being charged to PIV drivers and the amount of energy being delivered. No fees were levied during the two case study projects, as an incentive to encourage PIV adoption and public recharging. However, following RCN project closure, fees were introduced on the EH recharging network, so pricing information was collected from the EH website and combined with energy delivery data obtained from the recharging event dataset to calculate the revenue generated from the sale of energy through recharging infrastructure in the EH estate.

3.7.2 *Business model investigations*

During the RCN project the author assisted in the construction of a business model using capital expenditure, operating costs and use data from 64 rapid chargers deployed on main highways. Since no fees were charged to users at that time and PIV adoption was at the innovator stage, the model was used to identify the conditions in which a profit could be made from rapid charger operation using assumptions for market growth. The development of the model and its findings are described in the Energy Policy journal (Serradilla *et al.*, 2017). In this thesis, data collected during the two EH fee periods were used to test the RCN model by comparing the point estimate profitable year predicted in 2015 with the result gained using empirical recharging data. The model was subsequently updated with empirical recharging data to compare the effect on forecasted profitability of each EH fee studied and using the willingness-to-pay survey results collected in the 2015 RCN surveys.

The model was then amended to reflect NECYC fast charger cost and use data to study financial return for fast chargers. Fees were modelled in various forms: fixed fees; per kWh; and by duration, and at various levels using the preference responses obtained from the willingness-to-pay questions in the 2016 drivers' survey.

To investigate the wider value of public recharging infrastructure, the second iBUILD workshop introduced in section 3.4.3 was structured to obtain value data from recharging market actors. An iBUILD study (Hall and Roelich, 2016) exploring complex value resulting from business model innovation in energy supply markets identified the benefits of workshop activities to identify stakeholders' opinions and motivations. Participants discussed the need for public recharging facilities for residents without off-street parking who cannot recharge at home and assessed the relative value of three alternative public recharging scenarios: EV Filling Stations (EVFS); rapid chargers; and on-street fast chargers. The workshop trialled the iBUILD Infrastructure Value

Framework (iBUILD, 2018) as a structured approach to elicit ideas for alternative business models for public infrastructure at a local scale. The iBUILD framework was adapted to suit the topic, providing the seven-stage process attached in Appendix I. Firstly, the participants discussed the outcomes of solving the lack of home recharging problem and identified enablers and challenges. Following the presentation of three alternative solutions, the stakeholders discussed the benefits of each solution (the value proposition) and its beneficiaries (the value network), and where and when those benefits might be realised. This method enabled a collective map of recharging benefits to be created by each group, followed by a facilitated discussion where ideas were challenged and constraints identified. Unfortunately, this half-day session did not reach the final steps of funding and business model discussion, indicating that the agenda was overambitious.

3.8 Case Studies

Recharging event data was required to define the historical use of recharging infrastructure but, because the recharging market is still emerging, this data is commercially sensitive and usually unavailable for public research. Literature reports recharging results from short trials, but longitudinal data for public charger use and associated deployment and operating costs is largely missing. Access to PIV drivers and charge point owners was also required to gather data on their recharging experiences and preferences, but contact details are not readily available outside of the industry. Consequently, case study data was sought to begin this research.

At the beginning of this research the author was delivering two major recharging projects at Zero Carbon Futures, considered as social-technical experiments, providing access to recharging event data, cost data and stakeholders. The motivation for this research came from questions for further study arising from the unexamined datasets of the regional North East Plugged in Places recharging project (NEPIP). The national Rapid Charge Network project (RCN) then provided the opportunity for direct data collection to inform this thesis. Recharging data from both case studies was historical, drawn from early PIV adopters, driving PIVs equipped with maximum 24kWh batteries and 3kWh on-board chargers, using first generation recharging equipment which was free-to-use. This early adopter behaviour may change as PIV battery capacity increases, drivers undertake longer journeys more frequently, recharging technology and equipment changes, and recharging fees are introduced. This thesis addresses those concerns by conducting a longitudinal study to investigate changes in recharging behaviour as the environment changes beyond the case study projects.

The results generated by this place-based approach will provide evidence of how PIV users recharge in both urban and rural public locations. This information could be used by UK local authorities with similar demographic characteristics including vehicle ownership, mileage, residents' wealth and housing stock to understand their area's public recharging infrastructure needs. A comparison of relevant demographic characteristics between UK regions is provided in chapter 5.

3.8.1 *North East Plugged in Places project (NEPIP)*

The NE Plugged in Places project (NEPIP) was one of the UK's first public recharging deployment projects, funded by OLEV and regional stakeholders from 2010 to 2013. NEPIP provided primary data for this research: type, location and cost of chargers deployed; recharging event data (2010–2013) which the author was involved in defining; and stakeholder contacts from national and local government, charge point owners and PIV drivers. Therefore, NEPIP enabled primary quantitative recharging data and qualitative data to be collected regarding policy, recharging requirements, experiences and perceptions.

The NEPIP project created a recharging network encompassing a region of 8,600 km^2 between April 2010 and June 2013, including 1,138 slow, fast and rapid charge points installed in public places, workplaces and in PIV drivers' homes. Hosts were attracted to have charge points installed on their property using capital incentives, so recharging locations reflected hosts' rather than PIV drivers' requirements. Each host took ownership of their charge points and responsibility for maintenance and public and workplace hosts provided public access, free electricity and free parking to PIV drivers for three years ending in June 2013.

All charge points in workplaces and public places were operated by CYC, providing PIV drivers with access to the entire regional recharging estate using a radio-frequency identification (RFID) card, each with a unique ID used to identify the user. PIV drivers joined CYC's membership scheme at a cost of £100 per year or £10 per month and received free electricity and parking whilst recharging. Data for each recharging event was transmitted via the Global System for Mobile communications (GSM) network to CYC's Charge Point Management System (CPMS). The data was collected from the CPMS and analysed for this thesis alongside charge point location and type data collected from the NEPIP project and CYC website.

The NEPIP dataset was limited by: the involvement of innovator and six-month trial PIV drivers; PIVs with 24 kWh maximum battery capacity; and the free parking and recharging incentives. Consequently, sequential data was collected from 2013 to 2018 providing a large longitudinal dataset to fulfil the research objectives. Additionally, the dataset did not contain home recharging data for comparison with public and workplace recharging behaviour which would be useful for further research.

3.8.2 *The Rapid Charge Network project (RCN)*

Zero Carbon Futures and Newcastle University delivered the RCN project from 2013 to 2015 deploying rapid chargers along main roads linking UK and Republic of Ireland, funded by the EU's TEN-T programme and vehicle manufacturers. The RCN project provided the following data for this research: type, location and cost of chargers deployed; recharging event data (2013–2015); access to key stakeholders including four PIV manufacturers (Nissan, BMW, Renault and VW), electricity suppliers and recharging network operators (Ecotricity's Electric Highway and Ireland's ESB ecars). RCN conducted questionnaires with over 200 PIV drivers which the author contributed to designing, with specific questions formulated to inform this research.

The RCN Project deployed 74 rapid chargers equipped with three charging outlets accommodating the mainstream recharging protocols: CHAdeMO; CCS; and AC. The chargers were installed at privately owned sites including motorway service stations, fuel stations, retail facilities, air and seaports. The route included main motorways and traversed rural areas containing main road links to Ireland. The project aimed to enable PIVs to drive beyond the 24 kWh battery range constraints of that time by using rapid chargers at key staging points.

The RCN chargers were operated on a free-to-use basis by two recharging network operators: Ecotricity's Electric Highway network in Great Britain; and ESB's ecars network in Ireland. PIV drivers registered with either network to obtain an RFID card to access all chargers and a whitelist approval mechanism was used to enable Ecotricity and ESB ecars customers to roam between the two networks. Each CPMS recorded the unique charge point ID, user RFID, recharging event start and end date and time, and energy supplied for each recharging event. Recharging event data from 2013 to 2015 was supplied from EH's CPMS for analysis in this research. The author's data format specification enabled comparative analysis with the regional NECYC dataset.

The RCN dataset only contained rapid charging data from innovator PIV drivers and the free-to-use recharging incentive may have influenced users' behaviour. However, Ecotricity subsequently introduced recharging fees in 2016 and provided recharging data for 2016 and 2017 exclusively to enable a study of comparative use before and after fees, previously unavailable for academic research. The combined national rapid recharging dataset is referred to as EH throughout this thesis.

3.9 Summary

The goal of this chapter was to outline the hypotheses, objectives and approaches used to address the two research aims. Two hypotheses with associated objectives were defined to explore the first aim using qualitative and quantitative methods, whilst an interpretivist approach was taken to address the second aim. A mixed methods interdisciplinary research approach was used to collect and analyse transport, business and social science primary and secondary data. The procedures, study participants, data collection and analysis methods were explained for each of the four study areas, together with the case studies which provided the motivation and early data for this research. Chapters 4, 5, 6 and 7 present the results and discussion of the four study areas performed using the methodology described: Recharging stakeholders; Vehicle demand for recharging; Public recharging characteristics; and Public recharging business models.

Chapter 4. Public Recharging Stakeholders

The purpose of this chapter is to present the results of the analysis of stakeholders in the evolving public recharging market and to discuss their roles, objectives and requirements. Chapter 2 identified gaps in the understanding of the interests and interfaces between diverse roles in public recharging, so the identified stakeholders are discussed within the recharging business ecosystem in section 4.1. Chapter 2 highlighted that stakeholder comprehension is required to plan successful e-mobility transitions, especially at the local level so key actors in NE England were identified through the case studies and ZCF's contacts for further engagement. Three stakeholder groups were selected for consultation based on their likelihood to experience material outcomes from public recharging and their access to likely respondents. As described in section 3.4, preference data was collected using questionnaires and workshops and analysed to identify their requirements and objectives for public recharging. PIV drivers' results informed the demand study conducted to test hypothesis 1 described in 3.3.1, charge owners' results informed the supply study 3.3.2 and wider stakeholders' results informed both the supply study and aim 2 described in 3.3.3. Each group's results are presented and discussed in sections 4.2, 4.3 and 4.4.

4.1 Discussion of Stakeholders in the Recharging Ecosystem

Stakeholders are those people or groups who are affected by or who can affect an organisation's activities in any way. The effects can be positive or negative and either intentional or unintentional. Chapter 2 identified the importance of defining stakeholders and understanding their interests and agency, in order to make policy decisions which can lead to successful socio-technical transitions. This need is pertinent to the transition from ICE vehicles to e-mobility solutions and the recharging services required to enable that transition.

The literature review (Kley *et al.*, 2011; San Roman *et al.*, 2011; Bakker *et al.*, 2014; Williander and Stalstad, 2015; ACEA, 2016) and ZCF's contacts identified many stakeholder groups in recharging services, which are illustrated in Figure 4.1. Workshop results were supplemented by experience gained at ZCF to produce the discussion of each group's interests and constraints presented in the following sections 4.1.1 to 4.1.4. Some identified recharging stakeholders that had no prior experience of the transport sector because recharging provides new opportunities and risks which affect society as a whole (Bakker, 2014; Malmgren, 2016). This diversity presents new economic opportunities for actors to develop new products and services (Ceschin, 2013), whilst also causing risks for other stakeholders such as energy security for future generations.

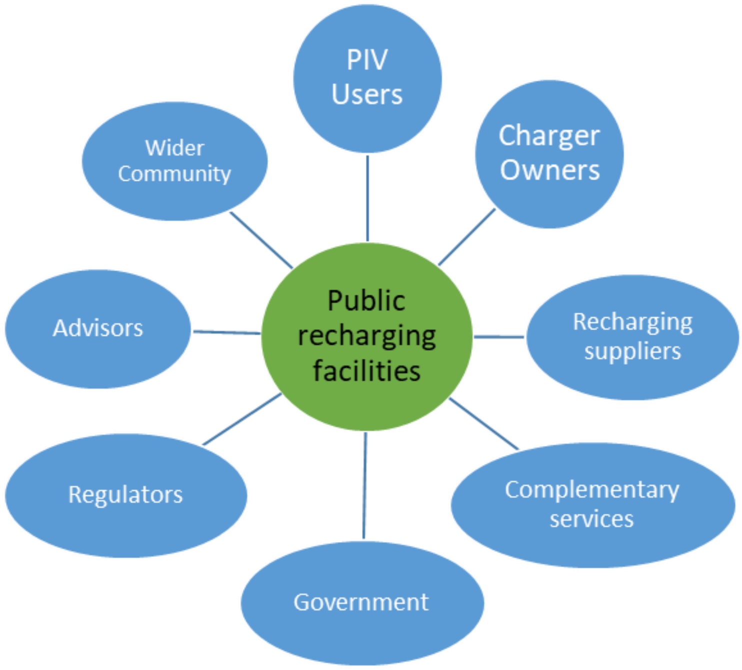


Figure 4.1 – Stakeholders in the recharging market

According to Moore's business ecosystem (BE) definition (Moore, 1993) the diverse stakeholders form an interactive business community in which economic actors produce goods and services of value to customers, supported by intermediary actors. Using Shang's method of BE representation (Shang *et al.*, 2015), stakeholders in the public recharging business ecosystem are depicted in three sub-systems in Figure 4.2: BE supply, BE demand and BE intermediaries.

The stakeholders providing demand in the recharging ecosystem are PIV users with differing use cases and resultant need for public recharging services, which are discussed in section 4.1.1. Charger owners and their recharging suppliers fulfil the supply functions within the ecosystem, discussed in sections 4.1.2 and 4.1.3. Finally, intermediaries in the recharging ecosystem are discussed in section 4.1.4.

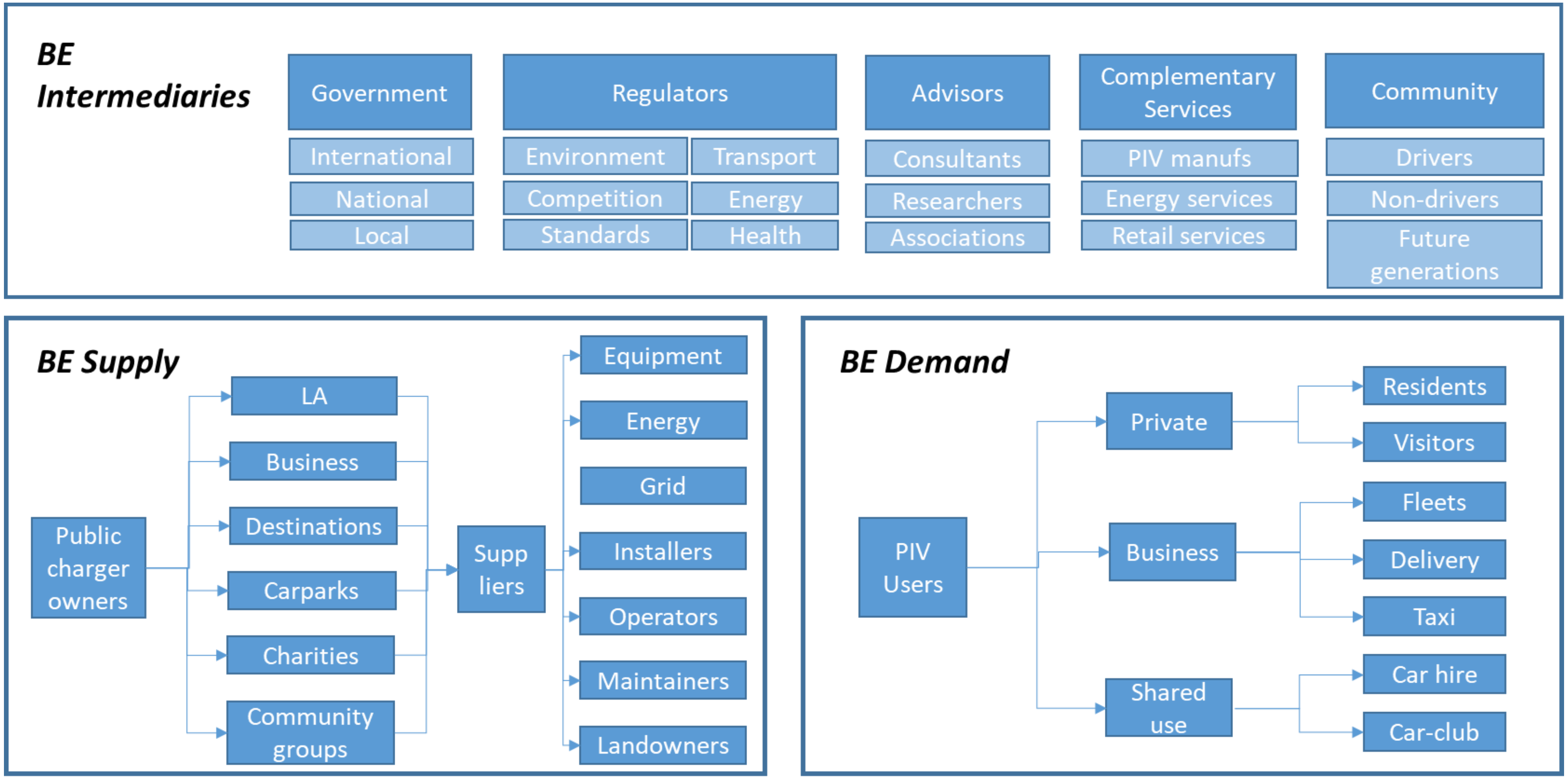


Figure 4.2 – Public recharging business ecosystem

4.1.1 *Business ecosystem demand – PIV users*

PIV users provide demand for public recharging services and Chapter 2 has identified that their requirements vary according to their travel behaviour, so this section discusses the public recharging needs of a selection of PIV use cases summarised in Figure 4.3. Private, business and shared vehicle users will need to adopt e-mobility solutions to meet the government's transport emission reduction objective, but their recharging needs are likely to differ.

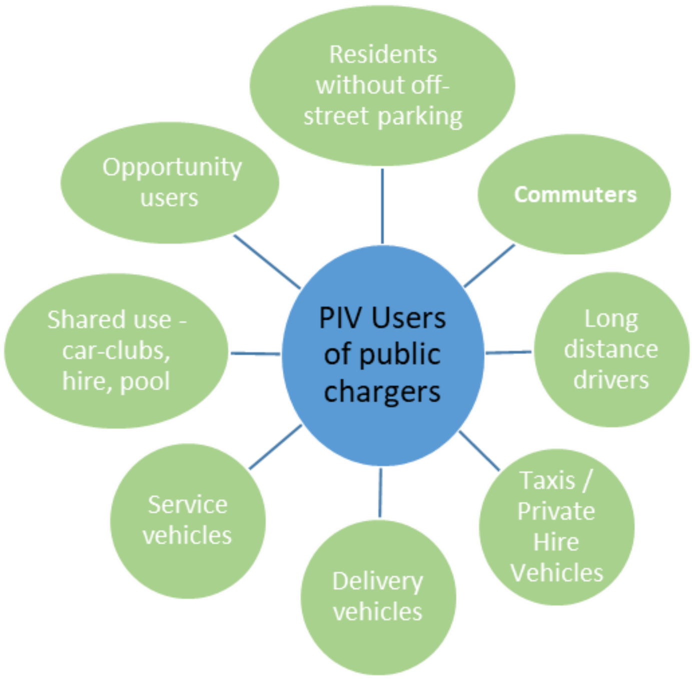


Figure 4.3 – PIV users of public recharging facilities

Literature (Skippon and Garwood, 2011; Morrissey *et al.*, 2016) indicates that PIV drivers prefer to recharge at home overnight so **residents without access to off-street parking space at home** could find this a barrier to PIV adoption. Consequently, public recharging facilities are required elsewhere to enable them to recharge. Convenience is key to residents' use so distance from home, access hours, availability, security and pricing are important considerations for PIV users without off-street parking. All charger types could meet their needs if publicly accessible. Slow or fast chargers close to home on residential or local high streets or in car parks which are empty overnight could provide recharging services whilst vehicles are parked for long durations. Alternatively, rapid charging hubs in central locations could provide quick turnaround recharging solutions similar to fuel stations.

Drivers who commute to work could recharge whilst their vehicle is parked throughout a working shift (Hardman *et al.*, 2018), providing a top-up recharging service for long-distance commuters, replacing home charging, or an opportunity charge if cost and convenience allows. Slow or fast chargers in workplace car parks provide a convenient solution, but power requirements and cost may be prohibitive to employers so fees could be charged via salary sacrifice schemes in conjunction with a booking system to maximise utilisation as demand grows. Workplace recharging could also provide local energy management solutions for employers and additional revenue from grid optimisation services for DNOs. Companies which rely on vehicles such as delivery and service fleets will require low-cost, highly reliable smart recharging solutions in depot locations to ensure PIVs are ready for use with sufficient range when required. Vehicles with predictable daily routes and distances within PIV battery range can be scheduled to recharge automatically between shifts using smart recharging solutions, however unpredictable travel behaviour increases recharging risk making PIV adoption unlikely in the short term. Depending upon such operational considerations, employers may choose to limit workplace chargers to employees and company vehicles only or open them to public use during or after working hours.

Drivers wishing to travel beyond the range of a single battery recharge require quick recharging solutions close to their travel route to top-up during their journey (Hübner *et al.*, 2013b). Rapid chargers in transit locations provide this solution for most PIVs currently but recharging durations approach 60 minutes for the largest PIV batteries, limiting its convenience to drivers. High-power recharging solutions with faster recharging speeds could reduce this constraint whilst also increasing capacity for recharging operators in the future. However, transit recharging solutions incur high capital costs and high utilisation may be required to provide return on investment in a timeframe which meets investors' financial demands.

Taxi, private hire, delivery and service vehicles typically travel further each day than private vehicles and as consumers' quick home delivery and service demands increase these vehicles may need to recharge during a shift. Light commercial vehicles registered in NE England travelled an average of 11,045 miles per year in comparison to the 8,652 miles travelled by cars (DfT, TRA0106; DfT, VEH0104). Convenience, availability and reliability of public recharging during both day and night shifts will be essential to minimise lost operating time, so rapid chargers close to main routes with preferential booking services may provide an increasing revenue opportunity as fleets adopt PIVs. However, the unpredictability of routes and variations in daily mileage make PIVs a risky solution for business fleets which have limited public recharging demand to date. Public recharging services will also be necessary for fleet drivers without depots or off-street parking who take their vehicles home, for example an estimated 40% of London taxi drivers (TfL, 2019). Business-critical drivers without alternative workplace or home recharging solutions are therefore key customers for recharging operators.

Shared-use vehicles could also convert to PIVs requiring recharging facilities. **Car-clubs** are an attractive sustainable transport solution, reducing car ownership by offering shared-use services and PIVs can reduce their emissions impact. There are two operating models in the UK requiring different recharging solutions: dedicated fast chargers could support cars collected and returned to a specified bay; however widespread public chargers are required for the second model in which cars are collected and dropped off anywhere. Availability and reliability of chargers is essential for both car-club business models and real-time state of charge data is required to manage vehicle availability, so smart charging solutions which communicate between PIV and car-club systems are valuable to car-club operators. Vehicles shared by company employees through a **pool-car scheme** could also use workplace and public recharging services depending on their base and travel behaviour. **Hire vehicles** travelling within battery range could use depot charging facilities, but public recharging services will be required to extend journeys beyond the current PIV range at transit locations. Shared-use vehicles can increase PIV awareness and experience for many drivers and wider community stakeholders, whilst also providing certainty of recharging demand to operators.

The final user category discussed is **opportunity users** who top-up their PIV battery whenever the opportunity arises regardless of need or duration of stay. Fast chargers at destinations or rapid chargers in transit locations could meet this requirement, however this use is highly dependent upon price, reliability and availability of the recharging facility and its use is unpredictable, causing uncertainty for business models.

4.1.2 *Business ecosystem supply – public charger owners*

Many different organisations chose to provide recharging facilities for public use, summarised in Figure 4.4. The charger owners then use recharging suppliers to deploy the equipment and operate the service on their behalf as discussed in section 4.1.3.

Figure 4.4 – Typical owners of charge points for public use

The deployment of publicly accessible chargers in the UK up to 2019 has been heavily funded by UK government through capital incentives targeted at **Local Authorities (LAs)**, so much of the UK's fledgling recharging infrastructure is under local government ownership. However, LA revenue funding is scarce for ongoing maintenance and operation and little opportunity for revenue from electricity sales has stifled these assets, so some suppliers now offer new charger lease packages retaining asset ownership and maintenance responsibilities.

Private owners of chargers seek long-term revenue and so look to secure long-term lease agreements at locations which are likely to have high recharging demand in the future, creating a "land-grab" activity. Ecotricity's rapid charging agreement with all UK

MSA operators and IONITY's similar strategy for high-powered charging, described in 2.8.5, both focus on high traffic routes demonstrating both energy companies' and vehicle manufacturers' interests in public recharging.

Operators of retail, leisure and tourism destinations where visitors travel by car are interested in providing recharging facilities as a complementary service for their customers, aiming to generate additional revenue from electricity sales and facility use resulting from longer visit durations. **Commercial car park operators** also see the attraction of recharging as a revenue-generating added-value service for medium- and long-stay customers. However, destinations where parking is scarce such as healthcare and academic sites cannot satisfy additional parking demand, so are unlikely to regulate charging bays for PIV use only which reduces the charger asset's value. For destination operators unable or unwilling to make capital investment, both private and charitable recharging organisations now offer financed solutions such as Zerocarbonworld[8] which provides free charging equipment that the destination then installs, owns, maintains and operates.

Increasingly **community groups** are investigating opportunities for low-carbon transport and community energy groups and co-operatives have highlighted recharging infrastructure as a growing area of interest (Community Energy, 2019). Members of an investment group contribute towards the capital cost of an energy-generating asset, e.g. solar panels, to reduce energy costs for the members and surplus revenue is reinvested in further projects in the local economy. Community members who contribute to recharging infrastructure could have sole or preferential use of chargers, paying zero or lower fees than non-members. Such schemes could also utilise renewable energy, reducing costs for everyone, and help to manage peak demands on the grid if energy storage services are also employed. However, low PIV

[8] Further information can be found at https://zerocarbonworld.org/free-charging-stations

adoption and therefore low recharging demand is still a major barrier for such organisations.

4.1.3 *Business ecosystem supply – recharging suppliers*

There are many recharging supplier stakeholders as illustrated in Figure 4.5 and new entrants continue to join. Some perform multiple roles in the business ecosystem, whilst some supplier consolidation across functions is also evident in the UK market.

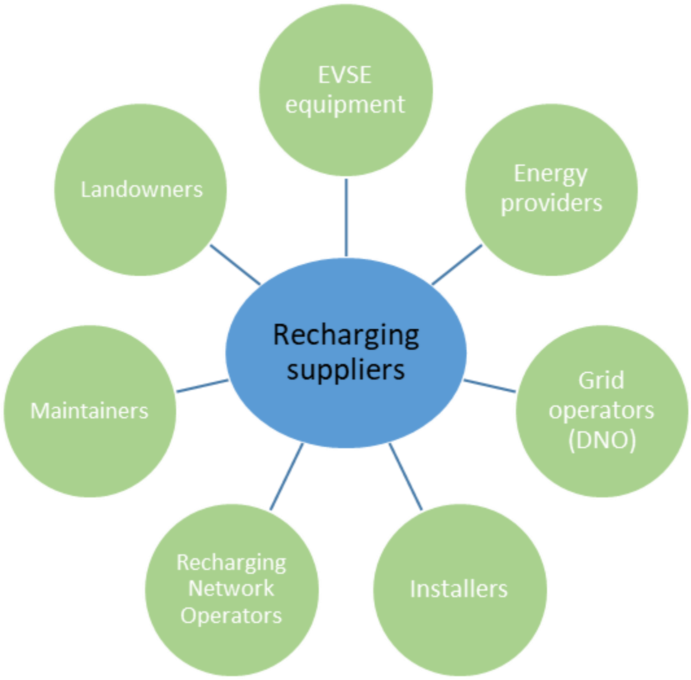


Figure 4.5 – Recharging suppliers summary

Equipment suppliers provide appropriate chargers and associated equipment to meet the varied recharging needs of PIV users. Different types of charger suit different duration requirements, space and grid power constraints and multiple manufacturers now offer a wide product range described in section 2.8.5. Some charger owners choose a single EVSE supplier for ease of operation and economies of scale, whilst others create a mixed-manufacturer network to compare capabilities and costs. Many EVSE suppliers also offer installation, maintenance and operation services using either their own or a partner's back office.

Energy providers supply the electricity delivered to PIVs by chargers and are beginning to play a leading role in UK recharging by setting up recharging networks, buying or partnering with EVSE suppliers and network operators. In Europe PIV drivers can chose from several energy suppliers when using public chargers, providing choice on price and carbon intensity. Mobile electricity packages are available from domestic energy suppliers across multiple recharging networks, however the UK regulatory framework does not currently enable this.

Distribution Network Operators (DNOs) provide new power connections from the grid to chargers where existing power supplies lack spare capacity. The 14 licensed UK DNOs are each responsible for a regional distribution area and are regulated by Ofgem to protect consumers from abuse of monopoly power. DNOs have legal responsibility for continuity of power supply and therefore have genuine concerns about peak loading levels exacerbated by recharging behaviour.

Installers perform all civil and electrical works required to deploy a charger including commissioning services where the charger is connected to the power supply and tested in-situ for safety, communications and operation. Many installers also provide ongoing maintenance services.

Maintainers provide preventative and reactive after-care services to charger owners and network operators in partnership with EVSE suppliers to ensure charger availability.

Recharging Network Operators manage multiple chargers in a network, providing the Business-to-Customer (B2C) link between chargers and PIV drivers by facilitating access, payments and customer support services. Recharging Network Operators also deliver services to charger owners including reporting, maintenance and energy and can provide revenue from recharging and associated services such as parking. In future, providing energy management services to DNOs is likely to be an increasing revenue stream.

Landowners own the land where chargers are sited and allow access for PIV drivers to use recharging facilities. The location of and easy access to chargers is critical to their use as discussed in section 4.2 and in Chapter 6, so securing suitable locations is a critical task for recharging network operators. Private landowners and LAs with control over highways and public car parks can act here by making suitable land available for recharging deployment. However, landowners can also help to accelerate e-mobility and consequently grow recharging demand by providing PIV education and awareness to their own stakeholders through local business, social and community networks.

4.1.4 *Business ecosystem intermediaries*

Intermediaries are key stakeholders required to promote and accelerate the transition of socio-technical innovations such as e-mobility, enabling the business ecosystem lifecycle to move through four phases: birth; expansion; authorities; and renewal. Five intermediary roles identified in the public recharging ecosystem are discussed in this section (Kivimaa *et al.*, 2019) highlighting the motivations, change agency and the transition levels at which each intermediary acts, in line with the MLP and SNM approaches to explaining socio-technical transitions outlined in section 2.3.

As introduced in section 2.8.1, **governments** at the **international level** have policies and legislation aimed at reducing emissions from transport, which in turn affect national UK government actions and subsequently local government actions. But international government policy such as EU vehicle emission requirements also affect other intermediary actors such as regulators and vehicle manufacturers, demonstrating how stakeholders are interconnected across the business ecosystem.

The UK recharging market has developed specifically to support the **national government**'s policy to replace ICEs with PIVs to reduce transport emissions as described in section 2.8.2. Hence recharging infrastructure is relevant to multiple government departments: transport; environment; energy; business; health; and treasury. However, section 2.8.4 indicated that PIV uptake is still in the early stage of consumer adoption, rendering public recharging demand too low to be financially viable. Consequently, the government has major interests in the recharging market's ongoing development, intervening where market failure is perceived or to ensure that policy goals can be met as described in section 2.8.2. However, it is vital that new technologies achieve sufficient early adopters to establish a market niche (Geels, 2002) so government acts as a **systemic intermediary** with high agency, opening up space for new recharging solutions to develop whilst providing some protection from the ICE regime through incentives.

Local government is responsible for providing vital services for people and businesses within a defined area, including housing, schools, social care, road maintenance and planning services. Elected councillors in local authorities work with local people and businesses to agree and then deliver local priorities. UK LAs are required under Local Air Quality Management (LAQM) legislation to review air quality and take action where concentrations exceed national objectives, reported in a local Air Quality Action Plan (AQAP). Typical responses include encouraging PIV uptake, so the provision of recharging facilities is an important tool for LAs who can play a valuable role in making sites available for recharging provision. For LAs looking to expand their recharging infrastructure, supporting private providers and local groups to install and manage public chargers reduces demands on scarce LA finances, whilst benefitting local communities. LA financial support could instead be focussed on areas where private sector providers are unlikely to operate due to the current lack of demand, making recharging facilities accessible for all sectors of society in readiness for mass adoption of PIVs as prices reduce and the second-hand market grows in future.

Recharging services span many **regulatory** areas including transport, energy, environment, health and safety, and competition. Regulation is used to protect people, businesses and the environment and to support economic growth where markets would fail to act in accordance with public interest if left to their own devices (National Audit Office, 2017). Clean air policy is one such area in which recharging services play a key role and the recent Automated and Electric Vehicles Act (AEVA) (HM Government, 2018a) legislation can require public recharging provision if the market does not grow as required to enable PIV adoption. A number of national regulatory bodies are involved: Ofgem because recharging services are part of the electricity market; Office of Road and Rail (ORR) because chargers are provided on strategic roads; and the Health and Safety Executive (HSE) to ensure chargers are safe to operate in public places. Multiple standards have developed governing recharging technology, installation and operation as described in section 2.8.5, with input from transport, energy and construction actors which demonstrates vertical and horizontal interaction of stakeholders. The Competition and Mergers Authority (CMA) has also become involved with the acquisition and merger of leading market players such as Elektromotive by Chargemaster and subsequently BP’s acquisition of Chargemaster. The acquisition of charger suppliers, particularly by energy suppliers, is currently a feature of the UK recharging market raising consumer concerns about pricing which may require further regulation. Regulators at the local level cover transport and building activities which can enable recharging provision: traffic regulation orders governing change of land use on public roads and in parking areas; and upcoming building regulation requirements due to be announced in 2020. LA officers must be mindful of public objection, cost and revenue implications, to balance those concerns against transport emission reduction objectives.

The term **advisors** is used to describe the organisations which conduct research, provide policy and strategy advice or represent industries within the ecosystem. Advisors are usually politically and technologically neutral organisations acting as **systemic intermediaries**, trusted as independent, using public and private funding to deliver projects creating knowledge to be shared to accelerate change. However, as transition progresses advisors such as ZCF are able to identify common issues and diffuse accumulated experience to assist isolated stakeholders in successful e-mobility adoption, evolving into a **niche intermediary role.**

Complementary services are offered in addition to a business’ core service and have an indirect impact on the utility a customer receives. Sometimes the complementary service has low value when consumed alone such as retail refreshments consumed whilst recharging, but it can add to the total value of recharging services. Hence recharging facilities could become complementary services for any business providing car parking services, e.g. to destination operators such as retail, leisure and tourism facilities. Similarly, advertisers may consider recharging facilities as a complementary service, taking the opportunity to direct information about other products and services to captive customers during charge events. In recompense these opportunities could add revenue to the recharging business model.

In reverse, PIV manufacturers and providers such as dealerships, car-hire and car-share businesses must rely on recharging services in order to sell their own products and services. This understanding caused significant investment in national public recharging networks by PIV manufacturer Nissan from 2011, later joined by Renault, BMW and VW, and the creation in 2017 of IONITY, a high-power charging network joint venture founded by the BMW Group, Daimler, Ford Moto and VW Group with Audi and Porsche. Vehicle manufacturers are also part of the dominant ICE regime but are mandated to develop new mobility solutions with lower emissions and their technology choices drive recharging demand, acting as **regime-based intermediaries** in the recharging ecosystem. This mandate impacts on their traditional ICE business models which have established financial and sales projections, introducing uncertainty and risk into future operations. In contrast, new PIV manufacturers such as Tesla have novel business solutions focussing on energy and communications business opportunities as well as mobility, enabling greater agency than their incumbent competitors in the e-mobility niche. Tesla originally developed bespoke recharging technology and provided the associated recharging infrastructure across the world for Tesla drivers. However, the CCS recharging technology is beginning to dominate mobility solutions which gives Tesla the opportunity to take advantage of mass public infrastructure by adapting its products to suit. Tesla is an example of **a niche intermediary** in the recharging business ecosystem, able to change direction quickly in response to market changes to gain market advantage.

Energy service providers are new entrants to the transport sector, acting both as suppliers of electricity to PIV drivers and as intermediaries providing complementary energy management services to the grid and large fleets, illustrating the multiple roles stakeholders can perform. Whilst demand is currently low for novel energy management services because PIV adoption is low, mass adoption will generate the need for distributed energy services, spreading demand away from peak grid load and electricity cost periods. Both incumbent energy suppliers and new businesses offering novel energy solutions act as **process intermediaries** focussed on directing e-mobility transition in ways which can protect the UK's electricity distribution system. The relatively low agency often associated with process intermediaries is partly mitigated because their supplier roles have greater agency in the recharging ecosystem, enabling them to direct the recharging innovations towards wider energy objectives, such as smart communication and metering systems.

The **community stakeholders** represent drivers who have not yet converted to PIV, non-drivers who are nonetheless affected by road transport and future generations who cannot speak for themselves. Community stakeholders act as **user intermediaries,** peers or user support organisations helping to accelerate adoption by sharing knowledge and experience through social networks and online discussion forums, as well as representing the future needs of society currently outside of the recharging ecosystem.

A wide variety of stakeholders were identified performing demand, supply and intermediary roles in the UK's public recharging business ecosystem. There is evidence of both new niche and incumbent ICE regime stakeholders performing multiple functions and changing roles in the emerging recharging market, indicating that co-evolution is occurring as a result of stakeholders' interactions.

4.2 Drivers' Requirements for Public Recharging Facilities

This section presents results from the RCN questionnaires conducted with UK drivers in 2015 (Appendices A, B and C) and two questionnaires designed to seek NE PIV drivers' opinions on public recharging in 2016 (Appendix D) and 2019 (Appendix F). During the seven years of this research ZCF has undertaken many recharging surveys with PIV and non-PIV drivers which supplement these findings. Results regarding PIV use and recharging preferences are presented in this section, whilst the results of questions pertinent to the business model are presented in Chapter 7.

4.2.1 *UK PIV drivers*

During 2015 the RCN project conducted three self-administered questionnaires (Appendices A, B and C) with PIV drivers across the UK and the results were used to inform this research. Each questionnaire contained between 35 and 41 questions regarding PIV purchasing decisions, PIV travel, recharging behaviour and experiences, and willingness to pay for rapid recharging and additional services. Between 171 and 202 responses were received to each survey, the largest proportion being from men, the 41–50 age group and 87% reported household income above the UK 2015 median figure of £25,700 (ONS, 2016) indicating a high level of affluence.

The majority of respondents drove PIVs with 24 kWh maximum battery capacity and 60% responded that they were very or quite satisfied with the range this provided on a single charge, however 65% said that up to 10% of required trips were impossible due to limited range, passenger or luggage capacity. 85% of respondents said the PIV was their primary vehicle. 55% of PIVs had replaced petrol vehicles, 32% replaced diesels and 49% of replaced vehicles were over 5 years old, whilst 71% of respondents drove over 8,000 miles annually, together indicating that high mileage polluting vehicles were being replaced by PIVs. 88% said they were more pleased with the PIV than their previous vehicle.

The most important factors influencing respondents' decision to drive a PIV were long-term cost savings and environmental concerns and 47% reported saving up to £150 per month in fuel, although a further 16% reported saving more than £250. 78% of respondents said using green energy to recharge was important although only 33% were willing to pay more for this service, and 48% also had photovoltaic panels fitted at home indicating their environmental values.

99% of RCN respondents had a home charger installed and 79% indicated that home was their most frequent recharging location, although rapid chargers were used to extend journey distances. At the end of the RCN project 62% of participants reported making longer PIV journeys and 50% said they made more PIV journeys due to the increased availability of rapid chargers. Figure 4.6 shows that home charging remained the most frequent recharging method but that rapid chargers were used a few times each month. RCN drivers also reported that they were comfortable to reach 20% state of charge or less before rapid charging, indicating a reduction in range anxiety which may lead to a reduction in short duration, low energy top-up recharging behaviour and an increase in longer duration, higher energy charge events in future.

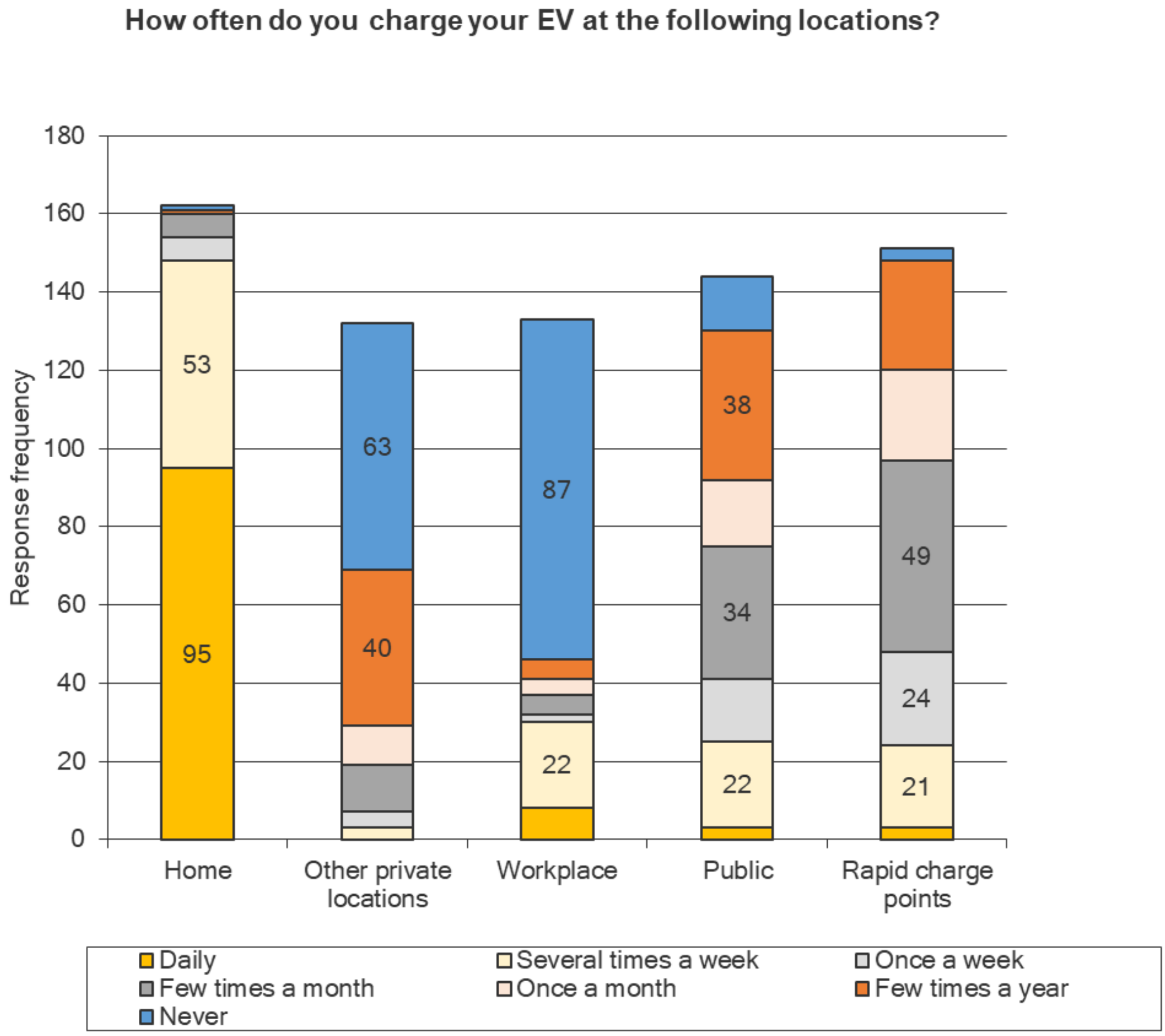


Figure 4.6 – RCN drivers' recharging locations 2015

When questioned about how they spent time whilst rapid charging, the most popular responses were waiting in the car or using free toilet facilities. Figure 4.7 illustrates participants' reported use of facilities whilst recharging, highlighting the preference for toilets followed by cafes and shops, although 8% said they weren't willing to spend anything whilst recharging. However, 64% of respondents said they usually spent up to £10 in nearby shops and cafes, and the 6.5% who reported spending more than £20 explained this as grocery shopping or buying refreshments. 35% said the benefit of being able to reserve a charger would outweigh the inconvenience of arriving to find it already in use, but 40% said they were unlikely to pay for that convenience. Interestingly, the reservation feature is now available in many urban areas, e.g. London.

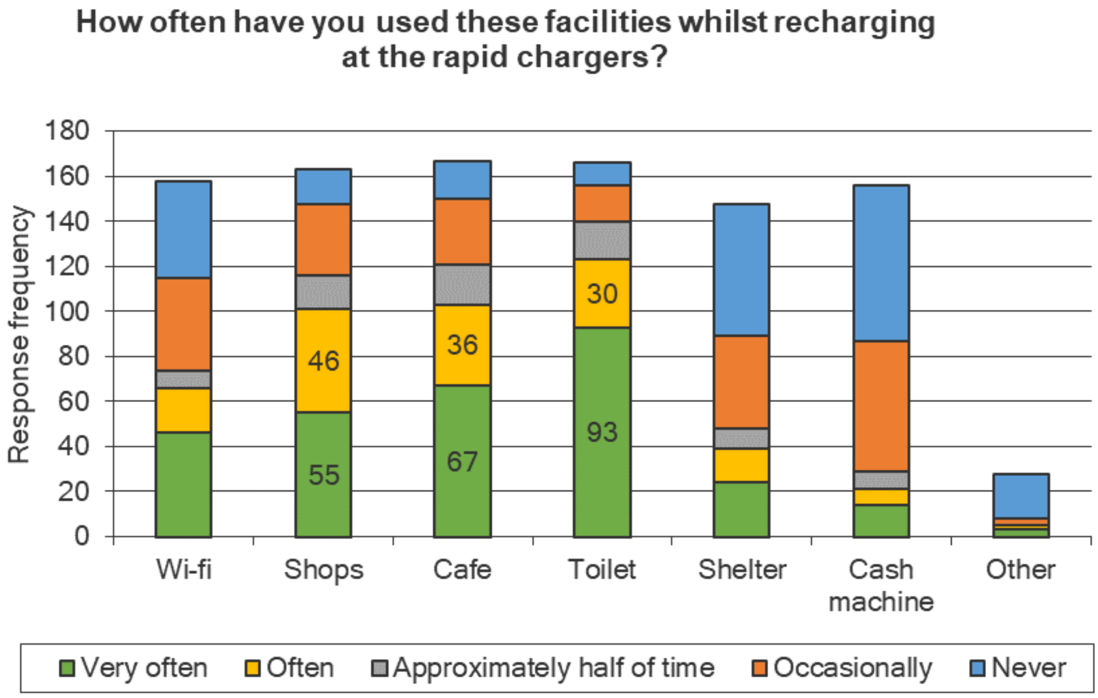


Figure 4.7 – RCN drivers' use of additional facilities whilst recharging

Following the RCN project, participants reported limited PIV range as the biggest barrier to mass PIV adoption, closely followed by the need for more rapid chargers. Reliability was identified as drivers' biggest recharging concern and although 72% said they were prepared to pay to use rapid chargers, poor reliability affected their perception of value. The cost of public recharging was also raised as a concern which is discussed in Chapter 7. Respondents also mentioned poor availability, having to queue to use a rapid charger and 56% said they were willing to wait up to 30 minutes maximum. Drivers called for real-time availability information to be made available alongside contactless payment access systems, both of which are now common features of UK rapid recharging networks in 2020. The most popular locations for more rapid chargers were reported to be Motorway Service Areas (MSAs), petrol stations, supermarkets and shopping areas as shown in Figure 4.8.

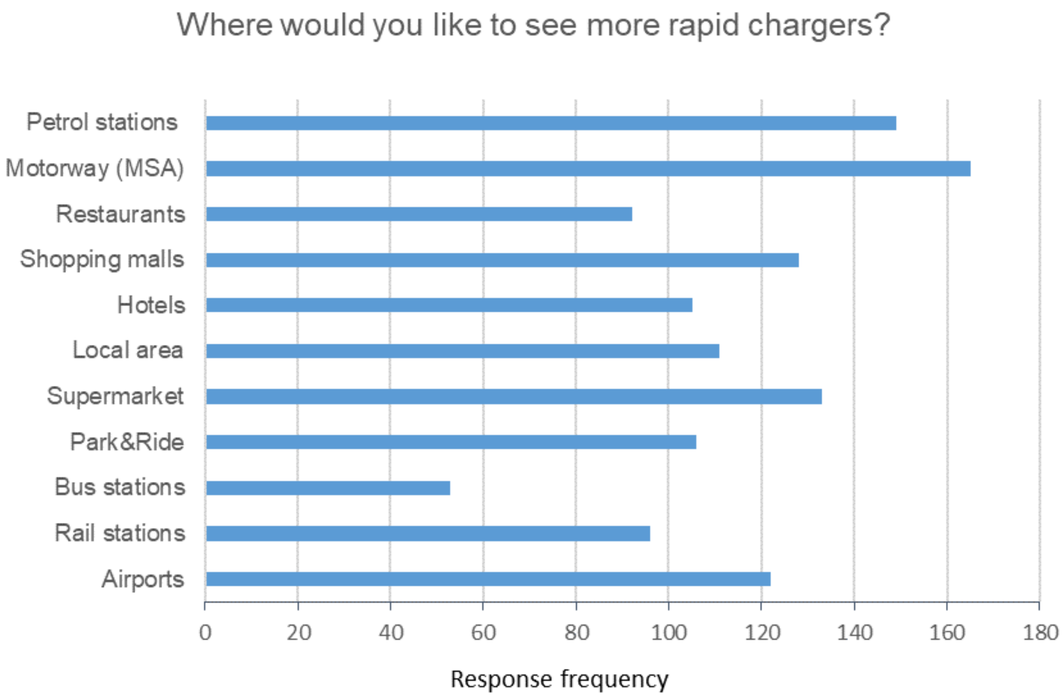


Figure 4.8 – Locations where more rapid chargers are required

In 2015 RCN participants reported that recharging mostly took place at home and rapid chargers were used to extend journeys but only a few times each month. 64% reported spending up to £10 on other facilities whilst rapid recharging, indicating demand for additional services. RCN participants identified PIV range as the biggest barrier to mass adoption and called for more rapid chargers at MSAs, petrol stations, supermarkets and shops.

4.2.2 *NE PIV drivers*

The results of two surveys designed to gather information about NE PIV drivers' vehicle choices, driving and recharging behaviour and preferences for future recharging were analysed to compare requirements for public recharging in 2016 (Appendix D n=179) and 2019 (Appendix F n=91). The demographics of respondents are summarised in Table 4.1. The majority of respondents to each survey were male and in the 45–54 age range.

		Gender		Age range					
Questionnaire	Respondents	Male	Female	<25	25-34	35-44	45-54	55-65	>65
2016	179	83%	17%	1%	6%	25%	48%	16%	4%
2019	91	74%	26%	1%	7%	30%	34%	20%	8%

Table 4.1 – Summary of NE PIV drivers' survey respondents

The majority of respondents to both surveys drove BEVs, as shown in Table 4.2, although 12% of 2019 respondents did not report their PIV type. In both years most respondents reported that the PIV had replaced another vehicle, rising from 71% to 84% over the period. However, the balance changed from Petrol to Diesel vehicles replaced, which reflects the growing UK disincentives for diesel use including increased business and road taxes and emission charging scheme consultations ongoing in the NE region. The adoption of a PIV as an additional household vehicle dropped from 27% to 10% between 2016 and 2019, coinciding with new evidence of electric models being replaced by newer models, indicating that drivers became more comfortable with PIV capabilities over the period.

	PIV type			Vehicle replacement				
Questionnaire	BEV	PHEV	Not advised	addit vehicle	1st vehicle	Petrol	Diesel	Electric
2016	80%	20%	N/A	27%	2%	36%	35%	N/A
2019	75%	13%	12%	10%	1%	40%	42%	7%

Table 4.2 – Respondents' vehicle summary

Respondents' reasons for converting to PIV were ranked in order of importance as shown in Figure 4.9 (2016) and Figure 4.10 (2019). Cost savings were reported as the most important factor in both surveys, but the relative importance of environmental concerns rose considerably by 2019. Financial incentives were reported as only a minor consideration which matches the profile of innovator and early adopter consumers (Rogers, 2003). Appealing design was found to be the least important factor in both surveys.

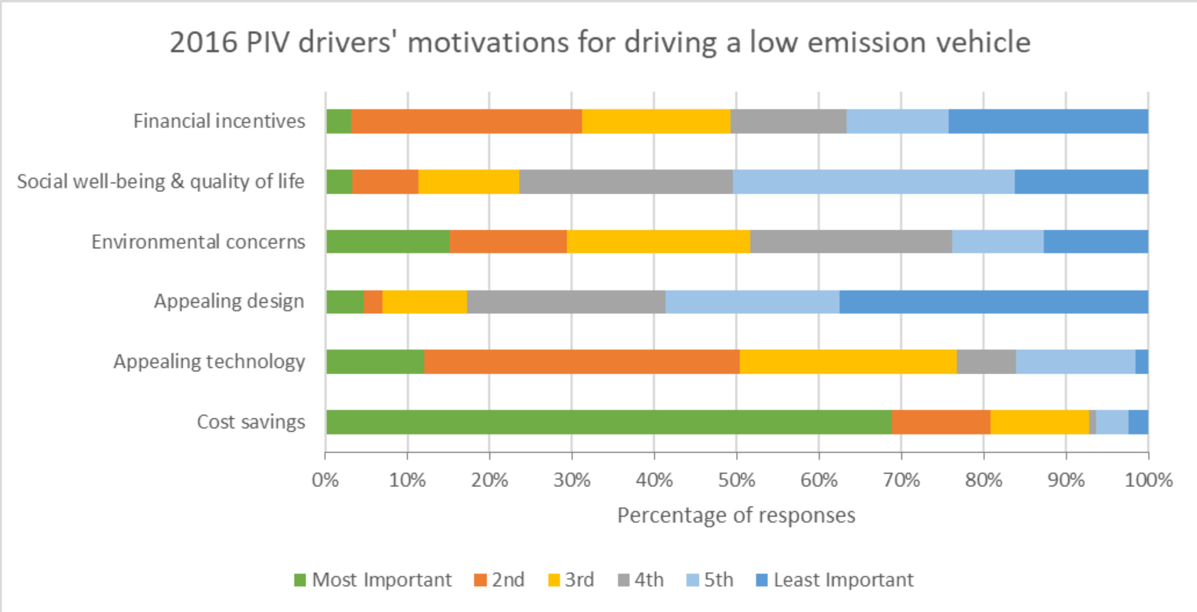


Figure 4.9 – PIV drivers' motivations 2016

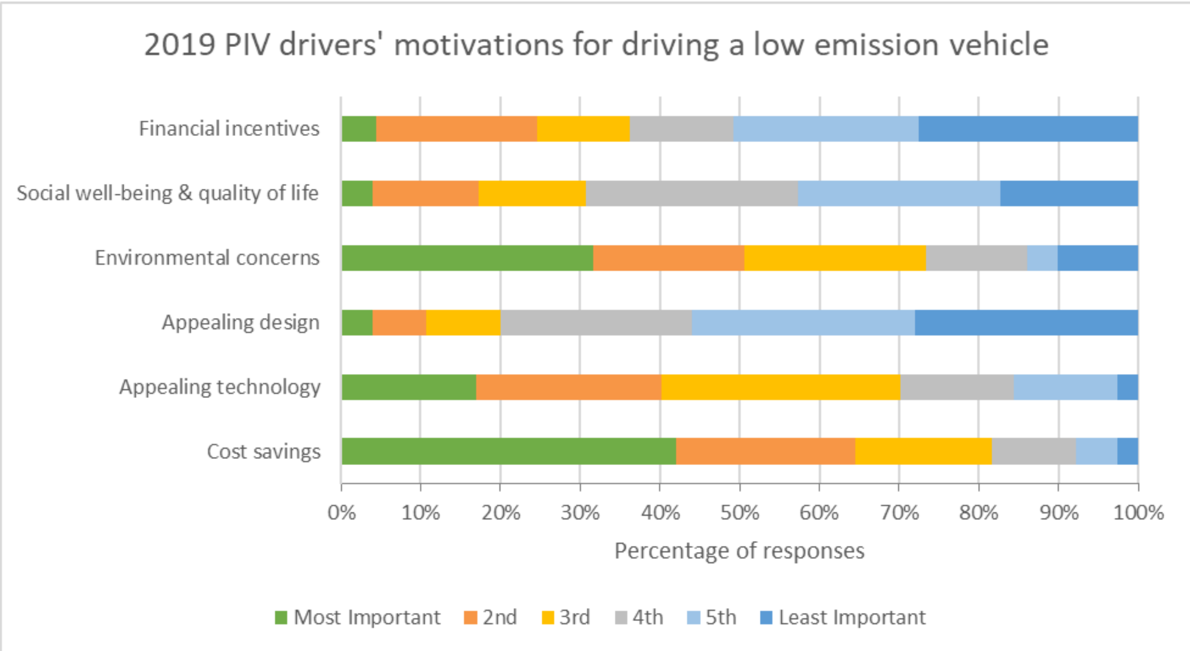


Figure 4.10 – PIV drivers' motivations 2019

The annual PIV mileage reported in Figure 4.11 appears relatively high in comparison with the national average of 7,800 miles per household vehicle (DfT, 2018c). The percentage of respondents travelling over 10,000 PIV miles per year increased from 40% to 60% by 2019 which suggests increased confidence in PIV range and recharging capabilities. Commuting trips were reported as delivering the most PIV mileage and business trips the least in 2016; further trip details can be found in Appendix J. Furthermore, 86% of 2019 respondents said the PIV was for personal use, with only 14% reporting business use, which provides evidence for the PIV use cases discussed in 4.1.1.

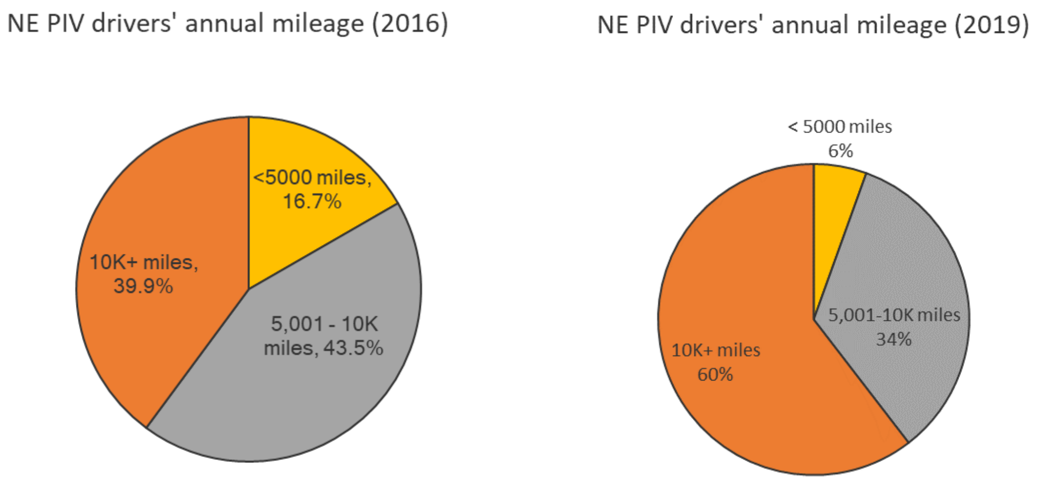


Figure 4.11 – Annual mileage of NE PIV drivers

Respondents were asked how frequently they recharged in three key locations: at home, work and in public places and the results are reported in Table 4.3. Unsurprisingly given the high off-street parking and therefore home charging capability reported, most recharging activity was reported at home. Chargers in public places received the lowest response in 2016, but rose above workplace charging by 2019, indicating increasing demand for public recharging. The home recharging proportion is much lower and the public recharging proportion much higher than literature suggests, which could reflect the high proportion of chargers per PIV in the NE as discussed in Chapter 5. In addition, the 2019 survey found that only 26% of respondents recharged every day but the majority (42%) recharged a few times each week, reflecting growing confidence in PIV range. However, the NE's free-to-use public recharging incentive may have biased the recharging location results so NE public charger use will be explored further in Chapter 6.

	Recharging activity			Home charging capability	
Questionnaire	**Home**	**Work**	**Public chargers**	**Yes**	**No**
2016	53%	30%	17%	93%	7%
2019	44%	22%	34%	88%	12%

Table 4.3 – NE PIV drivers’ recharging locations

Further 2016 questioning broke down respondents’ use of public chargers into recharging location types as displayed in Figure 4.12. Short- and long-stay car parks received the most ‘often’ responses, closely followed by city centre streets. Transport interchanges and residential streets received the most ‘never’ responses, closely followed by ‘service areas’ including MSAs and fuel filling stations. These results may be biased by the composition of the NE recharge estate in 2016 which will be investigated in Chapter 6, suggesting that drivers’ recharging behaviour reflects availability of infrastructure rather than recharging preferences.

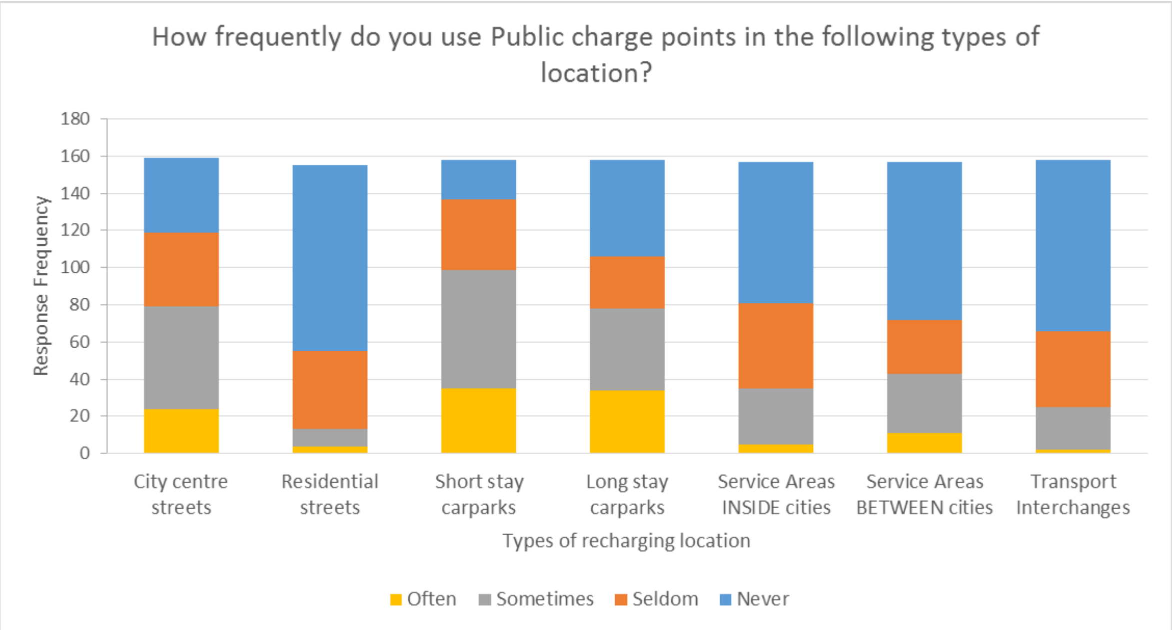


Figure 4.12 – NE PIV drivers' public recharging location use 2016

2016 respondents were asked to rank the relative importance of certain characteristics to their use of public charge points. Figure 4.13 indicates that reliability of chargers was the most highly valued public recharging characteristic, with availability and location coming close behind. Conversely, cost was seen as quite unimportant which is unsurprising since most of the NE recharging estate was free-to-use at the time. The high ranking of reliability, availability and location is likely to be related to respondents' experience using the NE recharging estate. 62% reported either never or seldom having to wait to use a public charger and only 8% reported having to queue often. However, 80% reported often or sometimes finding chargers out of service and the need to register or have a specific RFID access card was the highest reported barrier to public recharging.

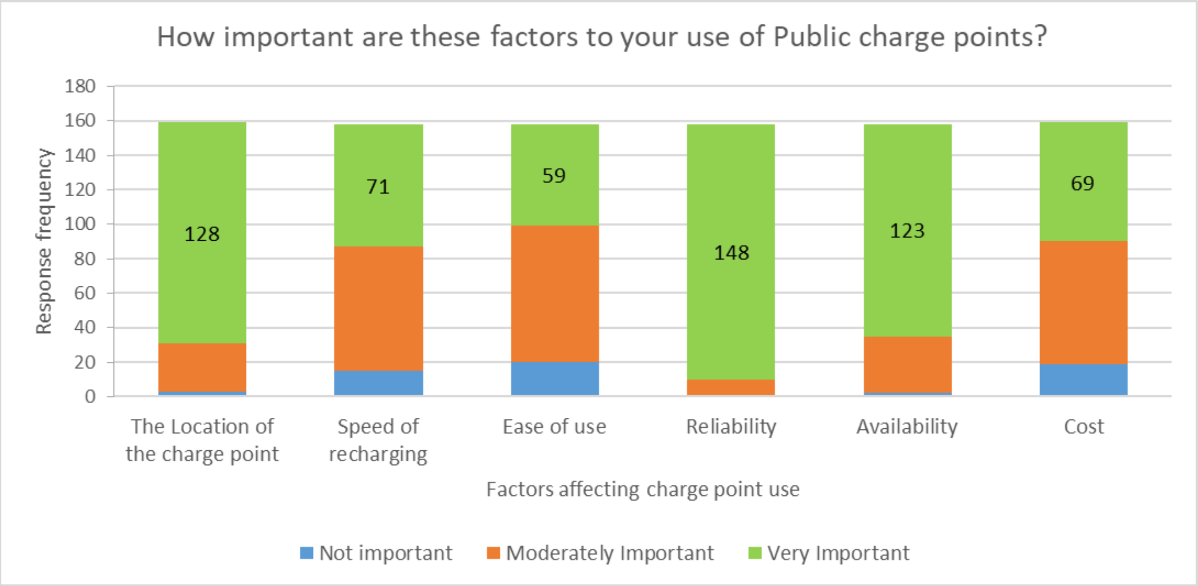
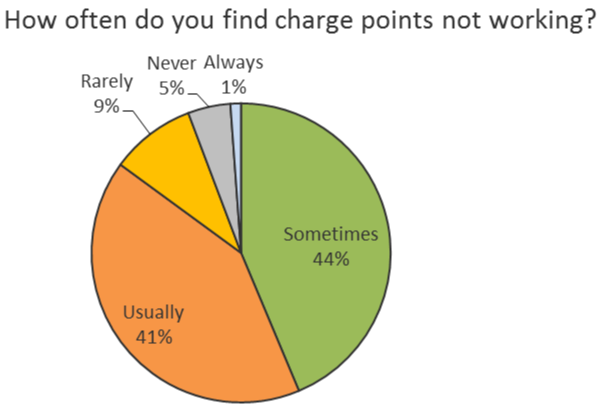


Figure 4.13 – Relative importance of public charging characteristics

Following up on the 2016 findings, 2019 respondents were asked about their reliability and availability experience of NE chargers. The high frequency of Sometimes and Usually responses in Figure 4.14 suggests the reliability of the charging network in 2019 was poor and that additional chargers were needed in existing locations because poor availability was limiting use. Respondents gave the NE recharging estate a low average satisfaction score of only 3.33 out of 10 in the 2019 survey.



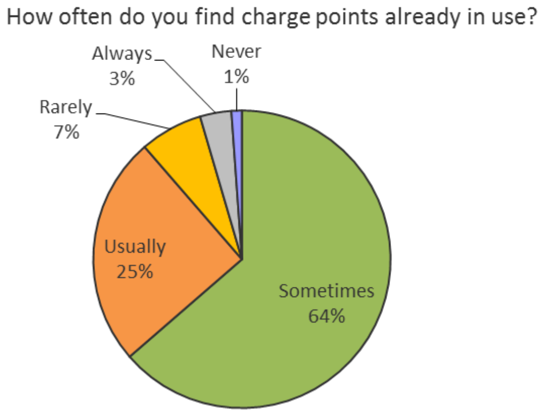


Figure 4.14 – Frequency of charger unavailability 2019

Responses regarding drivers' choice of recharging location shown in Figure 4.15 reinforce the importance of location, highlighting PIV drivers' requirement for proximity to regular routes, work, homes and destinations with facilities close by.

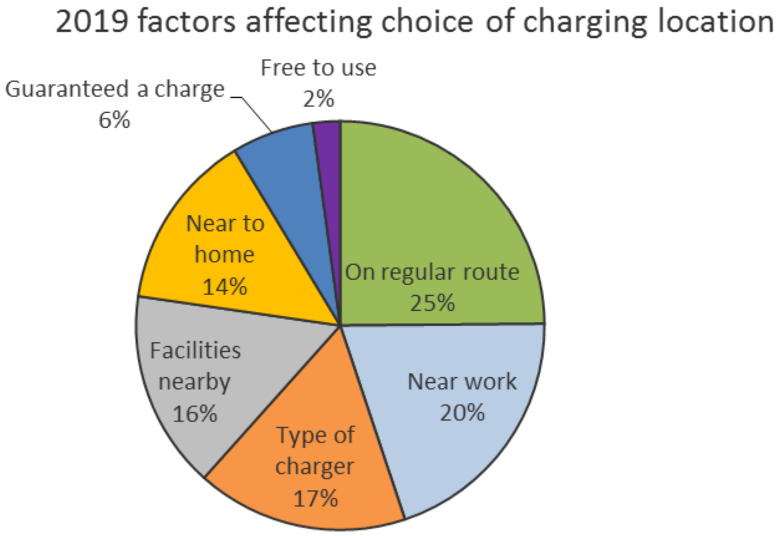


Figure 4.15 – Factors affecting recharging location use 2019

To investigate the importance of nearby facilities to the use of public chargers, in 2016 respondents were asked how frequently they used various services whilst recharging. The most 'often' and 'sometimes' responses were recorded for shops and cafes which provide additional revenue opportunities for charger owners, whilst toilets and WIFI which are usually free-to-use services received the next highest 'often/sometimes' responses, as shown in Figure 4.16. NE drivers ranked toilets in third rather than first place as reported by RCN drivers in section 4.2.1, possibly because NE participants also considered slow and fast public recharging solutions which have much longer durations than rapid chargers. However, the demand for shops and cafe facilities remained high, indicating an opportunity for additional service revenue.

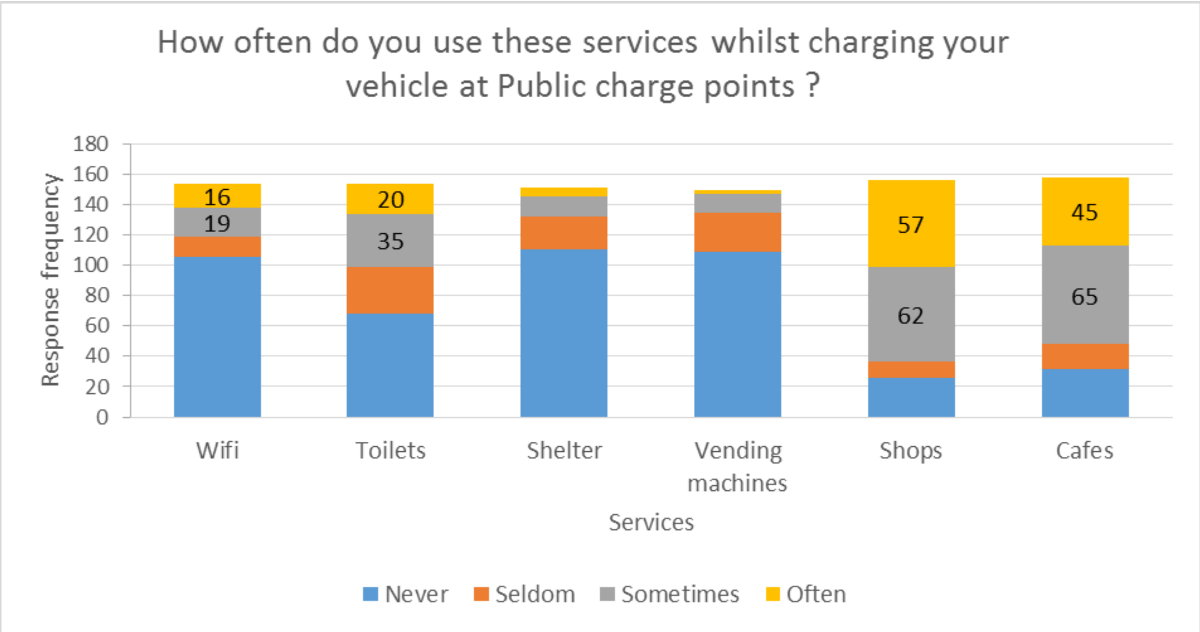


Figure 4.16 – Use of nearby facilities whilst recharging 2016

Finally, respondents to both surveys were asked about their preferences for future public recharging locations as shown in Table 4.4. Whilst city centre was the preferred location in 2016, Transit locations were preferred by 2019 where rapid chargers provide quick recharging services en route to a destination. This change may reflect the growth in rapid charging facilities in the region over the period which will be explored in Chapter 6. Residential areas moved into second place in 2019 which may reflect a growing PIV demand from those without off-street parking who are unable to charge at home and therefore need the convenience of overnight public recharging facilities close to home. Further details of 2019 public recharging location preferences can be found in Appendix J.

	Public recharging location preferences				
Questionnaire	Out of town	Workplace	City centres	Transit	Residential
2016	2nd	N/A	1st	3rd	4th
2019	3rd	4th	5th	1st	2nd

Table 4.4 – PIV drivers' public recharging preferences

In 2016 respondents indicated a preference for the shortest duration of recharge in public, as shown in Figure 4.17 suggesting that rapid chargers were the most popular public charger type. Respondents preferred to recharge during daytime, but little difference was expressed between weekday and weekend charging demand.

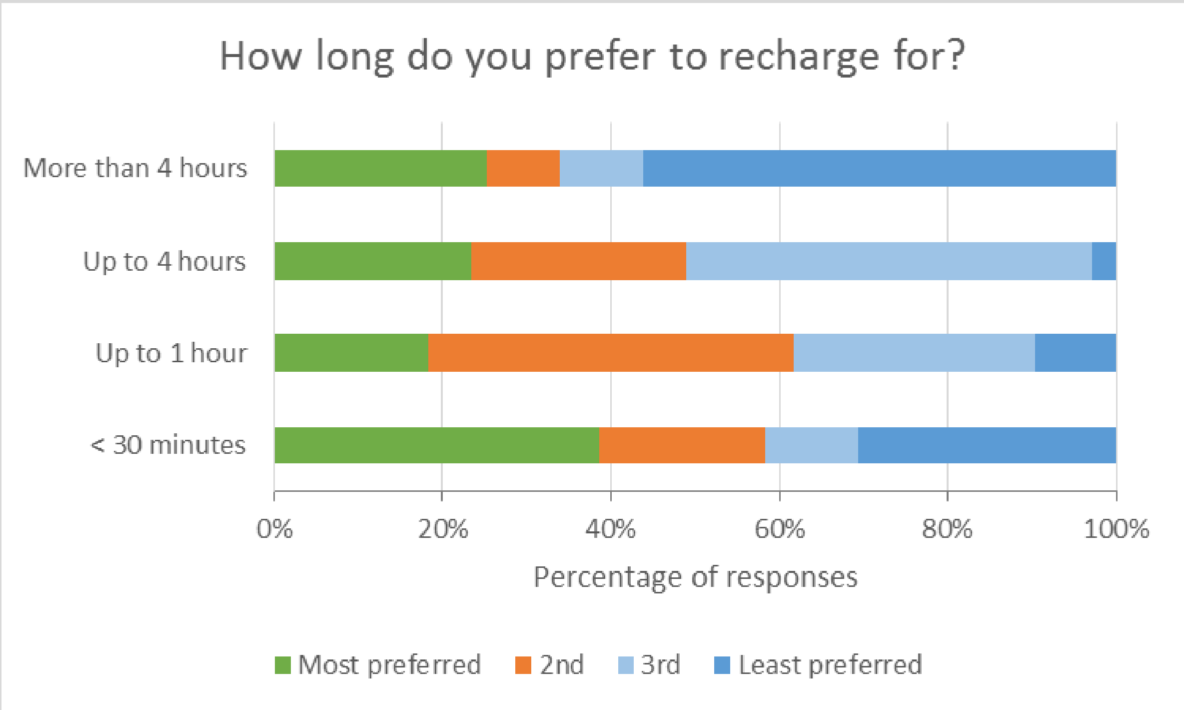


Figure 4.17 – Preferred duration of public recharging

Most NE respondents drove BEVs rather than PHEVs and cost savings were reported as the main reason for PIV adoption in both 2016 and 2019, however the importance of environmental concerns rose considerably by 2019. The majority of 2019 respondents (60%) drove above average annual mileage and the majority (42%) recharged only a few times each week, reflecting growing confidence in PIV range and recharging capabilities. Most recharging took place at home and reliability followed by availability and location were identified as the most important factors for public recharging. Location preferences were close to regular routes, work, homes and destinations with facilities close by. By 2019 transit locations overtook the city centre as the preferred location for public chargers.

4.3 Charger Owners’ Attitudes to Public Recharging

This section presents and discusses the results of survey questions (Appendix E) related to the motivations and strategic importance of recharging provision to charger owners. Responses to questions regarding the business model contribution are covered in Chapter 7. A total of 46 questionnaire responses were received from charger owners in NE England during 2015 to determine their motivations for charger provision. Charger owners reported that providing chargers contributed to Corporate Social Responsibility (CSR), sustainable transport, carbon reduction and environmental policies, but few reported setting any associated targets for chargers to meet, as shown in Figure 4.18. However, 55% of respondents declined to answer this question which suggests little focus on performance monitoring of chargers and may indicate a low business priority for recharging infrastructure. 86% of respondents indicated that they also had a vehicle fleet, although 31% contained no PIVs, and 67% reported some employees using a PIV, generating a demand for recharging services.

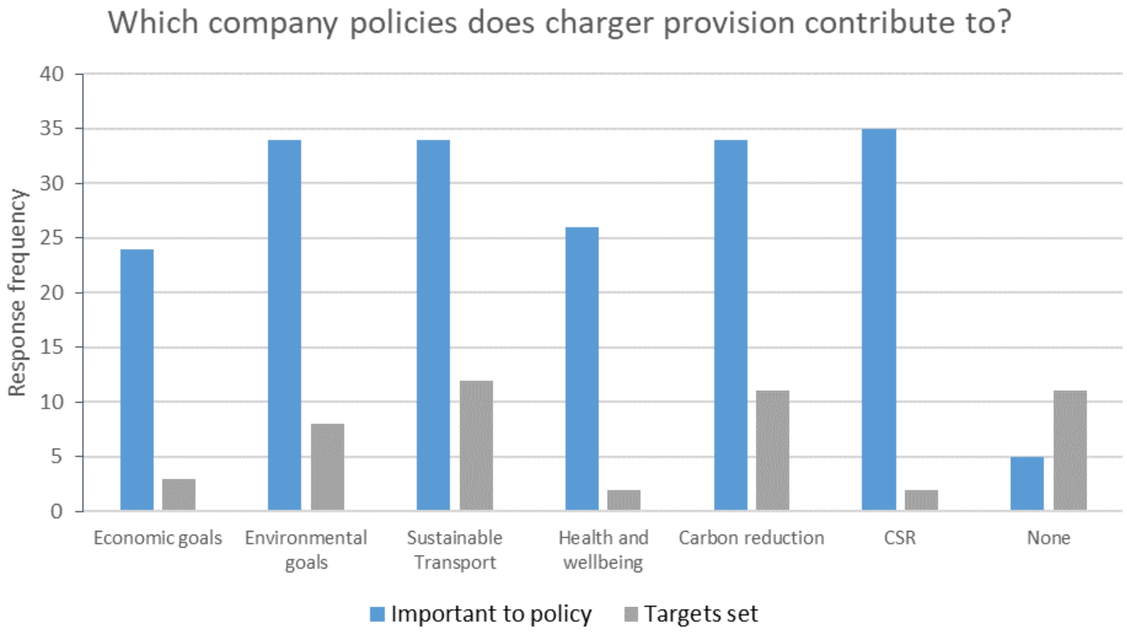


Figure 4.18 – NE charger owners' perception of strategic importance

Figure 4.19 shows that environmental concerns and the availability of grant funding towards infrastructure cost were the most popular reasons for charger provision. The role of regional and political strategy were also interesting findings considering the importance of Nissan's PIV and battery production to the region's economy.

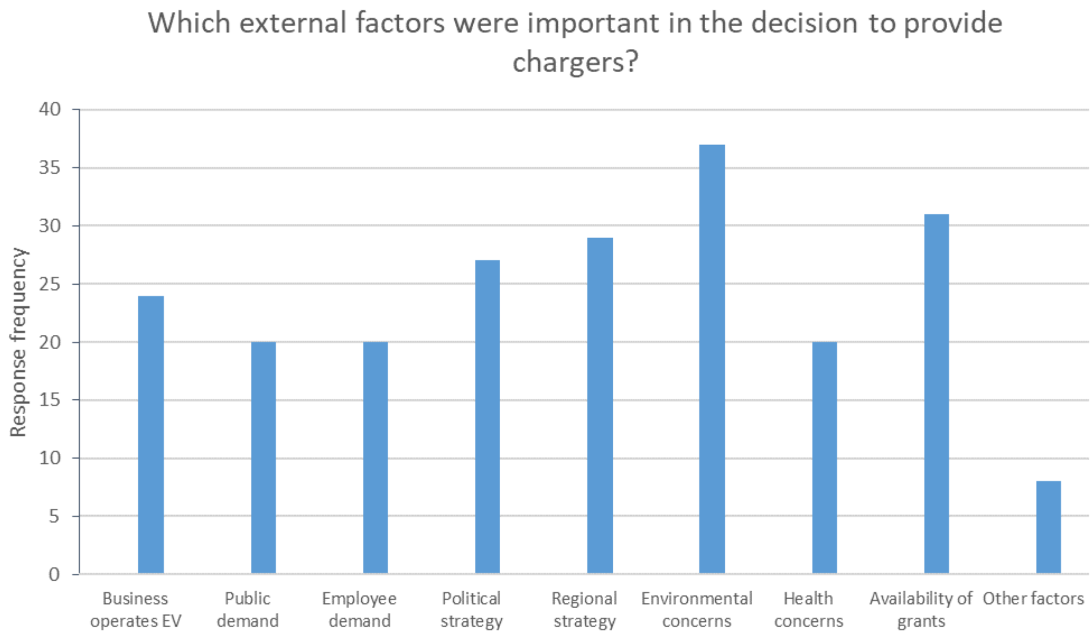


Figure 4.19 – Reasons for NE charger provision

The data also provided evidence that charger owners recognise the multiplicity of internal and external stakeholders in this market, illustrated in Figure 4.20. Beyond the most obvious direct interests of drivers, the business leaders' interests were also strongly identified, however 46% subsequently responded that they never reviewed charger use or cost data, suggesting recharging had a low priority in business plans. The financial managers' interests were also identified but only 14% of respondents had introduced recharging fees, indicating that financial performance of chargers was not a business priority in 2016. Local government interests were identified, probably because the regional development agency One North East administered the recharging infrastructure grants provided by the NEPIP project. The press' involvement was also an interesting finding given their ability to influence consumers using mass communications, either promoting or decrying the nascent PIV market depending upon their own interests.

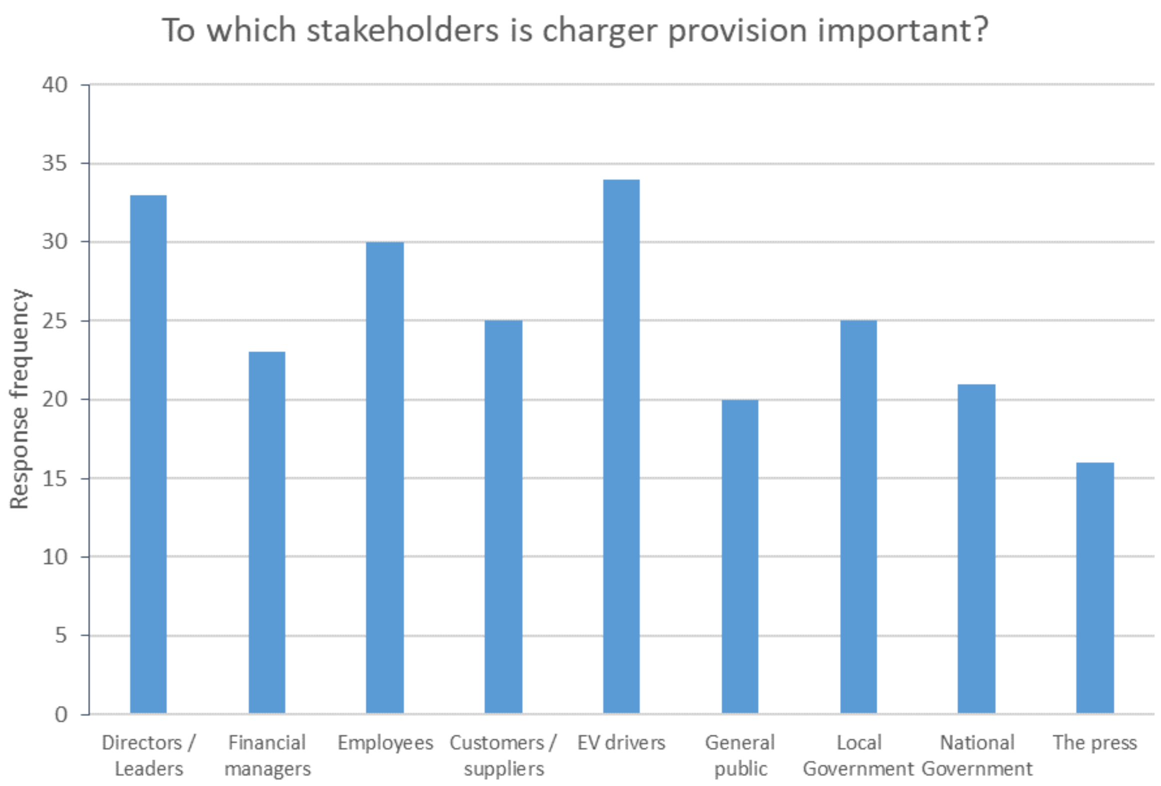


Figure 4.20 – NE charger owners' recognition of recharging stakeholders

NE charger owners reported the need for increasing demand and further grants before providing additional chargers, but few indicated that charger provision must be profitable. The results shown in Figure 4.21 suggest that NE charger owners considered charger supply sufficient to meet demand in 2015 and required additional funding to increase supply, recognising that charger provision was not profitable at the time.

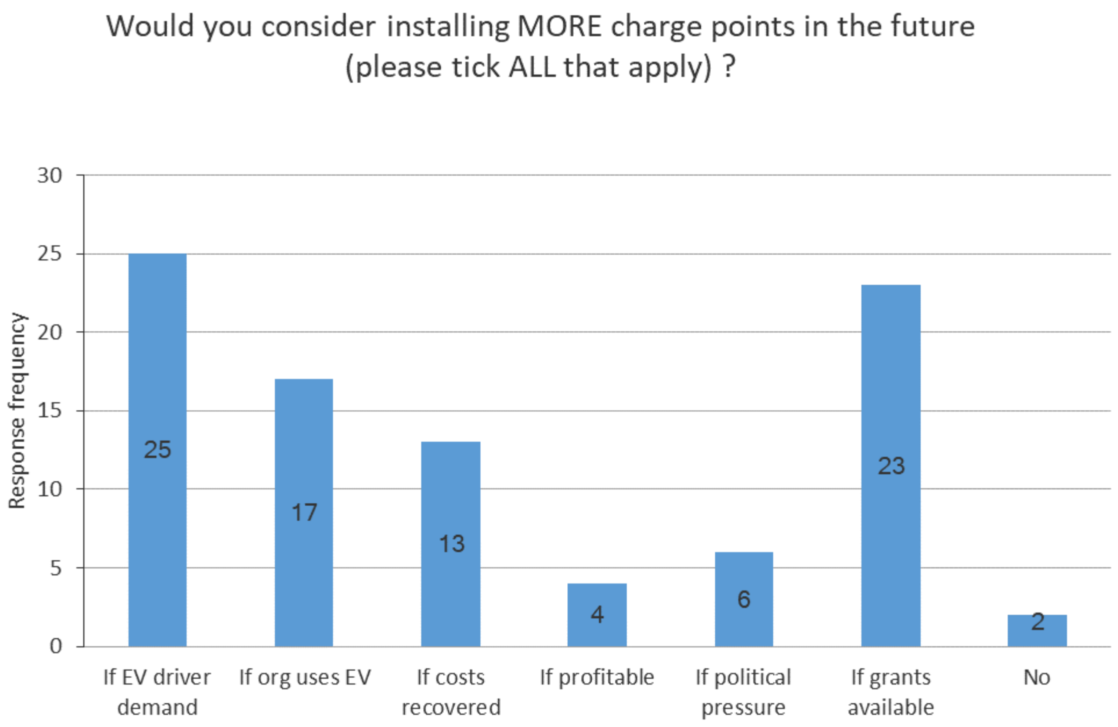


Figure 4.21 – NE charger owners' requirements for additional provision

In terms of charger operation, data showed that the majority (79%) of respondents did not limit the use of their chargers in any way, although 17% had experienced queues of drivers waiting to recharge. The biggest operational problem reported by owners was poor reliability, matching PIV drivers' reports in section 4.2.2. Reported charger issues ranged from a few short incidents of less than one week to multiple downtime of over one month leading to customer complaints, however 29% of charger owners reported no maintenance supplier in place to resolve these issues. Data also indicated some availability problems caused by ICE vehicles parking in recharging bays and PIVs parking without recharging, yet 59% of respondents had not introduced any recharging enforcement measures. Only 54% reported reviewing charger use periodically, using energy delivered followed by number of charge events as the primary measures, however they had few targets against which to judge performance as illustrated in Figure 4.18 previously. Together these findings suggest that chargers had a low business priority for NE owners in 2015.

Five responses to this questionnaire were also received from large recharging network operators elsewhere in the UK for comparison with the NE findings. Four respondents owned large recharging estates in addition to existing business, whilst the fifth Charge Place Scotland was the curator and operator for the Scottish national estate. These operators afforded a higher priority to recharging services within their business portfolio than the NE respondents. Use and cost data were reviewed at least weekly and charge event duration and energy data were set as key performance indicators because their variability was identified as a business barrier, as discussed in Chapter 6. Individual and repeat users with customer feedback were also reported as important measures of success. Whilst maintenance problems were reported by all national respondents, they all had maintenance services in place. Most had experienced some queues at their chargers and 60% had therefore introduced use restrictions either by duration or energy delivered, and 40% had also introduced recharging fees. The national operators reported environmental, health concerns and public demand as the key motivators for provision, followed by political will, and commented that economic goals were the least important target for charger provision in 2015. However, national government was recognised as the main stakeholder benefitting from recharging provision, which was consistent with the industry's call for long-term strategy and continued infrastructure funding.

NE charger owners reported objectives beyond financial considerations, and that multiple internal and external stakeholders were involved. They considered recharging supply sufficient to meet demand in 2015 and required additional funding to increase supply further. Recharging provision had a low business priority for NE owners with few targets set, little monitoring and few actions taken. However, larger recharging operators outside the region reported setting KPIs, reviewing data and levying fees, whilst calling for continued funding from government as the key stakeholder.

4.4 Wider Stakeholders' Attitudes to Public Recharging

Information from wider recharging stakeholders was gathered during workshops as described in Chapter 3. Results related to the roles and objectives of wider stakeholders are discussed in this section, whilst wider stakeholders' views on the public recharging business case are presented in Chapter 7.

The first iBUILD stakeholder workshop delivered in 2014 (Appendix G) provided data on the recharging roles and objectives of wider stakeholders. PIV recharging was considered to be a nascent market where major societal change was required to break down barriers to low-carbon transport, in order to respond to climate change concerns. The BE intermediary organisation CENEX, a transport advisor, commented that a strategic national recharging network was required to encourage PIV uptake whilst PIV range remained below ICE capability. CENEX also suggested that alternative methods could be used to encourage PIV conversion, such as taxing ICE vehicle use more heavily based on the health, social and environmental consequences of consumers' transport choices. Interestingly, the government subsequently introduced vehicle taxes linked to CO_2 emissions in 2017[9].

LA representatives, acting as suppliers in the business ecosystem, confirmed that breaking down barriers to e-mobility was important because decarbonising local environments was key to local government objectives, but commented that commercial destinations were primarily interested in attracting customers. This example highlighted diverse motivations for recharging provision but LA participants stressed that widespread public recharging provision was necessary to encourage changes in travel behaviour.

The BE supplier CYC, a recharging network operator, compared the need to strengthen communications infrastructure in the early mobile phone market with the

[9] Further information can be found at https://www.gov.uk/government/news/new-vehicle-tax-rates-from-1-april-2017

requirement for comprehensive PIV recharging facilities. CYC questioned the UK's free-to-use public recharging approach and stressed the need to charge fees to enable network operators to develop new products and services as technology develops and drivers' demands change. Recharging fees have since become more common and the effects are discussed in Chapter 6 and Chapter 7.

The BE demand representative from a PIV drivers' organisation, EV Matters, stressed that effective communication of how PIVs can add value to people's lives at a reasonable cost was essential to encourage the major changes in travel behaviour required for emissions reduction. The UK's Go Ultra Low promotional scheme[10], supported by government and PIV manufacturers, has since launched to provide PIV information to consumers through websites, events and multi-media advertisements. Additionally, the UK's first EV Experience Centre[11] has opened in Milton Keynes, providing brand-neutral PIV advice and test drives.

The BE intermediary Ofgem, the UK energy regulator, explained the need to encourage temporal and spatial recharging flexibility for consumers, whilst also encouraging recharging at times and places where grid capacity is not constrained. Ofgem recommended that a full systems approach be taken to recharging business models, defining and then accounting for both environmental and business benefits, to understand how diverse stakeholders can be given room to grow without regulatory barriers. Ofgem concluded that new business operating mechanisms would be required to facilitate low-carbon transport systems.

The role of OLEV vehicle and infrastructure subsidies was also recognised by participants, however there was some criticism of the lack of joined-up long-term thinking and involvement of PIV drivers in policy setting to date. Latterly, the government has released The Road to Zero strategy (HM Government, 2018b) which

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[10] https://www.goultralow.com/

[11] https://evexperiencecentre.co.uk/

addresses long-term emission reduction goals with consumers' needs as its focus. A recommendation was also made that the role of EU government policy and regulation should be better understood for the UK recharging market to develop.

The second iBUILD workshop held in 2017 (Appendix H) gathered stakeholders' views on the value of different recharging solutions as described in section 3.4.3. The public recharging requirements identified by stakeholders are reported in this section, whilst the value results are reported in the business model discussion in Chapter 7. The workshop focussed on alternative public recharging solutions for drivers who cannot recharge at home. The participants reported the key outcomes to be increasing PIV uptake to reduce air quality problems and increasing convenient, lower-cost mobility choices for drivers, in line with the first workshop's finding. The stakeholders then identified the priorities of such provision as: enabling private hire and delivery drivers who take vehicles home at night to convert to PIV; balancing demands on the energy grid with more efficient energy use; building profitable businesses and local economies; and the need for behavioural change in travel and energy use.

Interdependencies were identified between the transport and energy sectors, associated industries and between government departments, reflecting the complexity of the transport decarbonisation challenge. Some disadvantages of mass conversion to PIV were also identified: rare battery material supply and its production methods; recycling requirements; increased energy demand; changing vehicle servicing and vehicle manufacturers' sales propositions. Tensions between the different interests of key government departments for transport, health, BEIS and the Treasury were also mentioned as a barrier to long-term policy commitments. Together these findings suggested that a whole-systems approach, considering the objectives of and links between all stakeholders and their resultant positive and negative outcomes, would be required to encourage the changes in travel behaviour needed to achieve the overarching emission reduction objectives.

Wider stakeholders considered public recharging infrastructure necessary to encourage societal change in transport behaviour to ultimately decarbonise local environments. However, diverse motivations and tensions were identified both between and within each recharging business ecosystem group. Therefore, diverse business models which can adapt to changing motivations, PIV technology and user recharging behaviour are required.

4.5 Summary of Findings

The goal of this chapter was to present the results of the recharging stakeholders' analysis and to discuss their diverse roles and interests in public recharging to begin addressing the first research aim: ***To identify the demand and supply determinants for continuing and increasing recharging infrastructure provision in public places*****.**

The stakeholder framework reported in section 4.1 identified many PIV stakeholders performing demand, supply and intermediary roles in the recharging business ecosystem, including new and incumbent actors in the transport sector. Multiple PIV use cases were discussed including their potential public recharging requirements, which also enabled targeted invitations to the workshops.

Drivers' surveys addressed the first objective designed to test hypothesis 1: ***The majority of recharging will take place at home or at work, with little demand for public recharging facilities.*** The results identified a preference for home recharging followed by public recharging ahead of workplace recharging by 2019. Hence hypothesis 1 was only partially confirmed: ***NE PIV drivers preferred to recharge at home or in public places.*** Drivers' reported requirements for public recharging infrastructure are summarised in Figure 4.22, fulfilling the first element of the demand study, and the remaining demand investigations are addressed in Chapter 5 and Chapter 6.

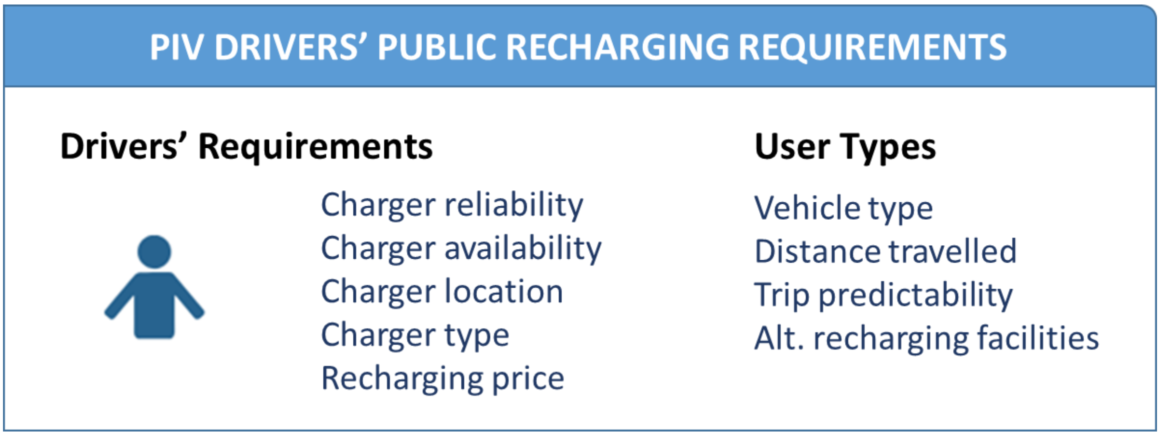


Figure 4.22 – PIV drivers' recharging requirements

Public charger reliability was reported as the biggest concern for NE PIV drivers and additional chargers were called for in some locations where poor availability was a problem. NE drivers also reported public charger type and location preferences. By 2019 short duration rapid chargers in transit locations and public chargers in residential areas were preferred, which may reflect growing PIV demand from drivers without off-street parking calling for quick convenient recharging or overnight solutions close to home. Drivers also identified a requirement for facilities such as toilets, shops and cafes to use whilst recharging. The percentage of participants reporting annual PIV mileage exceeding 10,000 miles per year increased significantly by 2019, which suggests drivers' increased confidence in PIV range and recharging capabilities and may lead to increased public recharging demand. In addition, drivers reported cost savings as the most important motivation for driving a PIV although the relative importance of environmental concerns rose considerably by 2019.

NE charger owners' surveys addressed the first objective designed to test the second hypothesis: ***Revenue generated by public charge point owners is not sufficient to match their total financial investment.*** The results indicated that environmental considerations and the availability of grant funding drove charger provision, rather than economic goals. Additionally, only 14% of respondents had introduced recharging fees and 46% of participants never monitored charger use or cost data, suggesting recharging infrastructure had a low business priority for NE owners in 2015. These results cannot test hypothesis 2 alone, so recharging finances are studied in Chapter 7. Charger owners' reported requirements for public recharging infrastructure are summarised in Figure 4.23, fulfilling the first element of the supply study addressing hypothesis 2.

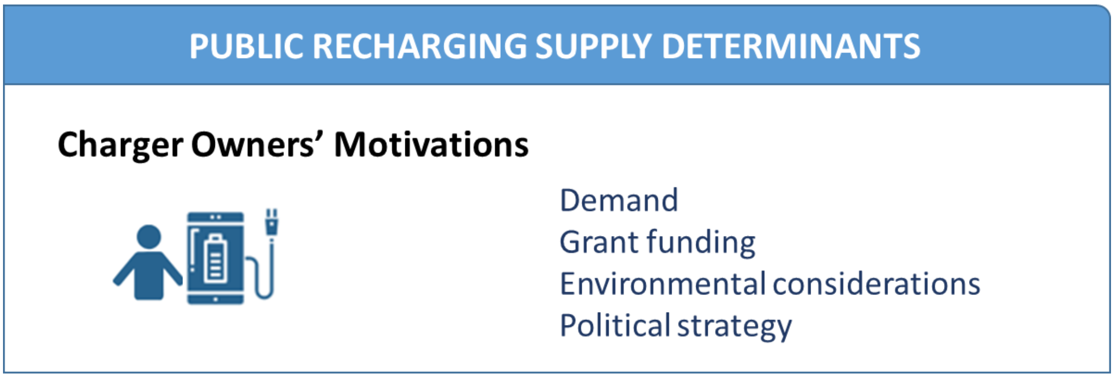


Figure 4.23 – NE charger owners' motivations for public recharging provision

Wider stakeholders' interests were also investigated in the supply study to identify opportunities and constraints for public recharging provision which may affect the recharging finances pertinent to hypothesis 2. Wider stakeholders' views were also required to address research aim 2 which is covered in Chapter 7. Disparate recharging interests were identified during the stakeholder workshops, ranging from decarbonisation of local areas to protecting the electrical grid and attracting custom. However, all stakeholders agreed that widespread public recharging infrastructure and mass communication of PIV benefits would be needed to encourage the changes in travel behaviour required to make the necessary environmental improvements. The remaining supply study investigation concerning recharging finances is reported in Chapter 7.

Chapter 5. Vehicle Demand for Public Recharging Services

The purpose of this chapter is to present the results of the PIV adoption study investigating demand for recharging infrastructure, to address the first research aim. Chapter 2 identified that there may be little demand for public recharging infrastructure so an analysis of vehicle registration data for NE England was performed as described in section 3.5, because recharging demand is generated by vehicles needing to plug into an electricity supply to recharge their batteries. This chapter provides a quantitative analysis of vehicle registrations from 2010 to 2018, to coincide with the period of NECYC recharging data studied in Chapter 6.

First ULEV registration data are reported against UK adoption targets in accordance with UK policy to determine the status of ULEV transition. Chapter 2 identified that local adoption targets are needed for local strategy planning and decision-making, so NE targets were calculated. However, ULEVs include some non-plug-in vehicles which do not require recharging, so plug-in vehicle adoption in each UK region was also reported to provide data for local recharging infrastructure planning, fulfilling the need for PIV specific data identified in Chapter 2. PIV adoption forecasts and energy requirements were calculated to discuss the scale of potential future recharging demand in the NE region. Finally, NE PIV adoption data were used to explore the link between vehicle adoption and use of the NECYC recharging estate, which is discussed further in Chapter 6.

5.1 Analysis of UK ULEV Adoption

A total of 200,295 ULEVs were registered in the UK by the end of 2018 (DfT, VEH0130), less than one third of the CCC's 2020 target as shown in Table 5.1. Therefore, a large increase in ULEV sales growth is required in the remaining two years which is unlikely given the growth so far. A second order polynomial trend line with a good correlation R^2=0.9992 to the registration data forecasted that only 327,204 ULEVs may be registered in the UK by the end of 2020, as shown in Figure 5.1.

	CCC UK ULEV Targets			Progress by 2018	
Year	**New ULEV Registrations (Annual sales & ULEV %)**		**Total ULEV Registered**	**Total ULEV Registered**	**Annual ULEV %**
2020	270,000	9%	680,000	200,295	2.14%
2030	2,100,000	60%	13,600,000		

Table 5.1 – CCC UK ULEV targets and progress to 2018

ULEVs represented only 2.14% of all new sales in 2018 (DfT, VEH0150), which confirmed that UK ULEV adoption was at the earliest Innovators stage in the Diffusion of Innovations Theory (Rogers, 2003) described in Chapter 2. ULEV sales must reach the next diffusion phase Early Adopter, where consumers begin to actively influence others, to achieve the CCC's 9% target. The 2030 target of 60% requires Late Majority adopters who are more risk averse and are unlikely to adopt a ULEV until it matches or exceeds ICE performance. Hence demand must be stimulated to accelerate adoption but the UK's existing incentives described in section 2.8.2 and promotional campaigns referred to in section 4.4 do not appear to be sufficient. Engaging wider stakeholders in new policy design could provide useful insight, using stakeholders' interests outlined in Chapter 4 and the wider value propositions described in Chapter 7.

The latest registration data available at the time of thesis submission indicated that 269,322 ULEVs were registered by the end of 2019 (DfT, VEH0130), with ULEVs representing 3.14% of 2019 new car sales (DfT, VEH0150). Whilst indicating a move from Innovator to Early Adopter diffusion stage, this data supports the conclusion that the CCC's 2020 target is now unachievable. The CCC's 2019 progress review agreed, concluding that both new vehicle CO_2 emission reduction and ULEV registrations fell short of the requirements (CCC, 2019b). Consequently, a more aggressive 2050 net-zero GHG emission target was recommended (CCC, 2019a) including accelerating the phase-out of ICE cars and vans from 2040 to 2035, which was adopted into law in June 2019 (BEIS, 2019b). BEVs rather than PHEVs must become the focus of policy and targets if the UK is to achieve its emission reduction targets, supported by high public engagement, skills, access to capital and aligned incentives.

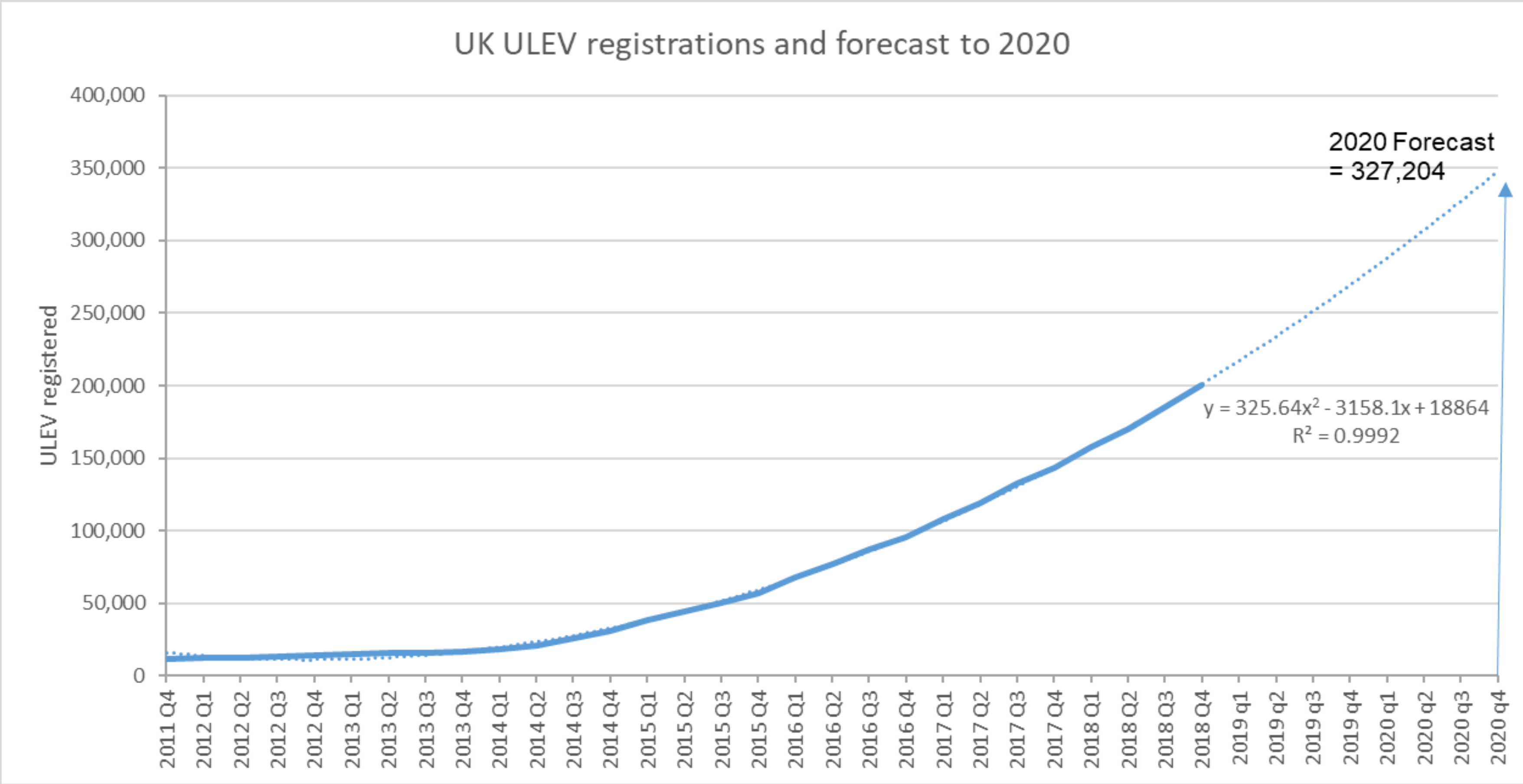


Figure 5.1 – UK ULEV registrations and forecast to 2020

However, PHEV models account for the majority of UK ULEV registrations (EAFO) and evidence provided in Chapter 6 shows that PHEVs use public recharging facilities less than BEVs. PHEV dominance therefore provides a less attractive financial proposition for recharging investors in higher BEV adoption areas. As a result, OLEV changed its vehicle incentives in 2016 to favour BEVs over PHEVs as described in section 2.8.2, which appears to have begun to redress the balance only in 2019 as shown in Figure 5.2.

Year	PHEV	BEV
2016	65%	35%
2017	67%	33%
2018	69%	31%
2019	64%	36%

Figure 5.2 – BEV v PHEV split in UK registrations

UK ULEV adoption only reached the early adopter stage in 2019 at 3.14% of new car sales and is now unable to achieve the CCC's 9% 2020 ULEV target. ULEV adoption needs to accelerate to achieve the UK's emission reduction requirements but PHEVs dominate UK registrations. Consequently, the CCC's recommended 2050 net-zero target and acceleration of the ICE sales ban to 2035 were adopted into UK law in June 2019. However, expanded recharging infrastructure, high public engagement, skills, access to capital and incentives are required to enable this. Using stakeholders' interests (Chapter 4) and wider value propositions (Chapter 7) may help to inform more ambitious policies generating long-term certainty to accelerate ULEV adoption.

5.2 Analysis of ULEV Adoption in NE England

Since UK policy and targets focus on ULEV models, this section reviews the NE region's ULEV adoption status considering the region's demographics. In 2018 1.379

million road vehicles were licensed in NE England, accounting for 3.50% of the 39.365 million vehicles licensed in the UK. Cars and light goods vehicles formed the majority 93.97% (DfT, VEH0105), providing the opportunity to decarbonise a large proportion of the NE road fleet as ULEV models come to market. The NE has the second lowest vehicle density of the 13 UK regions at 0.519 vehicles per head of population, which is below the UK average of 0.593 (DfT, VEH0104). 12,274 million vehicle miles were travelled by NE registered vehicles in 2018, the majority 79.84% by car (DfT, TRA89), suggesting a good opportunity to reduce transport emissions by encouraging NE drivers to convert from ICE to ULEV.

Figure 5.3 depicts the growth in NE total vehicle registrations since 2009 and, using a second order polynomial trend line with good correlation to the source data (R^2 = 0.9865), forecasts that 1.404 million vehicles may be licensed in the area by the end of 2020, and 1.529 million by 2025. This forecast assumes that total licensed vehicle figures increase following the historic pattern over the last nine years, however local policy intentions to increase walking, cycling and public transport use in preference to personal vehicle travel could reduce these forecasts but no contradictory data was available. The 2020 and 2025 forecast dates were chosen to facilitate comparisons between the NE's likely ULEV adoption and the UK-wide CCC targets.

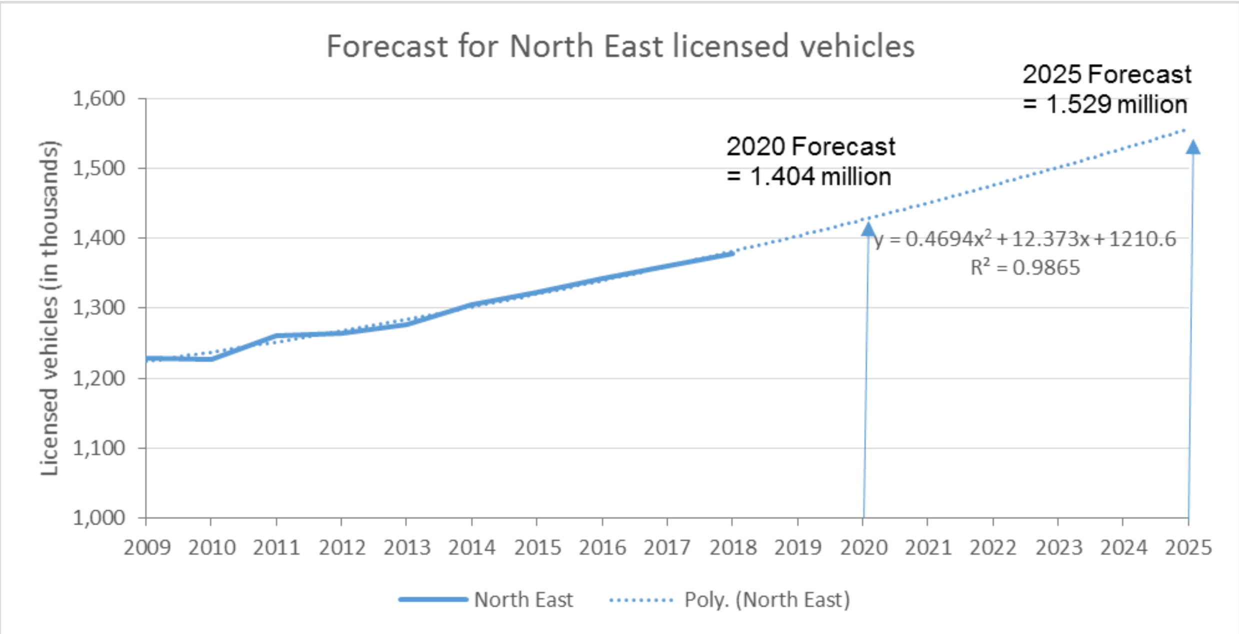


Figure 5.3 – Total vehicles licensed in NE England and forecast growth to 2025

The importance of local priorities and circumstances to regional sustainable transport planning has been identified (Hickman *et al.*, 2013; Government Office for Science, 2019), but Chapter 2 reported that no regional ULEV adoption targets were found. This means the NE cannot measure the effectiveness of its ULEV policy actions. Consequently, NE ULEV targets were calculated at 3.5% of the CCC's ULEV targets, in accordance with total vehicles licensed in the region. The associated ULEV target percentages of total vehicles were then calculated by dividing the target volumes into the NE's total vehicle forecasts provided in Figure 5.3. The results indicate that 1.70% by 2020, rising to 10.53% by 2025, of the NE's total vehicle population should be ULEVs for the region to be on track to achieve the UK's emission reduction goals, as presented in Table 5.2. However, only 3,551 ULEVs were registered by the end of 2018 (DfT, VEH0132), representing only 0.26% of the region's vehicle population and approximating to one sixth of the 2020 NE target.

CCC ULEV targets		NE ULEV target 3.5% of UK	ULEV as % of all NE vehicles	NE Progress by 2018	
Year	Total licensed ULEV UK			Total licensed ULEV NE	ULEV % of NE vehicles
2020	680,000	23,800	1.70%	3,551	0.26%
2025	4,600,000	161,000	10.53%		

Table 5.2 – Calculated NE ULEV targets and status by 2018

Figure 5.4 shows the erratic nature of NE ULEV adoption as a proportion of new vehicle registrations, calculated using total quarterly registration figures (DfT, VEH0132) since new ULEV registration data was not available at regional level at the time of this study. This pattern suggests there is no control over new registrations at regional level and questions whether current national policy focussed on new ULEV sales can be effective at a regional level. The lack of new ULEV registration data and achievable ULEV adoption targets at LA level are a barrier to gathering the evidence necessary for effective regional policy making.

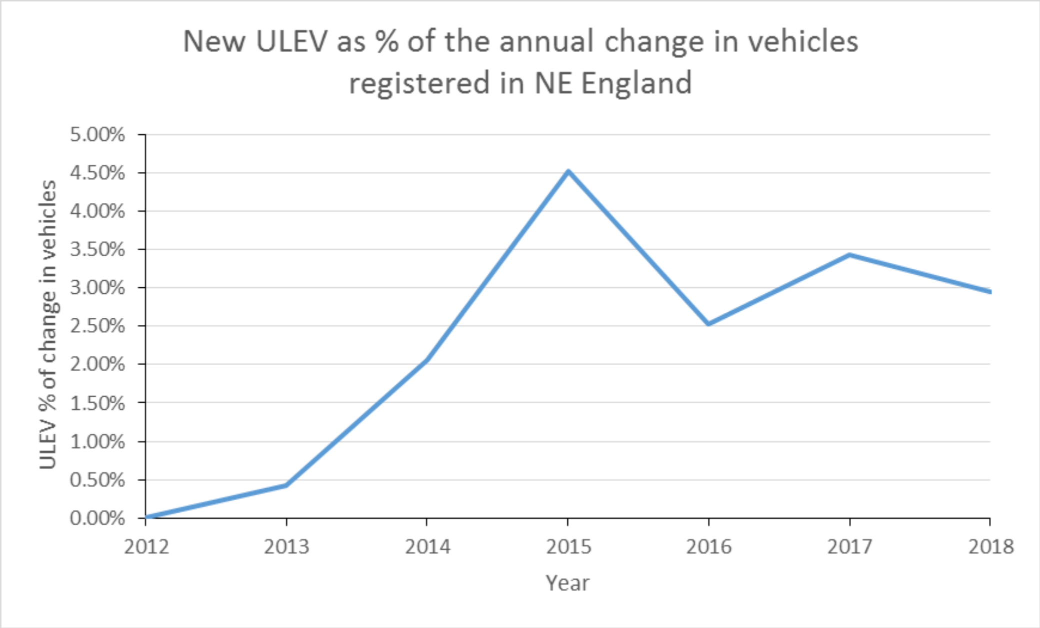


Figure 5.4 – ULEVs as a proportion of new vehicle registrations in NE England

ULEV adoption targets were calculated for the NE region to enable policy planning and subsequent monitoring of progress. Calculating proportionate NE ULEV targets based on CCC UK targets identified that only one sixth of the 2020 NE target had been achieved by the end of 2018.

5.3 Analysis of Plug-in Vehicle Adoption

Only Plug-in Vehicles are relevant to the recharging business case focus of this research, so PIV registration data was investigated at UK and NE level as described in 3.5.1. PIVs represented the majority (93.06%) of UK ULEV registrations by the end of 2018, however no targets exist for PIV sales making it difficult for recharging infrastructure investors to assess the UK market's potential.

By 2018, 3,383 PIVs were registered in the NE region (DfT, VEH0131) comprising 95.27% of the ULEV total, which exceeded the UK PIV average of 93.06% and may be influenced by the presence of Nissan's European BEV manufacturing facility and the lack of hydrogen refuelling facilities in the region. However, PIVs only represented 0.25% of all vehicles licensed in the region, in spite of over eight years of regional investment in free-to-use public recharging infrastructure and free parking incentives explained in section 3.8.1.

The NE is a diverse region of 12 LA areas containing both sparsely populated rural and densely populated urban areas, summarised in Table 5.3. Household wealth measured using Gross Domestic Household Income per head (GDHI), was below the national average of £19,432 in all NE areas and vehicle ownership is below the UK average in all but two areas. The average car mileage of 8,704 miles per year was higher than the national travel survey's published average of 7,800 miles (DfT, 2018c) and high mileage may be a barrier to PIV adoption because PIV range is currently lower than most ICE vehicles. Annual car mileage was highest in three metropolitan areas, Middlesbrough, Gateshead and Newcastle Upon Tyne, but vehicle ownership in these areas was found to be lower than both the regional and national average.

<table>
<tr><th>NE region - LA areas</th><th>2018 people per sq. km</th><th>Vehicles per head of population</th><th>Average annual miles/car</th><th>% miles driven by cars & LGV</th><th>2017 GDHI per head (£)</th></tr>
<tr><td>County Durham UA</td><td>237</td><td>0.54</td><td>8,343</td><td>77.10%</td><td>15,445</td></tr>
<tr><td>Darlington UA</td><td>540</td><td>1.04</td><td>7,914</td><td>79.13%</td><td>15,953</td></tr>
<tr><td>Middlesbrough UA</td><td>2,608</td><td>0.43</td><td>11,833</td><td>81.81%</td><td rowspan="2">14,955</td></tr>
<tr><td>Redcar and Cleveland UA</td><td>558</td><td>0.55</td><td>7,410</td><td>81.96%</td></tr>
<tr><td>Northumberland UA</td><td>64</td><td>0.61</td><td>8,840</td><td>77.78%</td><td>18,855</td></tr>
<tr><td>Stockton-on-Tees UA</td><td>962</td><td>0.54</td><td>8,258</td><td>80.13%</td><td rowspan="2">15,782</td></tr>
<tr><td>Hartlepool UA</td><td>997</td><td>0.48</td><td>8,438</td><td>80.58%</td></tr>
<tr><td>Gateshead</td><td>1,423</td><td>0.45</td><td>11,214</td><td>79.72%</td><td rowspan="4">15,432</td></tr>
<tr><td>Newcastle upon Tyne</td><td>2,646</td><td>0.36</td><td>9,789</td><td>82.60%</td></tr>
<tr><td>North Tyneside</td><td>2,502</td><td>0.50</td><td>7,680</td><td>83.48%</td></tr>
<tr><td>South Tyneside</td><td>2,334</td><td>0.45</td><td>6,632</td><td>81.74%</td></tr>
<tr><td>Sunderland</td><td>2,018</td><td>0.46</td><td>8,094</td><td>80.80%</td><td>14,976</td></tr>
<tr><td>UK average</td><td>274</td><td>0.59</td><td></td><td></td><td>£19,432</td></tr>
</table>

Table 5.3 – Demographic summary for the NE Local Authority areas

All NE LA areas made a smaller contribution to the UK PIV total than to the total vehicle population, but Table 5.4 arranged in order of total fleet size demonstrates that the LA areas with most vehicles did not have the highest PIV proportions. Instead, the densely populated urban South Tyneside area had the highest PIV proportion, ahead of the most affluent rural Northumberland area, followed by metropolitan Newcastle Upon Tyne. Although dissimilar in geography, each of these areas had invested heavily in recharging infrastructure, whilst the areas with lowest PIV proportions, Middlesbrough, Redcar and Cleveland, Darlington and Hartlepool, had relatively few recharging facilities according to the 2019 LA area report (DfT, 2019). Middlesbrough had the lowest PIV adoption but was the least affluent and highest mileage area and therefore possibly has most to gain from transport emissions reduction.

NE LA areas	Total vehicles as % of UK fleet	PIV as % of UK PIV fleet	PIV as % of LA area fleet	PIV % of ULEV
County Durham UA	0.73%	0.36%	0.23%	94.77%
Northumberland UA	0.50%	0.36%	0.34%	97.65%
Sunderland	0.33%	0.18%	0.26%	95.89%
Darlington UA	0.28%	0.09%	0.15%	91.26%
Newcastle upon Tyne	0.27%	0.18%	0.32%	96.35%
Stockton-on-Tees UA	0.27%	0.12%	0.21%	95.67%
North Tyneside	0.26%	0.14%	0.25%	96.24%
Gateshead	0.23%	0.14%	0.29%	90.38%
Redcar and Cleveland UA	0.19%	0.04%	0.11%	98.80%
South Tyneside	0.17%	0.13%	0.37%	96.53%
Middlesbrough UA	0.15%	0.03%	0.10%	93.85%
Hartlepool UA	0.11%	0.04%	0.16%	96.10%

Table 5.4 – Vehicle statistics for the 12 NE Local Authorities

The historical growth in PIV registrations is plotted in Figure 5.5 for each NE LA area. The most rural LA areas with the lowest population densities (ONS, 2017), County Durham and Northumberland, had the highest PIV registration volumes in the region, which is unsurprising since they also had the highest total vehicle registrations. For comparison, Figure 5.6 shows the growth in percentage of PIV adoption in each LA area over the previous five years. South Tyneside was confirmed as the highest adoption area although growth appeared to have slowed in the last year. Northumberland and Newcastle Upon Tyne's PIV percentages continued to grow and are likely to exceed South Tyneside's in the next year if this pattern continues. Since PIV adoption generates demand for public recharging facilities, recharging investment is most likely in the affluent areas of Northumberland, Newcastle and South Tyneside where demand is highest, and least likely in the least affluent and slow growth areas of Middlesbrough, Redcar and Cleveland.

However, as identified in Chapter 2, PIV drivers prefer to recharge at home (Skippon and Garwood, 2011; Morrissey *et al.*, 2016), so a lack of off-street residential parking is likely to increase demand for public recharging services in local areas. The analysis of NE housing stock by LA area summarised in Table 5.5 indicates that Newcastle Upon Tyne and South Tyneside had the highest percentage of homes without off-street parking in the region, strengthening the demand for public recharging facilities in these high adoption areas. The most affluent area Northumberland, however, has above average residential parking provision, so demand for public recharging may be lower here. Two areas with low PIV adoption, Middlesbrough and Redcar and Cleveland, also had above average residential parking provision reinforcing the low public recharging demand forecast.

NE region - LA areas	% homes without off-street parking
Newcastle upon Tyne	58.55%
South Tyneside	50.76%
Hartlepool UA	50.65%
North Tyneside	48.03%
Gateshead	47.69%
Middlesbrough UA	46.47%
Darlington UA	45.19%
Sunderland	45.18%
County Durham UA	44.36%
Northumberland UA	39.25%
Redcar and Cleveland UA	38.00%
Stockton-on-Tees UA	34.72%
UK average	46.78%

Table 5.5 – Percentage of homes without off-street parking in NE LA areas

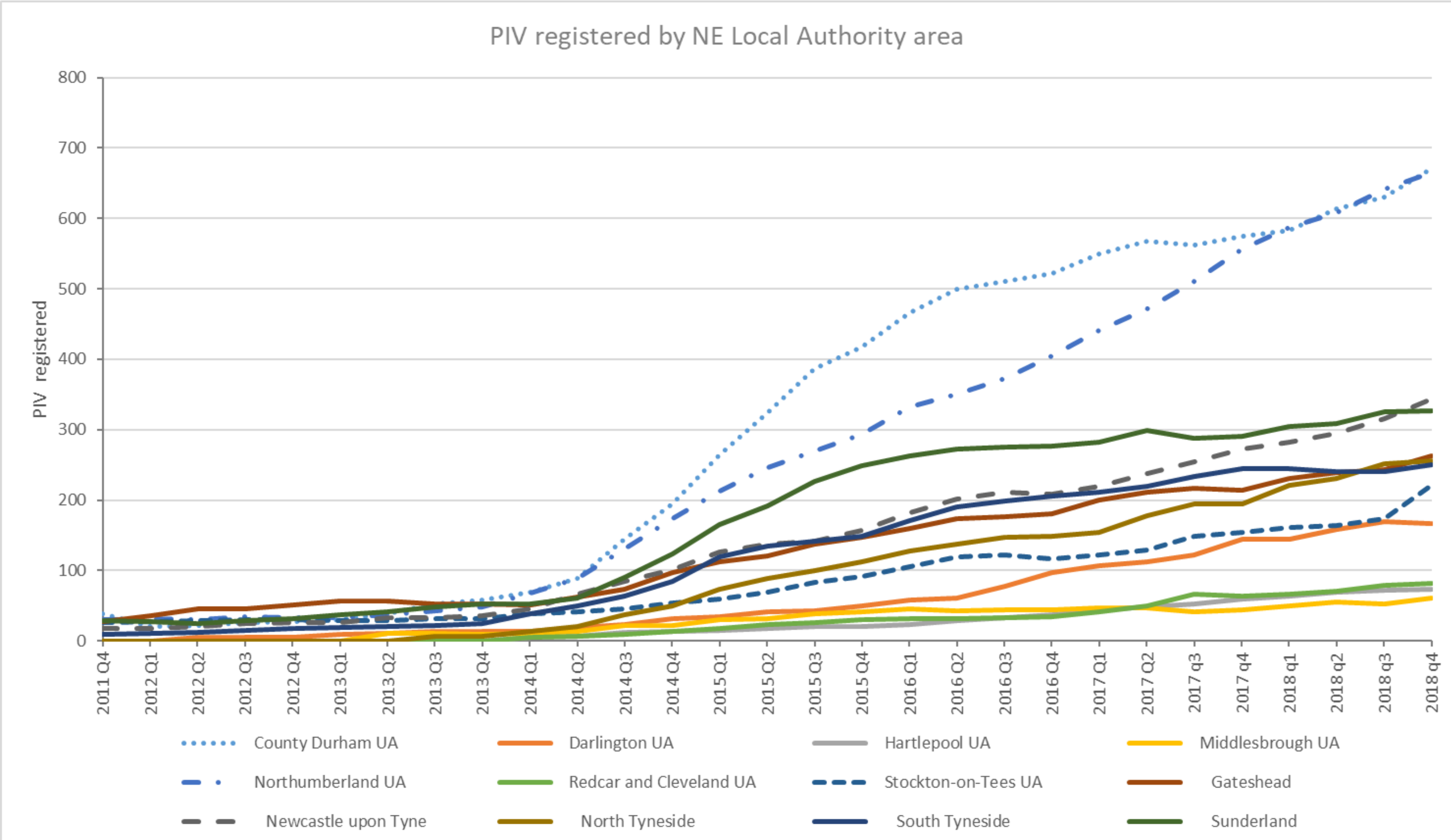


Figure 5.5 – NE England PIV registrations by Local Authority area

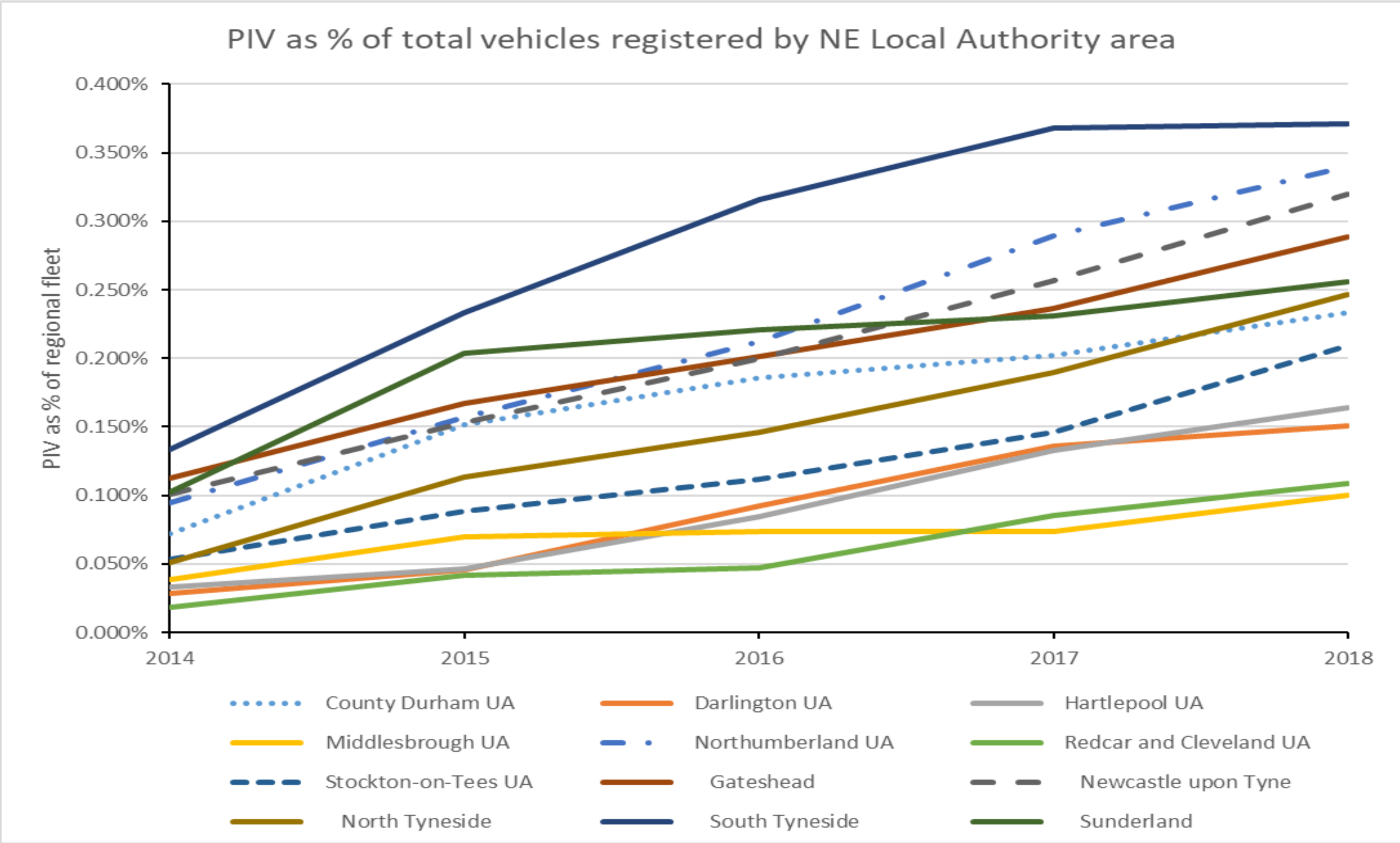


Figure 5.6 – PIV as a proportion of total vehicles registered in NE LA areas

Finally, to investigate the relationship between charger provision and PIV adoption in NE England, quarterly PIV vehicle registration figures were plotted against the number of unique NECYC charge points recording data from 2010 to 2018, generating Figure 5.7. Whilst this only represents very limited data at the beginning of a technology transition, it suggests that there is no clear correlation between public recharging infrastructure provision and PIV adoption. Adoption only began to increase once approximately 300 charge points were available and then continued to rise despite the poor reliability and availability concerns expressed by drivers in Chapter 4, leading to chargers disappearing from the data.

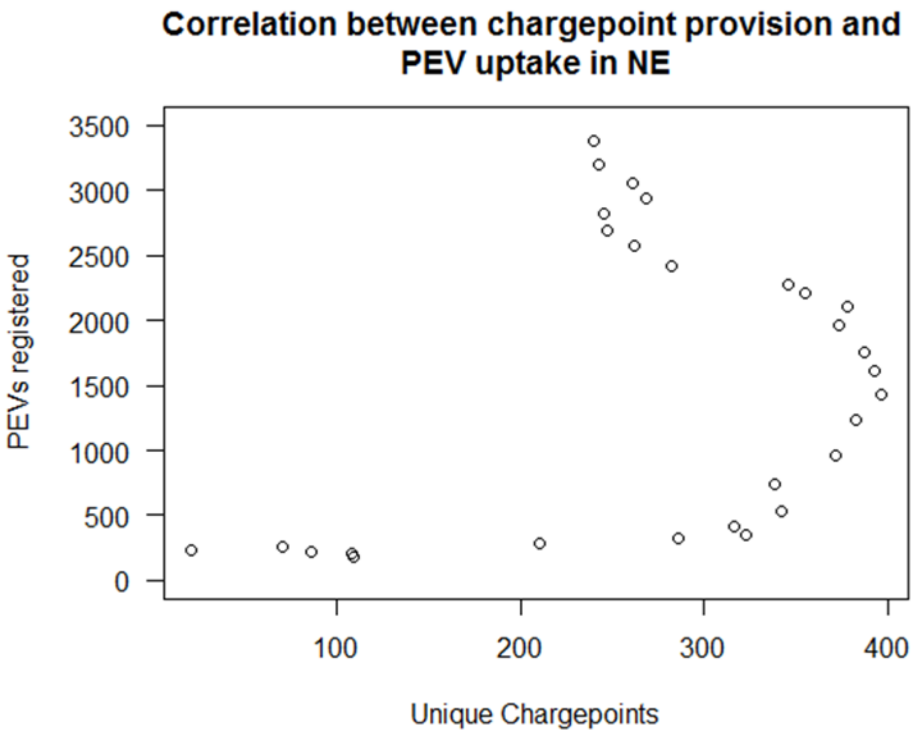


Figure 5.7 – Relationship between PIV adoption and charge point provision

In the diverse NE region, urban areas followed by affluent rural areas had the highest PIV adoption percentages. The LA areas with highest PIV adoption had invested heavily in public recharging infrastructure and the least affluent LA areas had the lowest PIV adoption and relatively few public recharging facilities. Further recharging investment is likely in the areas with highest PIV growth and scarce off-street residential parking, Newcastle Upon Tyne and South Tyneside, but is unlikely in low PIV adoption areas with adequate residential off-street parking such as Redcar and Cleveland. No direction correlation was found between charger provision and PIV adoption in the region.

5.4 Comparative Discussion with Other UK Areas

This section compares the NE's PIV adoption position with other UK regions to assess comparative demand for public recharging. The East Midlands (EM) region was identified as the closest NE comparator due to its combination of population density (ONS, 2017), vehicle ownership and car mileage data, as shown in Table 5.6. Both regions have below UK average wealth and above average annual car mileage. However, EM is home to just over three million vehicles (DfT, VEH0104), equating to 7.63% of the UK fleet, and although double the NE's figure this is the second lowest proportion within the English regions. However, the EM region has slightly above UK average vehicle density (DfT, VEH0104), in contrast to the NE's below average figure, and a low proportion of homes without off-street parking so many EM drivers should be able to recharge at home.

UK region	2018 people per sq. km	Vehicles per head of population	Average annual miles/car	GDHI per head 2017 (£)	% homes without off-street parking
North East	310	0.519	8,651	£15,595	45.59%
East Midlands	307	0.625	8,724	£17,042	32.36%
UK average	274	0.593	7,800	£19,432	

Table 5.6 – Comparison between North East and East Midlands demographics

The PIV adoption status for each region is compared in Table 5.7. By 2018 9,857 PIVs were licensed in EM (DfT, VEH0131), equating to 0.33% of the regional vehicle fleet and 5.29% of the UK registered PIVs, almost three times the NE's figure. However, PIVs account for only 89.57% of EM's ULEV total giving a proportionately lower demand for recharging than in the NE, which could be because EM's annual mileage is higher than the NE's resulting in a perceived need for the range security provided by PHEV over BEV models.

UK region	PIV as % of regional fleet	Total vehicles as % of UK fleet	PIV as % of UK PIV fleet	PIV as % of ULEV
North East	0.25%	3.50%	1.82%	95.27%
East Midlands	0.33%	7.63%	5.29%	89.57%
UK average	0.47%			93.06%

Table 5.7 – Comparison between NE and East Midlands PIV adoption

Both NE and EM's PIV contribution to their regional fleet is below the national average and also falls short of their contribution to total UK vehicles. Conversely, as Table 5.8 shows, five UK regions made a higher contribution to the UK's PIV total than to the national vehicle fleet: West Midlands; London; South East; East of England; and South West. Three of these regions have GDHI above the national average (ONS, 2018), indicating relative wealth and greater accessibility to PIVs where prices exceed similar ICE models. Therefore, high GDHI appears to be an important factor in PIV adoption, which matches the innovator and early adopter consumer profiles identified in Chapter 2. London has the highest GDHI in the UK (ONS, 2018) and the highest percentage of homes without off-street parking, suggesting a high density of public recharging will be required. However, London also has the lowest PIV percentage of ULEVs, suggesting that wealthy London drivers do not need to accept the range limitations of most BEV models, so they purchase premium hybrid vehicles that may therefore not require frequent recharging as evidenced in Chapter 6. London also has a much lower average annual car mileage than all other UK regions, limiting its contribution to emission reduction targets. Notably, the West Midlands region currently has the highest PIV adoption but a below average GDHI. The automotive industry's pivotal role in the West Midlands' economy may explain this high PIV adoption, suggesting that related industries may influence PIV adoption in local areas. However, the NE has a similar economy due to Nissan's involvement, but high early PIV registrations have since dwindled which warrants further research.

UK region	PIV as % of regional fleet	total vehicles as % of UK fleet	PIV as % of UK PIV fleet	Average annual miles/car	GDHI per head 2017 (£)	% homes without off-street parking	PIV as % of ULEV
West Midlands	0.69%	9.61%	14.03%	7,975	16,885	39.11%	95.85%
London	0.67%	7.80%	11.06%	5,271	27,825	75.09%	82.54%
South East	0.62%	15.95%	20.74%	8,321	22,568	43.69%	93.70%
East of England	0.60%	10.34%	13.04%	8,831	20,081	34.49%	95.67%
South West	0.53%	10.29%	11.49%	8,135	18,984	42.20%	95.92%
Yorkshire and Humberside	0.40%	7.67%	6.47%	8,378	16,119	42.69%	94.70%
Scotland	0.36%	7.60%	5.83%	9,102	18,099	55.31%	95.67%
East Midlands (EM)	0.33%	7.63%	5.29%	8,724	16,932	32.36%	89.57%
North West	0.25%	9.85%	5.27%	8,645	16,861	46.33%	92.49%
North East (NE)	0.25%	3.50%	1.82%	8,651	15,809	45.59%	95.27%
Northern Ireland	0.21%	2.95%	1.31%		15,813	35.03%	96.57%
Wales	0.20%	4.88%	2.03%	9,118	15,754	40.85%	92.87%
UK averages	0.47%				19,514	46.78%	93.06%

Table 5.8 – UK regions in order of PIV adoption 2018

Comparing the similar demographic EM region with the NE found that both regions' PIV adoption and contributions to the UK fleet are below the national average. Most regions with above average contributions to the UK PIV fleet have high GDHI, suggesting that affluence is an important factor in PIV adoption. The presence of PIV manufacturers in a region may increase local PIV adoption.

5.5 Discussion of Forecasts for Future Recharging Demand

This section discusses potential future demand for public recharging in the NE region and the associated energy requirement created by PIV adoption. Figure 5.8 illustrates the growth in NE PIV registrations since 2011 when records began and a forecast with a good correlation R^2=0.9762 to the registration data indicates that only 9,459 PIVs may be registered by 2025, far below the regional targets provided in Table 5.2, so local action is clearly required to increase PIV adoption in the region.

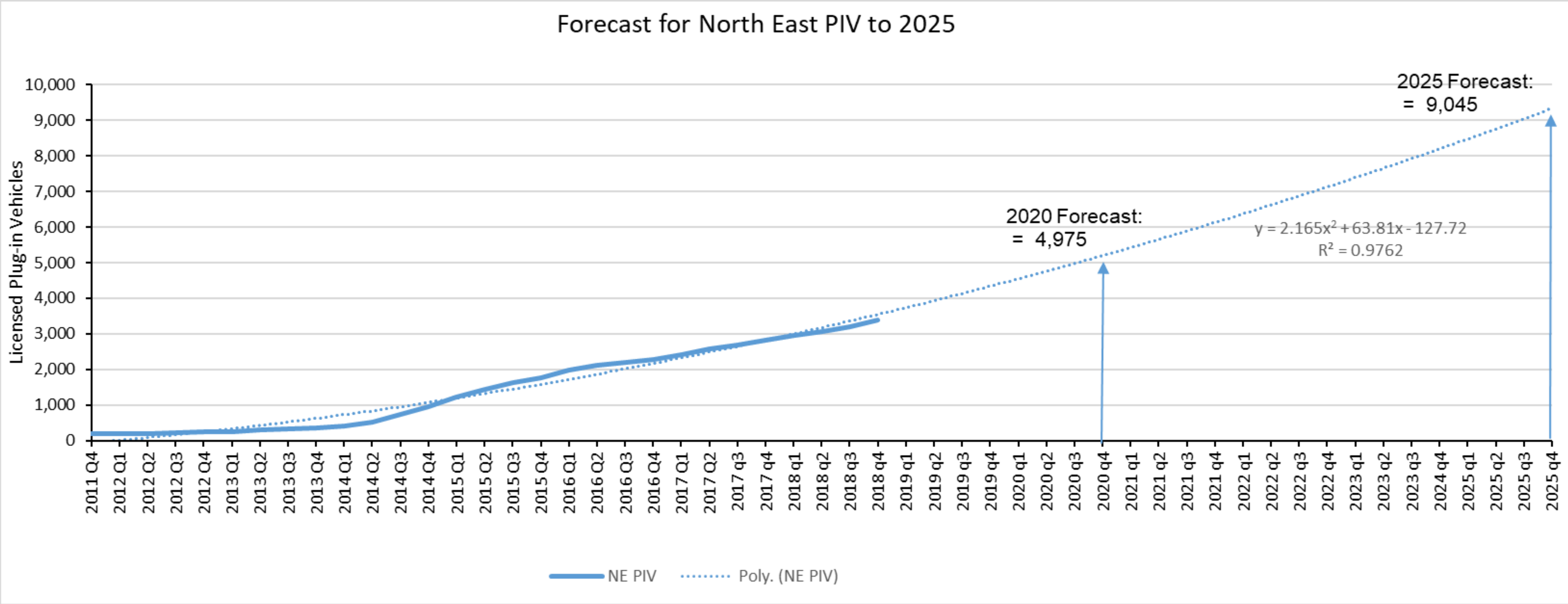


Figure 5.8 – Forecast for PIV adoption in NE England

To estimate the future demand for public recharging created by these PIV forecasts, LA area adoption was forecasted as described in section 3.5.1 and the total energy required by those PIVs was then calculated as described in section 3.5.3 using average efficiency of 0.3kWh/mile[12]. Public recharging demand was assumed to be 10% of total energy requirement in line with PIV driver survey findings in section 4.2. The energy results presented in Table 5.9 may be of use to grid operators planning future capacity and to energy suppliers and recharging network operators planning future investment.

		PIV registration forecasts		Public recharging energy demand @ 10% of total required, assuming 0.3kWh/mile driven	
NE LA areas	Average annual miles/car	2020 PIV Forecast	2025 PIV Forecast	2020 Energy MWh	2025 Energy MWh
County Durham UA	8,343.3	946	1,531	236.8	383.2
Darlington UA	7,914.0	290	633	68.8	150.4
Hartlepool UA	8,438.0	127	278	32.1	70.5
Middlesbrough UA	11,832.7	68	84	24.2	29.9
Northumberland UA	8,840.3	1,043	2,061	276.6	546.7
Redcar and Cleveland UA	7,409.6	135	294	30.0	65.3
Stockton-on-Tees UA	8,258.5	296	593	73.2	147.0
Gateshead	11,214.4	368	645	123.9	216.9
Newcastle upon Tyne	9,788.8	486	899	142.7	264.0
North Tyneside	7,680.4	404	806	93.1	185.7
South Tyneside	6,631.5	246	331	49.0	65.9
Sunderland	8,093.7	437	612	106.2	148.7
NE Region		4,975	9,045	1,256.6	2,273.9

Table 5.9 – Public recharging energy demand forecasts for NE England

Unsurprisingly, the areas with highest forecasted PIV adoption have the highest public recharging energy requirement. However, the largest energy demand areas, County Durham and Northumberland, have a low percentage of homes without off-street

[12] https://ev-database.uk/ an online database summarising available specification data for electric vehicles of all makes and models

parking and therefore low demand for public alternatives to home recharging. Conversely, Newcastle Upon Tyne, North Tyneside and Gateshead have relatively high public recharging energy demand and need for alternatives to home recharging, making them more attractive areas for recharging investment.

To investigate hypothesis 1: *the majority of recharging will take place at home or at work, with little demand for public recharging facilities,* the calculated 2018 energy requirement of NE PIVs was compared with the energy delivered by the NECYC public recharging estate reported in Chapter 6. Table 5.10 demonstrates that the public recharging estate delivered 61.8% of the calculated 2018 PIV energy requirement, disproving the hypothesis. However, the free energy and free parking incentives are likely to have biased the NECYC results, increasing use. Additionally, the NECYC estate is likely to have also delivered energy to visiting PIVs registered outside of the NE region, so local registration data only provides part of the demand for local public recharging services. Further monitoring of PIV registrations alongside NECYC recharging data when fees are levied is recommended to reassess public recharging demand once recharging behaviour normalises under commercial conditions.

NE LA areas	Average annual miles/car	2018 PIV Registered	2018 Energy Required MWh @0.3kWh/mile	2018 NECYC Energy delivered MWh
County Durham UA	8,343.3	670	167.7	
Darlington UA	7,914.0	167	39.6	
Hartlepool UA	8,438.0	74	18.7	
Middlesbrough UA	11,832.7	61	21.7	
Northumberland UA	8,840.3	665	176.4	
Redcar and Cleveland UA	7,409.6	82	18.2	
Stockton-on-Tees UA	8,258.5	221	54.8	
Gateshead	11,214.4	263	88.5	
Newcastle upon Tyne	9,788.8	343	100.7	
North Tyneside	7,680.4	256	59.0	
South Tyneside	6,631.5	250	49.7	
Sunderland	8,093.7	327	79.4	
NE Region			874.4	540.8
				61.85%

Table 5.10 – 2018 total NE PIV energy demand v NECYC delivery

5.6 Summary of Findings

The goal of this chapter was to present the results of the PIV adoption study performed to address the demand aspects of aim 1: ***To identify the demand and supply determinants for continuing and increasing recharging infrastructure provision in public places*.** Trends in ULEV and PIV adoption were identified and the implications for future public recharging demand at UK and NE LA level were discussed.

In 2019 UK ULEV adoption progressed from the innovator to early adopter stage in the diffusion of innovations cycle, reaching 3.14% of new car sales. However, progress failed to meet the CCC's requirements, so the phase-out of ICE car and van sales was brought forward from 2040 to 2035 to accelerate ULEV adoption. The CCC called for expanded recharging infrastructure and more ambitious policies to accelerate adoption, so the stakeholders' interests outlined in Chapter 4 and the wider value propositions described in Chapter 7 may be useful to policy-makers. UK policy should focus on BEV models rather than PHEVs to achieve the emission reduction targets, which provide a greater demand for public recharging infrastructure as demonstrated in Chapter 6.

The NE region has above average annual mileage and cars and light vans form the majority (93.97%) of vehicles, providing the opportunity to decarbonise a large proportion of the road fleet as ULEV models come to market. Chapter 2 identified that a lack of local targets stifles local strategy development and makes it difficult for recharging investors to assess market potential, so NE ULEV targets were established in line with national fleet targets, however only one sixth of the 2020 NE target was met by 2018.

NE PIV adoption was the lowest of all English regions although PIV's proportion of ULEV registrations was one of the highest, possibly due to Nissan's PIV manufacturing plant in the region. Further recharging investment was most likely in the high adoption affluent areas of rural Northumberland, urban Newcastle and South Tyneside and least likely in the least affluent and slow PIV growth areas of Middlesbrough, Redcar and Cleveland. Newcastle Upon Tyne and South Tyneside were also likely to have higher public recharging demand in residential areas due to their high proportion of homes without off-street parking. Forecasted PIV adoption for 2025 fell well short of the regional targets calculated, so local action is required to increase adoption. Hypothesis 1, that there would be little demand for public recharging, was disproved because the NE's public recharging estate NECYC delivered 61.8% of the total energy required by PIVs registered in the region in 2018, however the free energy and parking incentives likely biased this result.

The NE's closest demographic comparator East Midlands contributed almost three times more (5.29%) to the UK PIV fleet than NE (1.82%) despite the below UK average household wealth. Both the NE and EM regions made a smaller contribution to UK PIV figures than to the total vehicle population, however five regions made a higher contribution to the UK's PIV total than to the national vehicle fleet, suggesting that affluence and the presence of PIV manufacturers were important factors in local PIV adoption. Figure 5.9 summarises how PIV adoption affects demand for public recharging, fulfilling the second element of the demand study, and Chapter 6 addresses the final demand investigation.

Figure 5.9 – PIV adoption determinants of public recharging demand

Chapter 6. Recharging Behaviour

The purpose of this chapter is to present the results, analysis and discussion of the public recharging behaviour study forming the final element of the demand study conducted to address aim 1. The results show the impact of location, accessibility and technical capability on charger use in the NE recharging estate operated by Charge Your Car (NECYC) between 2010 and 2018, addressing the need for real-world longitudinal recharging studies to inform future recharging network planning identified in Chapter 2. The regional NECYC results are then compared with a national recharging network, the Electric Highway (EH) operated by Ecotricity. EH recharging data was analysed using the same categories, but EH also introduced fees in 2016 which enabled a study of the effectiveness of recharging fees to meet the research gap identified in Chapter 2. The results address both the demand and supply determinants for public recharging provision in the first research aim and are subsequently used to inform the business case discussion in Chapter 7.

6.1 Analysis of the NECYC Recharging Estate

The regional public recharging behaviour study covered the geographic area of NE England illustrated in Figure 6.1 using a screenshot from the CYC website which indicates the spread, density (black circles) and type of chargers (denoted S/F/R) installed across the region. The NECYC recharging estate analysed comprised 761 unique charge points providing data on recharging events delivered over nine years between 2010 and 2018. Figure 6.2 demonstrates the reduction in chargers providing data from the 2016 peak which could be due to data recording failures, chargers not being used, or falling into disrepair as reported by stakeholders in Chapter 4.

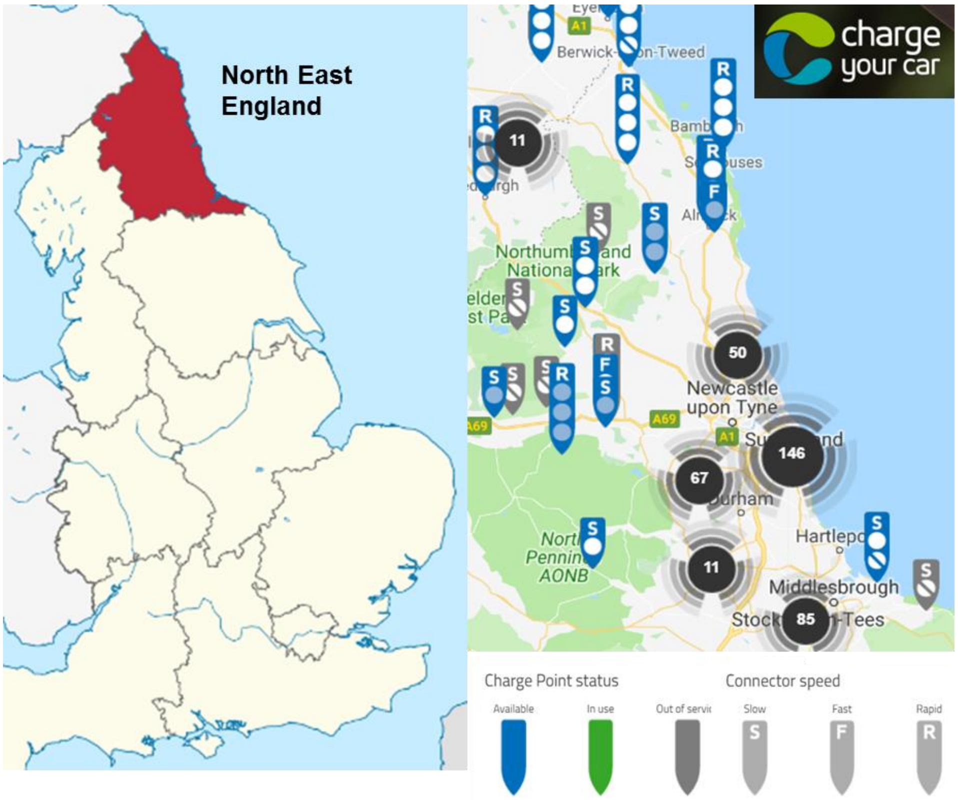


Figure 6.1 – NECYC recharging estate

Source: www.chargeyourcar.org.uk screenshot taken 30/08/2019

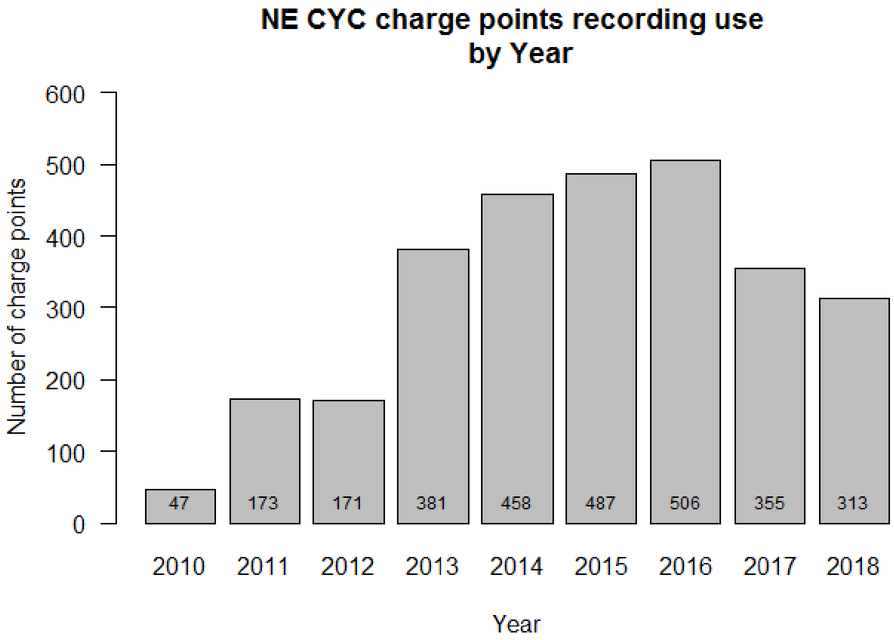


Figure 6.2 – Unique NECYC charge points providing recharging data

Figure 6.3 confirms that the majority of charge points were located in urban Newcastle Upon Tyne, the most densely populated LA area with the highest proportion of homes without off-street parking and relatively high PIV adoption. Conversely, the areas with lowest PIV adoption, Middlesbrough, Redcar and Cleveland, Darlington and Hartlepool, had the fewest chargers recording data, as discussed in Chapter 5.

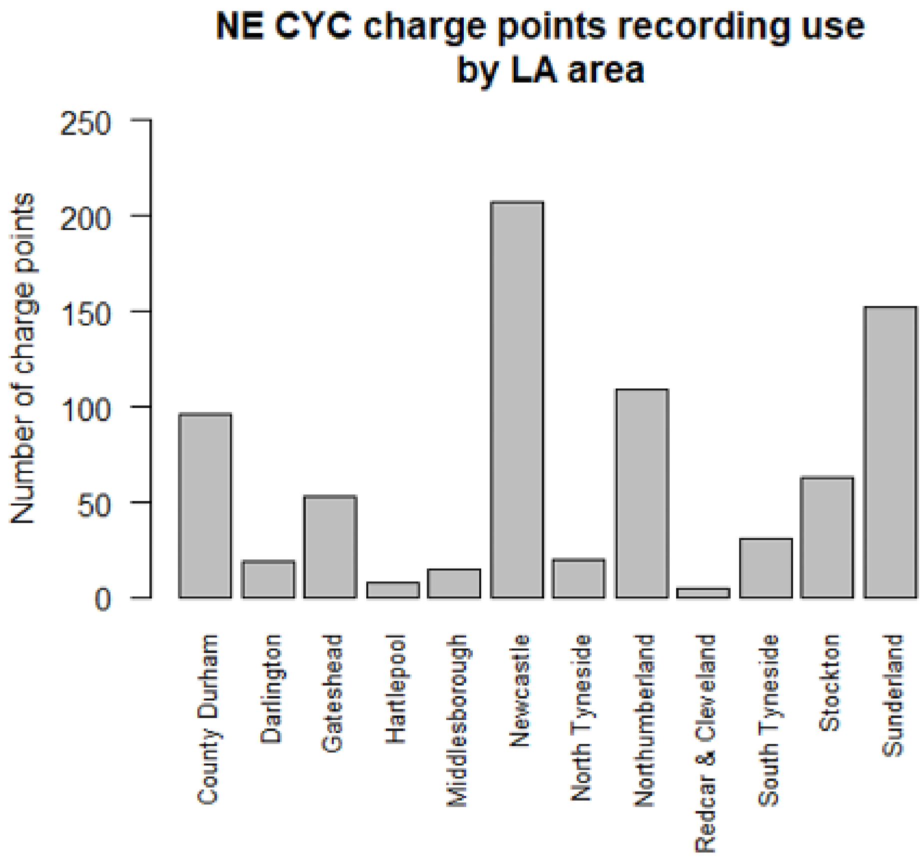


Figure 6.3 – NECYC chargers by Local Authority area

The NECYC estate contained 332 unique sites with charge points which delivered at least one recharging event over the study period. Each charge point was identified by a unique code designed by the NEPIP project to indicate one of five location types: Commercial places; Public on- and off-street places; Workplaces; and Transit locations. Transit locations are places where drivers' primary purpose is to recharge their vehicle quickly. By contrast, destinations are places where drivers go primarily to do other tasks such as work, shop or study, and therefore wish to park for a period of time when they may also choose to recharge as a secondary purpose. Destinations included both public and privately owned locations in this dataset. The Commercial term distinguishes destinations associated with a specific commercial operation such as retail parks, cinemas or leisure facilities from sites supporting multiple destinations such as car parks in urban centres. Concerns regarding the suitability of chargers for on-street installation led to a further distinction between on- and off-street public recharging locations. The final location category, workplaces, reflects destinations where chargers are usually provided for use only by employees and business vehicles operated by the site owner. However, visitor use was a requirement of the NEPIP funding, so workplace locations were included in this study.

The prevalence of public off-street and workplace charge points is demonstrated by Figure 6.4, with few in-transit and on-street locations. The quantity of charge points in commercial places reduced continuously from 2014 coinciding with the end of NEPIP funding for operating costs, which may indicate that some commercial owners ceased charger provision due to ongoing operating costs.

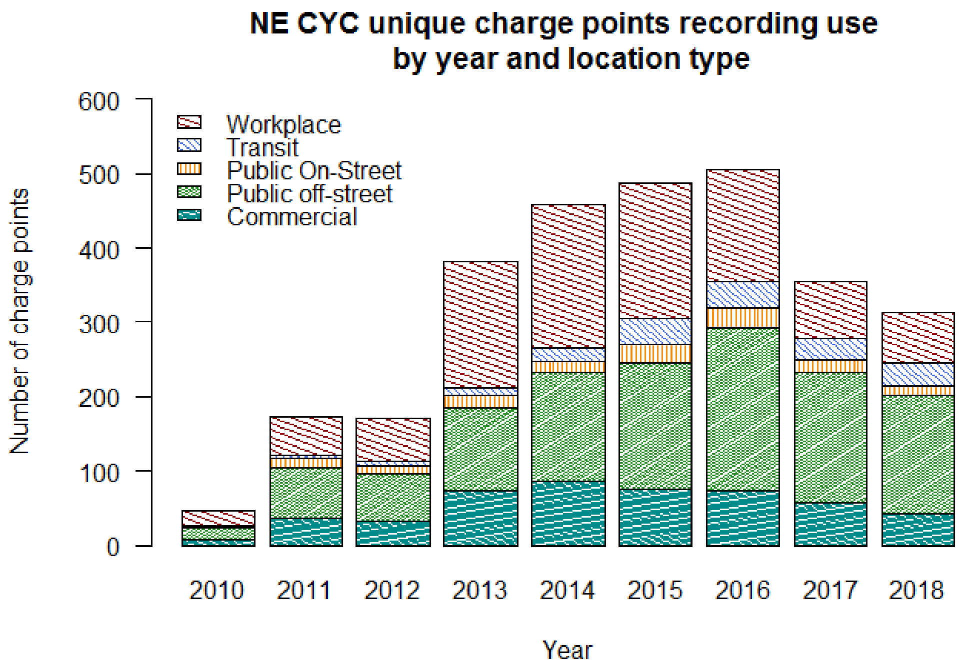


Figure 6.4 – NECYC estate categorised by location type

The majority (49%) of NECYC sites contained two charge points, although 30% contained only one. However, 3% of sites provided seven or more charge points in off-street public car parks, large workplaces and large commercial destinations such as the Metrocentre. Offering more than one charger per site was intended to provide greater certainty of availability, a concern highlighted by drivers in Chapter 4.

The charge points were also differentiated by Access type, which defined permitted users, to assess the effect of accessibility on charger use. NEPIP funding required that all chargers were accessible either by the public, or by staff and visitors at workplaces. The All Public access category covered commercial, public on-street and off-street locations, whereas workplace chargers were assigned Employee access. Transit locations were also publicly accessible, but because recharging was the primary visit purpose a Transit access category was assigned to compare use where recharging is the primary or secondary function. Figure 6.5 illustrates the dominance of publicly accessible charge points and the small proportion of Transit access chargers in the NECYC estate.

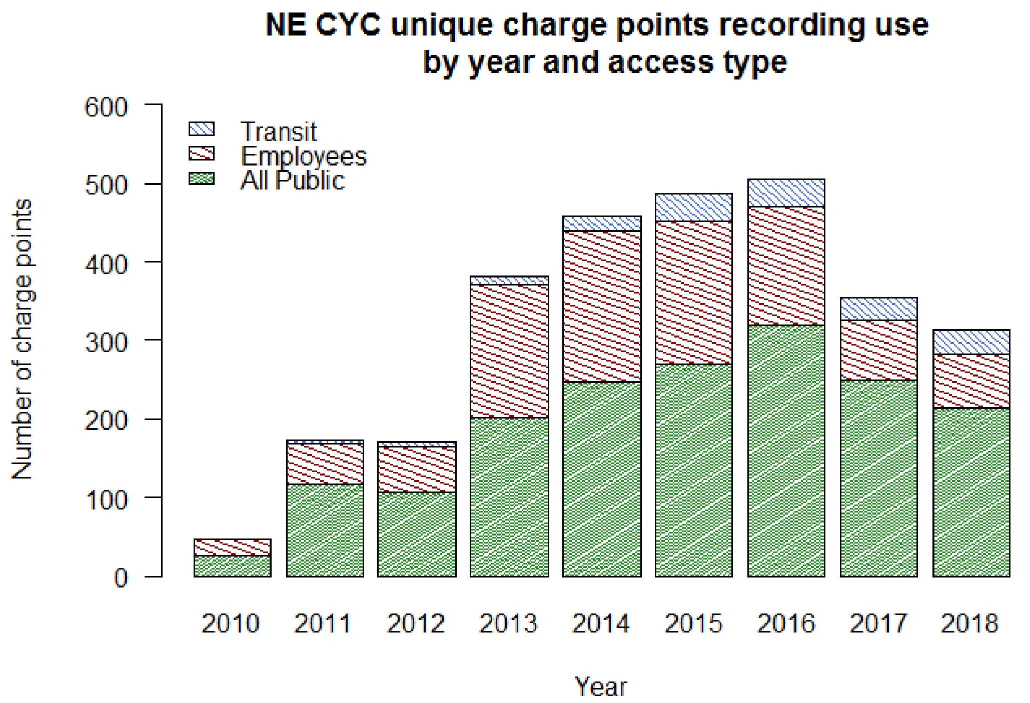


Figure 6.5 – NECYC estate categorised by access type

The maximum power delivery capability of a charge point dictated the duration of recharging events it could deliver and therefore determined its type: slow, fast or rapid using standard UK terminology (UK EVSE) as demonstrated in Figure 6.6. The recharging event duration limited the quantity of recharging events a charge point could deliver in a given period, defining its theoretical capacity. However, the PIV ultimately dictated the rate at which power was drawn from a charge point as defined in Chapter 2, indicating another variable for investigation in charge point use.

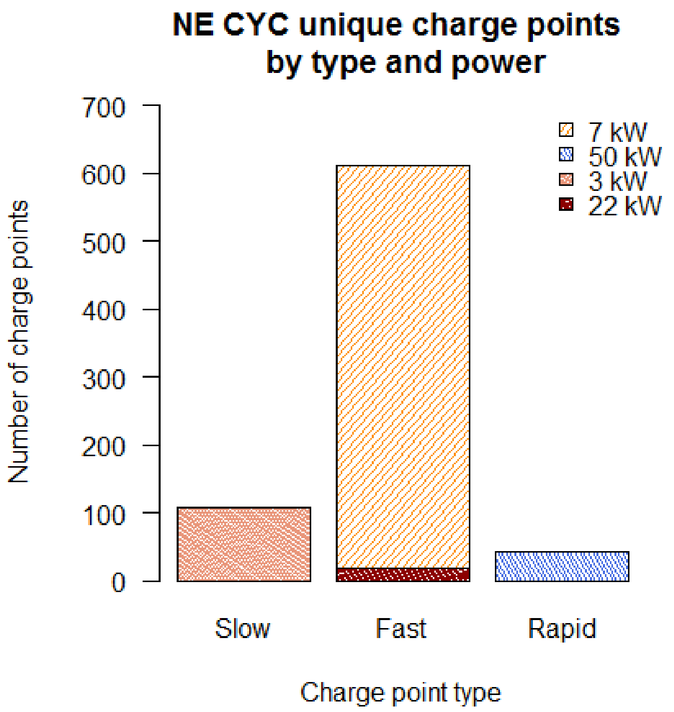


Figure 6.6 – NECYC estate by charge point power and type

Figure 6.7 illustrates the dominant proportion of 7kW fast chargers, the decreasing quantity of 3 kW slow chargers and the increase of 50kW rapid chargers over the period. Rapid charger deployment increased to a peak in 2015 due to OLEV rapid charger grants awarded to Northumberland and South Tyneside LAs and these were largely maintained. By contrast, slow and fast charger quantities decreased from 2016 reflecting drivers’ concerns about poor reliability and availability discussed in Chapter 4. In addition, new 22 kW fast chargers began to appear from 2014 with three-phase power supplies to future-proof the estate ready for new PIV models coming to market with higher-power charging capabilities.

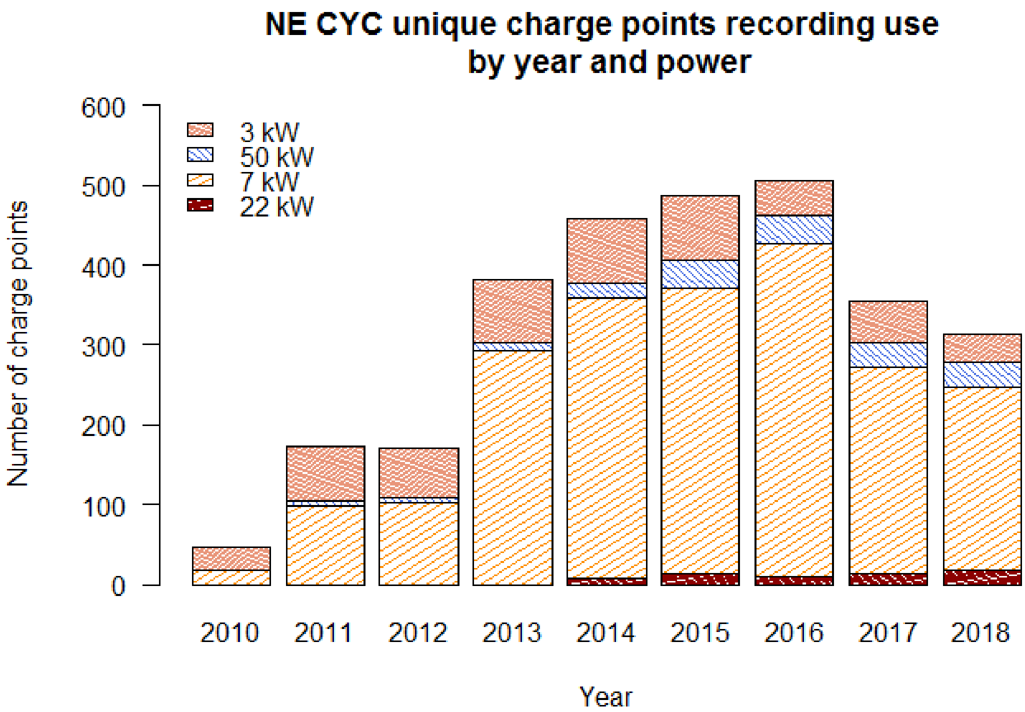


Figure 6.7 – Composition of NECYC estate by charge point power

Both slow and fast chargers were accessible by the public and by employees, but only rapid chargers were provided for transit users to match their primary purpose of recharging quickly as illustrated by Figure 6.8. Fast chargers formed the majority of the estate in each location type as demonstrated by Figure 6.9, whilst confirming that rapid chargers were only provided in Transit locations.

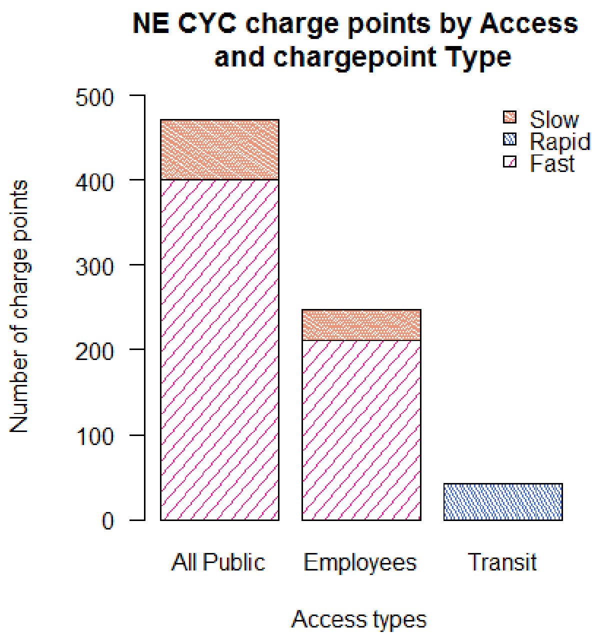


Figure 6.8 – Types of NECYC charge points by Access type

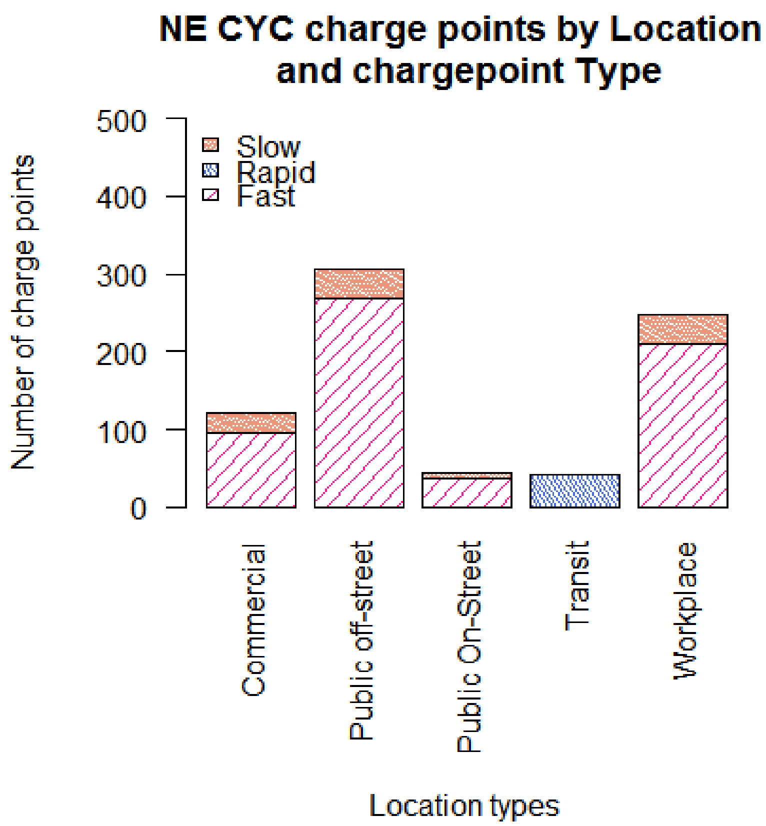


Figure 6.9 – Types of NECYC charge points by location type

7 kW fast chargers formed the majority (78%) of the 761 charge points studied in the NECYC estate, whereas rapid chargers represented only 5.5% of the estate. 62% of the charge points were available for public use, and the largest proportion (40%) were sited in public off-street locations. 70% of the sites studied contained two or more charge points. The number of charge points recording use peaked in 2016 and has subsequently fallen each year.

6.2 Ownership of the NECYC Recharging Estate

This section provides an analysis of the ownership of the NECYC estate in response to the need for a greater understanding of infrastructure ownership identified in Chapter 2. The owner of each charge point, called its host, was responsible for the ongoing operation and maintenance of the recharging estate after the NEPIP project ended in 2013. 99 unique hosts were identified in the NECYC dataset, the majority of which (57%) were private organisations, although all 12 LAs, local NHS, fire service and police organisations called government hosts, academic and third sector organisations were also identified in the data, indicating that diverse organisations are interested in charger provision. However, the relatively few LAs, called Council hosts, owned the majority (60%) of charge points in the estate as illustrated in Figure 6.10. Newcastle City Council owned the largest proportion (21%) of charge points, but 34% of hosts owned only one charge point and consequently the median number of charge points per host was only two.

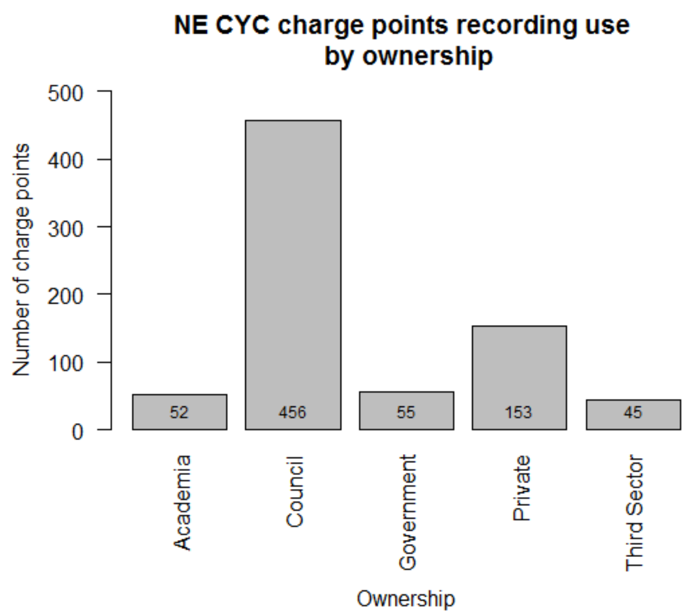


Figure 6.10 – NECYC charge point ownership by host type

Figure 6.11 illustrates that only Council hosts owned on-street chargers and the majority of off-street and transit chargers in the estate, whereas all host types owned chargers in workplaces and commercial locations.

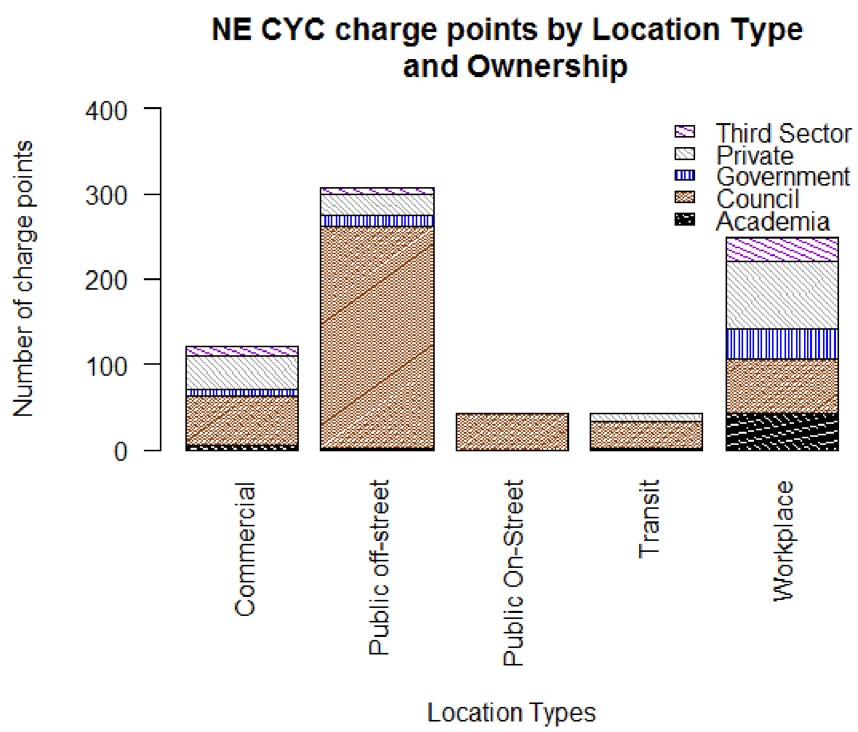


Figure 6.11 – NECYC charge points by host and location type

The few Council hosts owned the majority of publicly accessible chargers (All Public and Transit categories). All host types provided chargers for employee use, but only council and private hosts owned rapid chargers for transit users as shown in Figure 6.12.

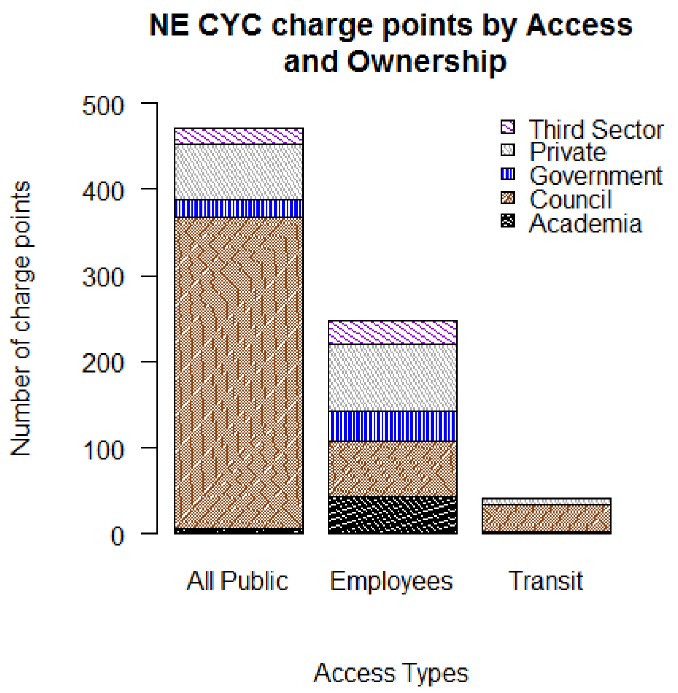


Figure 6.12 – NECYC estate by host and access type

99 unique hosts across LA, private, government, academic and private sectors owned charge points in the NECYC estate. The majority (57%) of owners were private organisations, however the 12 LAs owned the majority (60%) of charge points. All types of hosts owned chargers in commercial places and workplaces, but only councils owned chargers on streets and the majority of chargers in publicly accessible locations.

6.3 Analysis of NECYC Recharging Estate Use

This section addresses the need identified in Chapter 2 for longitudinal data regarding the location, frequency, duration and energy delivered by public recharging events, in order to plan future recharging provision. The historical public recharging behaviour study forms the final element of the demand study conducted to address aim 1 and provides data for use in the business model assessment in Chapter 7. The results of this analysis, together with the analysis of PIV uptake provided in Chapter 5 and stakeholder motivations discussed in Chapter 4, may be used to inform future recharging provision in the NE region.

6.3.1 *Recharging events*

The NECYC dataset provided a large population of 401,240 recharging events from 2010 to 2018 in NE England for analysis, after 19% of records were removed due to incomplete or erroneous data. Figure 6.13 illustrates the distribution of recharging events studied by year and access type, indicating a peak in 2016 followed by an annual decline in line with the reduction in charge points recording data shown in Figure 6.2. The largest proportion of recharging events (45.4%) was delivered by All Public chargers, while the lowest (31.3%) was delivered in locations restricted to employee use, which also diminished over time whereas the Transit access contribution increased. Therefore public rather than employee access appears to be a focus for the recharging business case, since transit access chargers are also publicly accessible. Ongoing monitoring could investigate whether this trend continues.

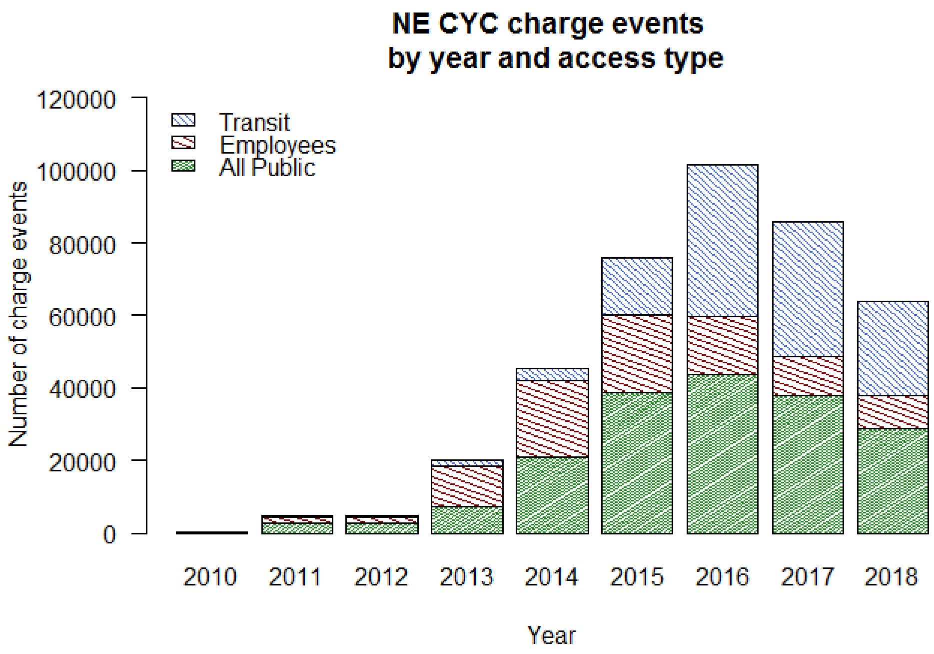


Figure 6.13 – NECYC charge events by access type

Figure 6.14 shows that the majority of recharging events took place using fast chargers, which also made up the majority of the estate as illustrated in Figure 6.6. However, the proportion of rapid charge events increased markedly from 2014, suggesting that rapid chargers may be a better future business opportunity than slow or fast chargers. Section 6.5 focusses on rapid charging behaviour in detail.

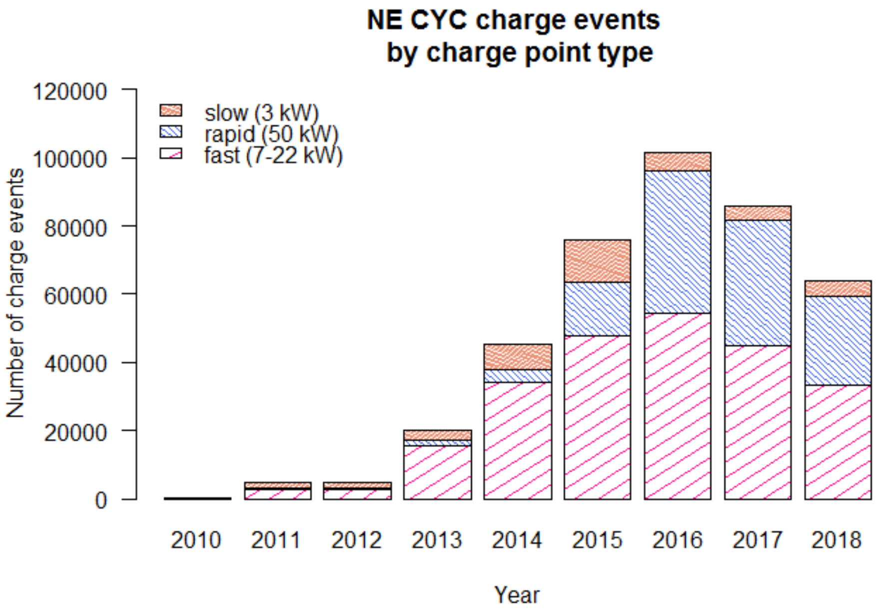


Figure 6.14 – NECYC charge events by charge point type

Analysis of recharging events by location type identified that Public off-street locations delivered the highest proportion (31.8%) of events as shown in Figure 6.15, coinciding with the highest proportion (40.2%) of charge points in the estate. However, Transit locations delivered the second highest proportion (31.3%) of recharging events from only 5.5% of the estate, confirming drivers' preferences for rapid charging in Transit locations identified in Chapter 4 and consequently their attractiveness to recharging providers. The volume of recharging events acts as one input to the public recharging business case, however duration and energy data are also required and will be investigated in the following sections.

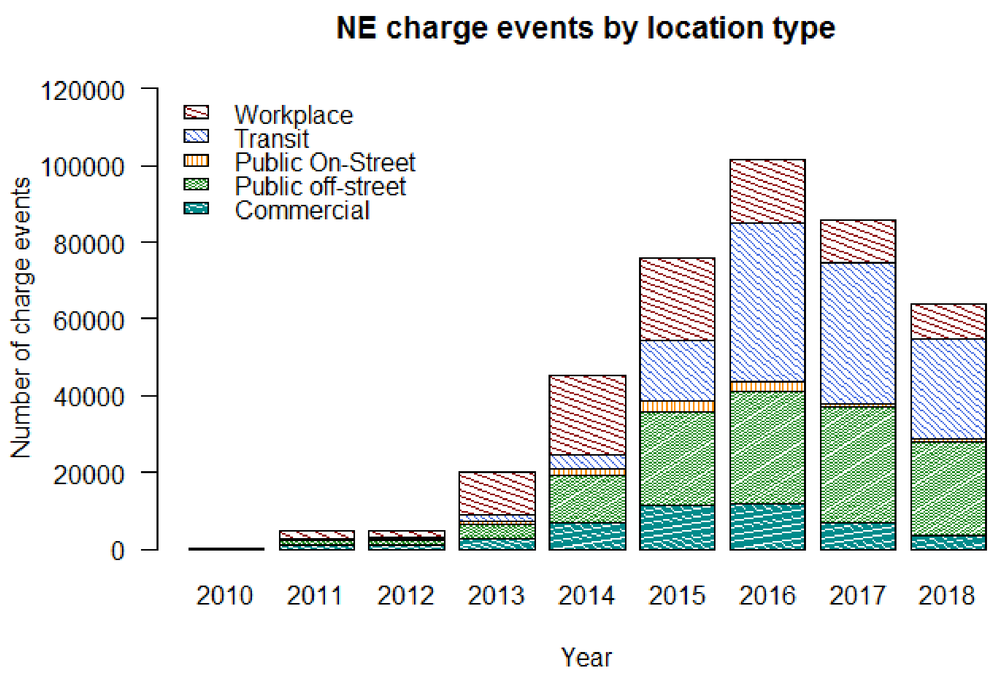


Figure 6.15 – Location types of NECYC charge events

NECYC annual recharging events peaked in 2016 and fell each year in line with the reduction in charge points. Publicly accessible locations delivered the largest proportion (45.4%) of charge events. Fast chargers, the majority of the estate, delivered the majority (58.7%) of recharging events, although the 5.5% of rapid chargers delivered 31.3% and increased each year.

6.3.2 *Energy delivered*

The energy delivered per charge event is a key factor when considering the required composition and business case for recharging estates because it is a saleable commodity.

Figure 6.16 highlights the importance of Transit locations and the comparative unimportance of public on-street and commercial locations to total energy delivered by the NECYC estate, suggesting that recharging estates wishing to make a financial return from energy sales should focus on transit locations.

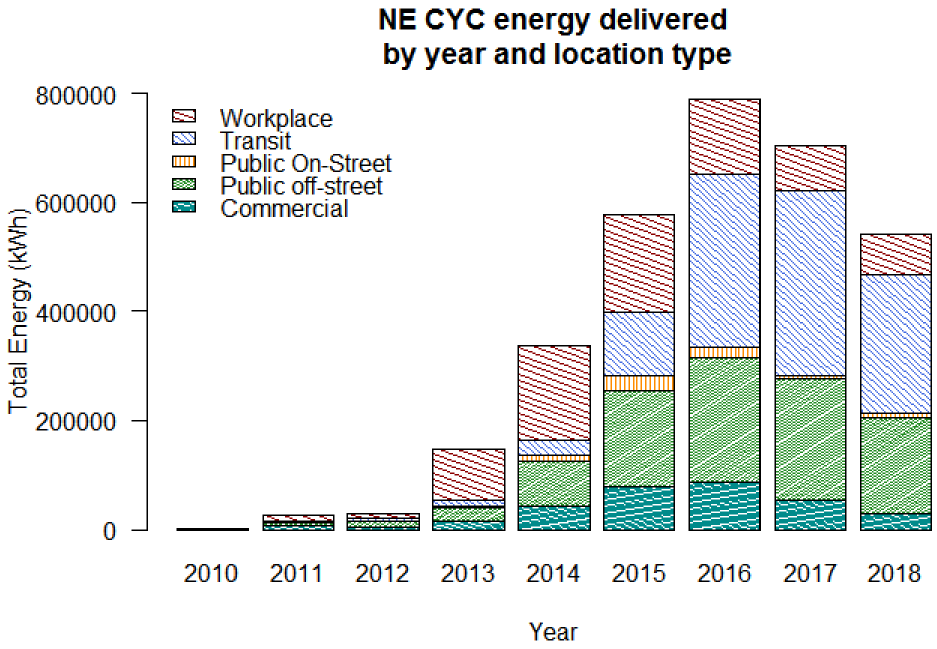
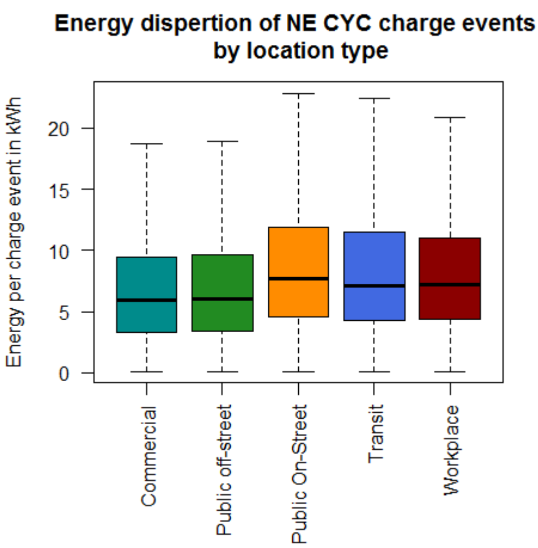


Figure 6.16 – Total energy delivered by location type and year

To investigate energy sales potential over the study period, Figure 6.17 compares the median energy delivered per charge event between location and access type. Public on-street locations exhibited the highest median charge event energy (7.71 kWh), with Workplace (7.25 kWh) and Transit (7.12 kWh) locations close behind. However, Figure 6.16 previously confirmed that public on-street chargers delivered the lowest total energy figure and Figure 6.15 showed the lowest total charge events, so the median is misleading without also considering the volume of charge events delivered. In addition, All Public access chargers delivered the lowest median energy of all access types at 6.08 kWh, suggesting they are a less attractive business opportunity than workplace or transit access chargers.



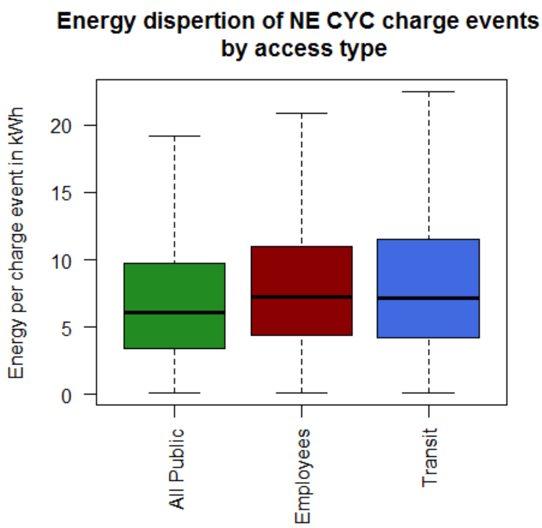


Figure 6.17 – Comparison of energy delivered per charge event

To consider future action it was also necessary to examine how the energy delivered changed over time. Figure 6.18 demonstrates how the annual median energy delivered per charge event changed for each location type over the period. In the final year of study, 2018, the highest median charge event energy was recorded at Transit locations (7.81 kWh), with Public on-street locations in second place at 7.38 kWh, but this fell annually from 2015. Together the volume and median energy findings suggest that Transit locations could be the most financially viable location for future chargers based on energy sales potential.

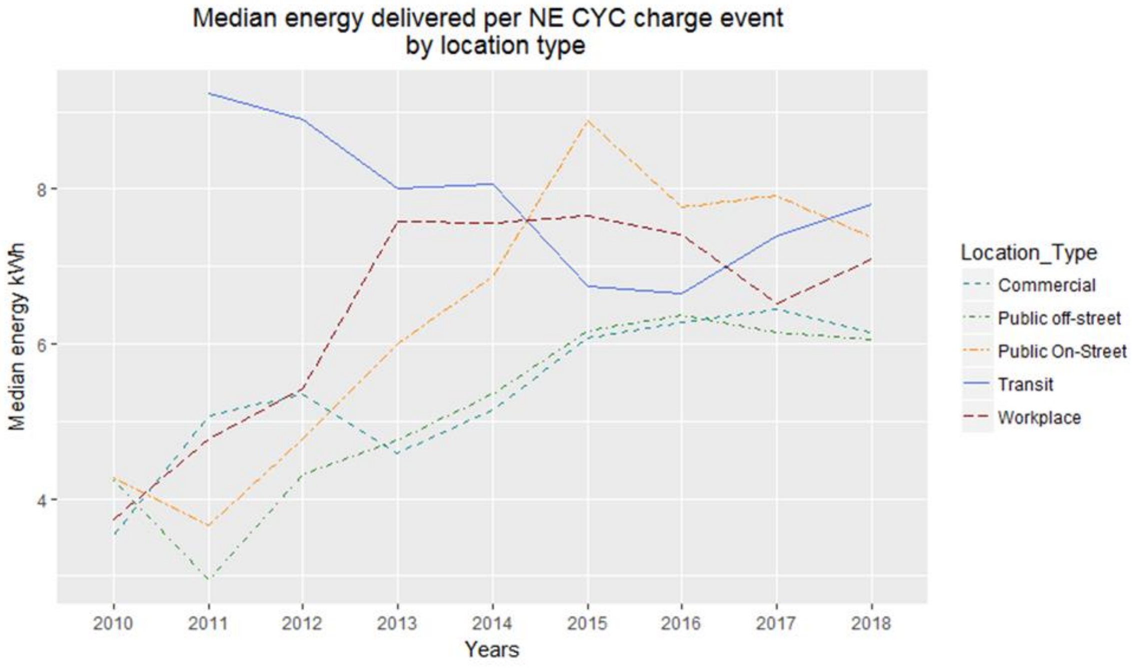


Figure 6.18 – Median energy delivered per charge event by location type

Before making business case decisions based on these findings, an assessment of their statistical significance was required. The Shapiro-Wilk test conducted on a December 2018 sample of NECYC data indicated that the data was not normally distributed, so significance was assessed using non-parametric tests. The Kruskal-Wallis test confirmed that the location type significantly affected the median energy delivered per charge event (H(4)=104.52, p,2.2e-16). In the December 2018 sample, transit locations delivered the highest median energy (8.09 kWh), whilst on-street chargers delivered the lowest (6.03kWh). Post-hoc pairwise Mann-Whitney U-tests with correction for multiple testing indicated that all location energy comparisons were statistically different, apart from Commercial and Workplace (p=0.3107) and Transit and On-street median energy (p=0.2137).

The Kruskal-Wallis test also confirmed that the access type significantly affected the median energy delivered (H(2)=76.345, p<2.2e-16). In the December 2018 sample, transit access delivered the highest median energy (8.09 kWh), followed by employee chargers (7.32 kWh) and finally public access chargers at 6.14 kWh. Post-hoc pairwise Mann-Whitney U-tests with correction for multiple testing indicated that all access type energy comparisons were statistically different (p<0.05).

To investigate whether **charge point type** affected the charge event energy delivered, Figure 6.20 illustrates the total energy delivered, Figure 6.20 its dispersion over the period and Figure 6.21 shows the change in annual median energy. Although fast chargers delivered the majority of total NECYC energy, rapid chargers were responsible for a high and annually increasing proportion of the total and reported the highest median energy over the study period. Figure 6.21 demonstrates that rapid chargers had the highest annual median energy figure in most years of study, ending in 2018 with a median charge event energy of 7.81 kWh compared with lower fast (6.33 kWh) and slow charger figures (6.49 kWh). Together these findings suggest that investment in rapid chargers may be financially preferable to slow or fast chargers for future recharging estate development.

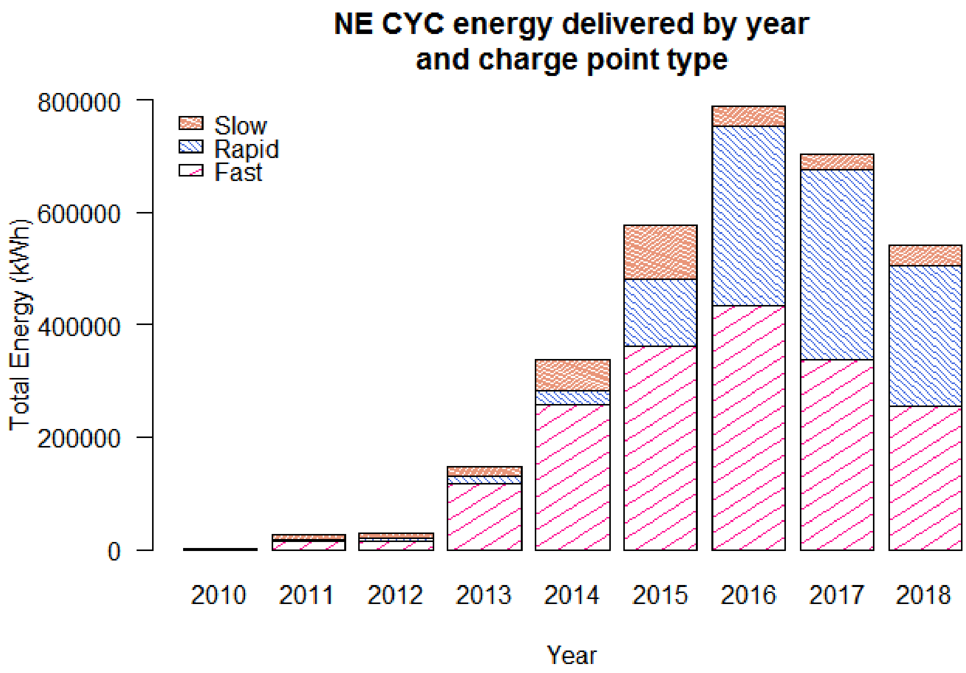


Figure 6.19 – NECYC total energy delivered by charger type

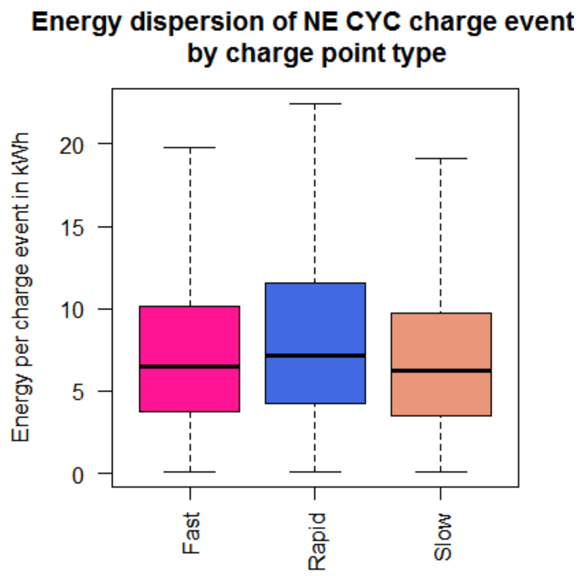


Figure 6.20 – Distribution of energy delivered by charge point type

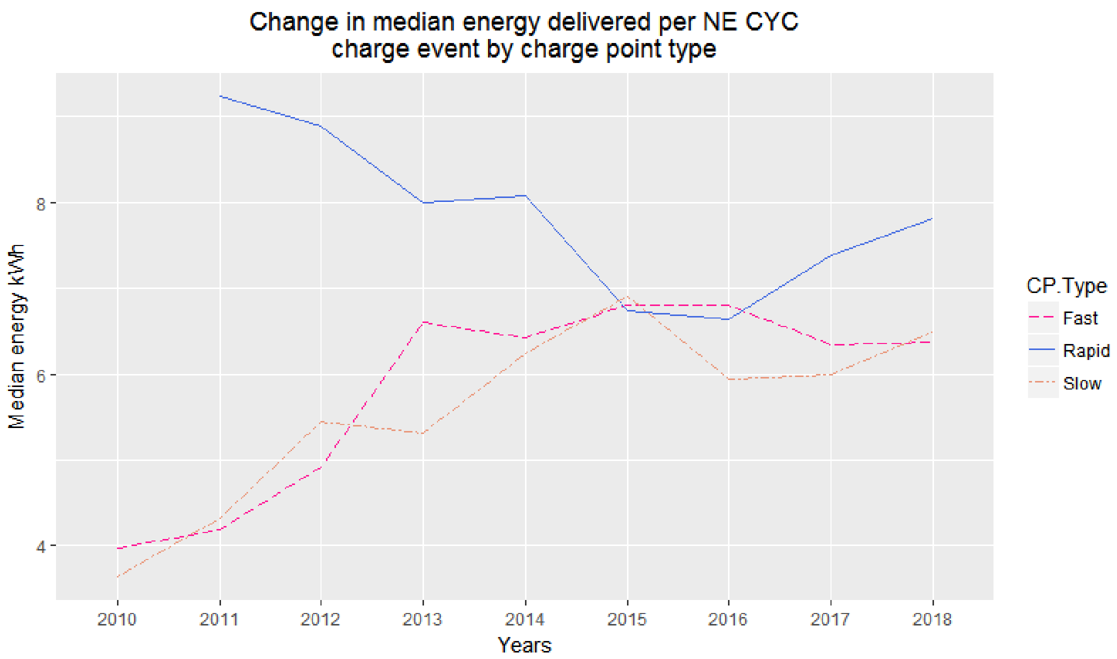


Figure 6.21 – Median energy per charge event by charge point type

The Kruskal-Wallis test confirmed that the charger type significantly affected the median energy delivered (H(2)=53.24, p=2.737e-12). In the December 2018 sample, rapid chargers delivered the highest median energy (8.09 kWh), slow chargers delivered 6.92kWh and fast chargers delivered the lowest median energy (6.48 kWh).

Post-hoc pairwise Mann-Whitney U-tests with correction for multiple testing indicated that all charger type energy comparisons were statistically different ($p<0.05$).

The median charge event energy delivered by NECYC fast chargers over the study period (6.33 kWh) was slightly lower than the national 6.7 kWh figure reported for public sector fast chargers (DfT, 2018b) shown in Table 6.1. However, few of the NECYC fast chargers were included in the DfT's public sector study because most were installed before the eligibility period. This thesis provides a useful benchmark for the conclusions drawn in the DfT fast charger report, supporting their validity, but no charger address information was provided in the DfT dataset preventing any comparative assessment regarding the importance of location. The 2017 median duration of NECYC fast charger use was also slightly lower than the national figure, which is investigated further in the next section.

Fast charger networks	Quantity fast chargers studied	Charge events (CE)	Median energy per CE (in kWh)	Median duration per CE (in mins)
DfT LA	542	103,346	6.70	179
NECYC	272	44,749	6.33	157

Table 6.1 – Comparison of DfT and NECYC 2017 fast charging behaviour

Transit locations delivered the highest proportion of NECYC energy in the final three years of study. Chargers in on-street locations demonstrated the highest median charge event energy (7.71kWh), however transit locations recorded the highest median in 2018 (7.81kWh). Rapid chargers recorded the highest median energy of all charge point types and a high proportion of total energy. Together these findings suggest that investment in rapid chargers in transit locations may be most beneficial for future network development.

6.3.3 *Recharging event duration*

The duration of recharging events indicates the period of time that a charge point is occupied, providing availability information necessary for business modelling, capacity and expansion planning. Due to recharging estates' back-office design the duration data reflected how long the PIV was plugged into the charge point, not how long it was drawing energy, therefore rendering the charger unavailable for another user. The correlation between duration and energy is investigated in section 6.3.5.

To investigate how location type affected recharging duration, Figure 6.22 illustrates the variation in median charge event durations for each location type. The duration data for each category was skewed right with much greater variability evident in the high than low durations generating uncertainty for the business case. However, transit locations demonstrated the lowest median duration (27 minutes), the lowest variability and therefore indicate less uncertainty. The short rapid charging median duration confirmed that the primary use of rapid chargers was for quick recharging rather than parking. Short charge event durations enable more daily charge events to be delivered than long durations, so Transit locations have higher daily availability than locations containing slow or fast chargers and therefore can deliver more energy. Consequently, chargers in Transit locations may present a better business opportunity than chargers in public or workplace locations if the business case is built upon energy sales.

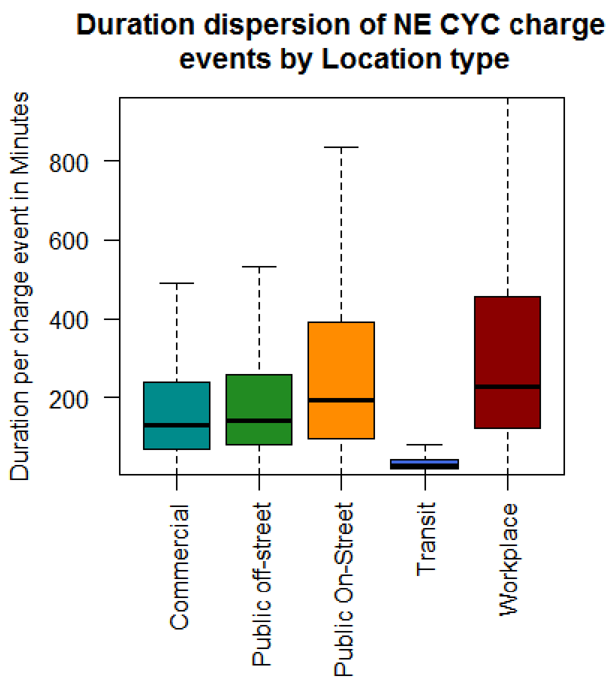


Figure 6.22 – Dispersion of charge event duration by Location Type

Workplaces, where only employees have access, demonstrated the highest median charge event duration (230 minutes, almost 4 hours) and the widest dispersion, suggesting parking was the primary purpose whilst at work rather than recharging. The median workplace duration was approximately half of a UK working shift, suggesting PIVs were moved off chargers when convenient e.g. during breaks. However, the high workplace dispersion and tails evident in Figure 6.22 may indicate fleet and employee vehicles remaining plugged in whenever not in use, representing parking time not recharging need and limiting the availability of workplace chargers. However, this use may be acceptable for workplace chargers dedicated to fleet use linked to the site owner's operation, the costs of which are built into a wider business case. Further study of workplace charger use cases would be required to test this theory, presenting an opportunity for further work.

Public on-street locations demonstrated the second highest median duration (194 minutes, approximately 3.25 hours) with a high level of variability, also suggesting parking use rather than recharging need. On-street locations were identified in both city centres and residential areas without off-street parking where long duration parking use was likely. Recognising this recharging behaviour, the business case for on-street locations may benefit from the provision of additional services such as parking and reservation with appropriate fees. The long duration results suggest a low efficiency in use of workplace and public on-street chargers in the NECYC estate, which is explored further in section 6.3.5.

The Kruskal-Wallis test confirmed that the location type significantly affected the median charge event duration ($H(4)=825.49$, $p<2.2e-16$). In the December 2018 sample, on-street locations demonstrated the highest median duration (327 minutes) of all non-transit locations, whilst commercial locations recorded the lowest (126 minutes) median duration. Post-hoc pairwise Mann-Whitney U-tests with correction for multiple testing indicated that all location type comparisons produced statistically different durations ($p<0.05$).

Figure 6.23 demonstrates that the median duration of fast charge events (166 minutes) and slow charge events (179 minutes) was similar, although variability was greater on slow chargers, suggesting little difference in users' recharging behaviour on fast and slow chargers in the NECYC estate. However, Figure 6.24 indicates that slow charge event durations exhibited an increasing trend since 2014, whereas fast charging event durations decreased which may be because parking fees were introduced in some locations containing fast chargers, requiring further investigation beyond this study.

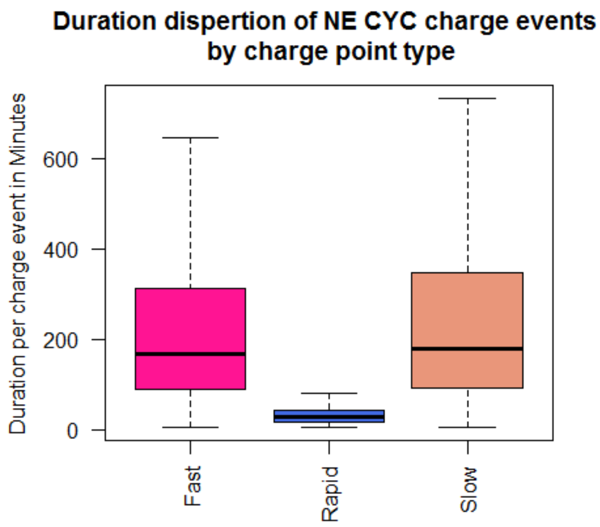


Figure 6.23 – Charge event durations by charge point type

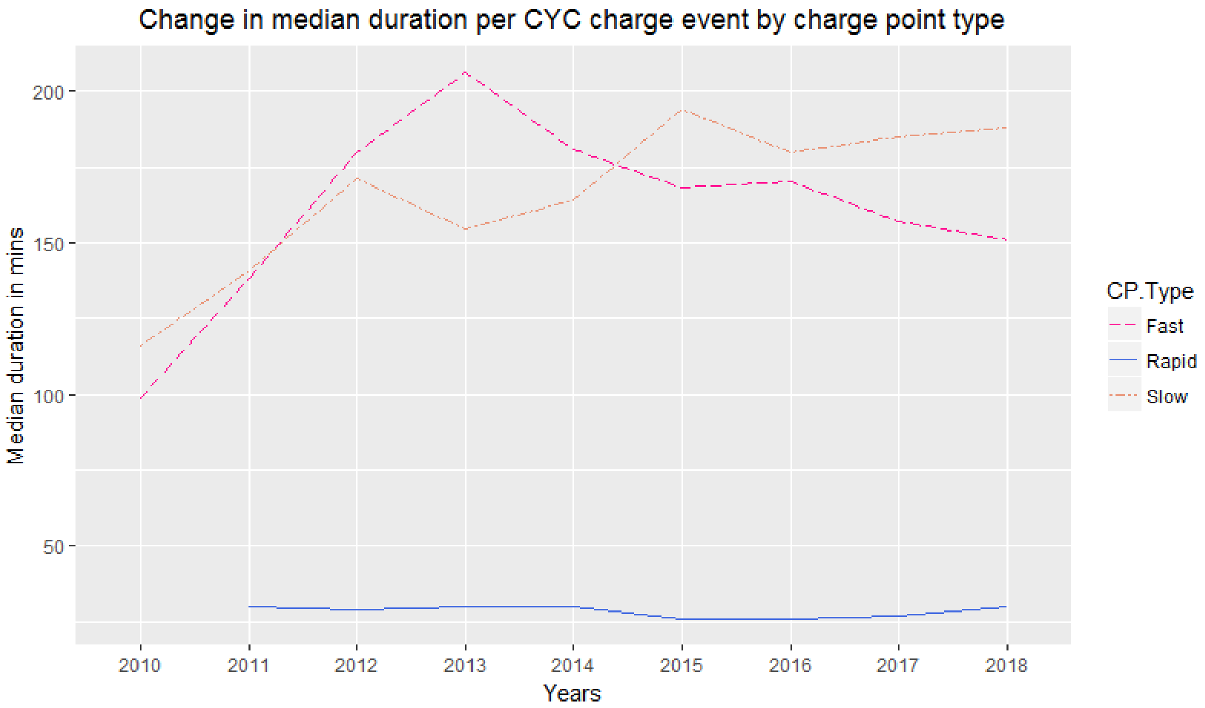


Figure 6.24 – Annual median charge event duration by charge point type

The Kruskal-Wallis test confirmed that the charger type significantly affected the median duration of charge events (H(2)=756.5, p<2.2e-16). In the December 2018 sample, rapid chargers unsurprisingly delivered the lowest median duration (39.5 minutes), fast chargers 142 mins and slow chargers recorded the highest median duration of 178 minutes. Post-hoc pairwise Mann-Whitney U-tests with correction for multiple testing indicated that all charger type duration comparisons were statistically different (p<0.05).

Transit locations demonstrated the lowest median duration (27 minutes) and lowest variability, reflecting quick recharging behaviour using rapid chargers. Workplace and public locations demonstrated high median durations and variability, suggesting parking rather than recharging was the primary user purpose in these locations.

6.3.4 *Time of use summary*

The start hour of charge events was plotted as a proportion of the total for each location type to inform decisions on the quantity of chargers required to meet peak demand. Figure 6.25 indicates that all location types, apart from transit, experienced a peak in start times between 7am and 8am then reduced steeply with a short demand plateau in the early afternoon before reducing again into the evening. Conversely, peak start time for transit locations came in the early afternoon but remained relatively stable from 9am to 6pm because short event durations enabled new charge events to start more frequently as discussed in section 6.3.3, providing the opportunity for greater energy delivery and higher utilisation at transit locations. Time of use information is also important for key stakeholders such as DNOs and energy suppliers who must manage peak loads and maintain supply at all times, so recharging time of use information will assist their forward planning activities.

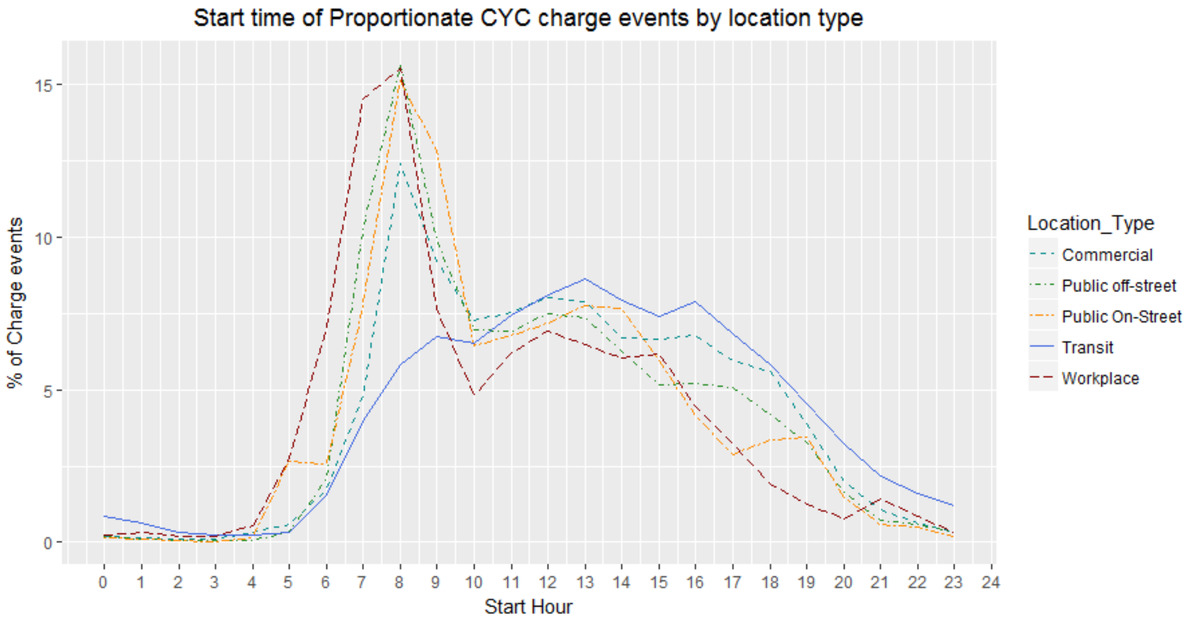


Figure 6.25 – Start time of charge events by location type

Figure 6.26 demonstrates the similarity between slow and fast charger start time of use and its distinction from rapid charger time of use, matching the findings of the DfT report on public sector fast charger use (DfT, 2018b). Unsurprisingly, the pattern is similar to the location type plot in Figure 6.25 because all non-transit locations contain fast and slow chargers.

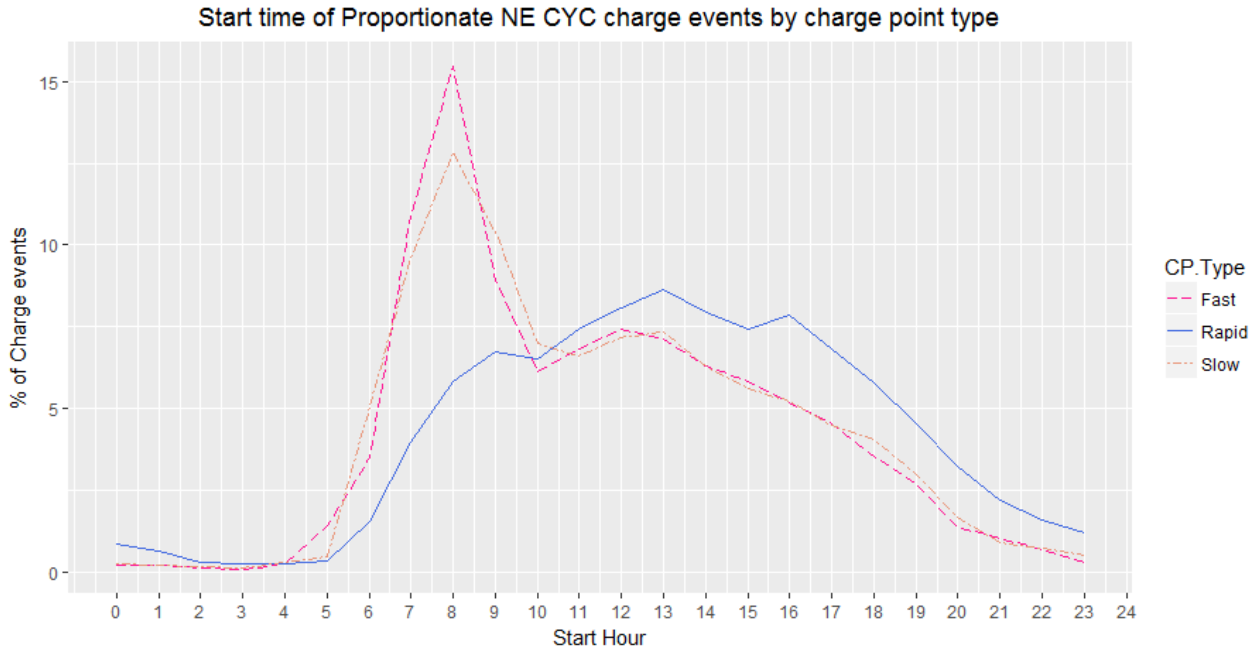


Figure 6.26 – Start time of charge events by charge point type

Figure 6.27 demonstrates that the majority of charge events took place between Monday and Friday, with lower use evident at the weekend. The quantity of charge events at employee access chargers fell considerably at the weekend, however transit events were relatively constant throughout the week and provided an increased proportion of weekend charge events. This daily pattern is also consistent with the results of the 2017 public sector fast charger study (DfT, 2018b).

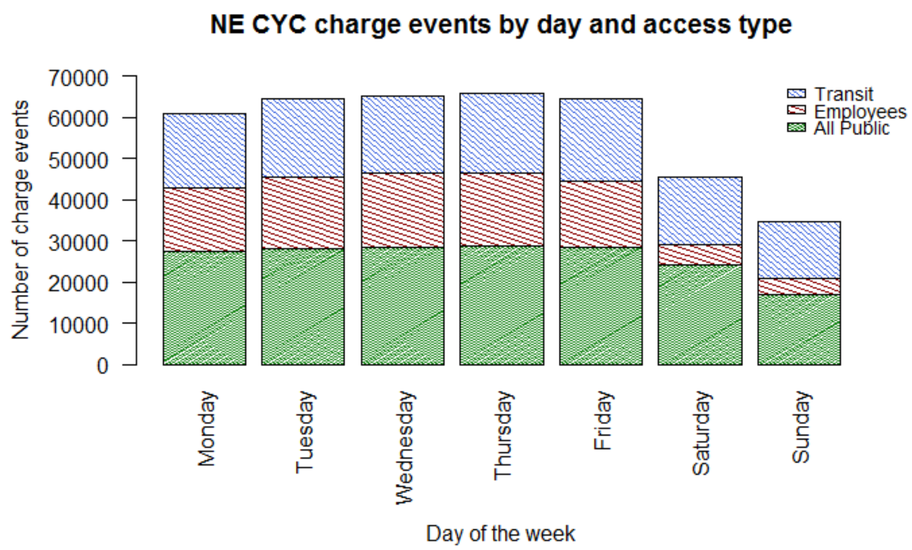


Figure 6.27 – Distribution of charge events throughout the week

Public and employee access chargers exhibited peak start times between 7–8am, dropping to a short lower plateau in the early afternoon, then tailed off in the evening. Transit chargers had a relatively stable pattern of start times between 9am and 6pm. The majority of charge events took place from Monday to Friday, but transit access charger use remained stable throughout the week.

6.3.5 *Utilisation discussion*

By 2018, the ninth year of NECYC operation, charge point utilisation summarised in Table 6.2 remained low, limiting charger hosts' ability to make a financial return on their investment. All categories recorded less than one daily charge event per charger, except for Transit locations where rapid chargers experienced the highest average utilisation of 2.36 charge events per day, with the highest median energy (7.81 kWh) and shortest median duration (30 mins). Therefore, investment in rapid chargers in transit locations is likely to attract the highest utilisation for operators and provide the highest availability for PIV drivers. In contrast, by charger type: slow chargers recorded the lowest daily utilisation and highest median duration; and on-street chargers demonstrated the lowest daily utilisation by location type. However, the costs of recharging infrastructure provision identified in section 7.6 must be considered alongside these utilisation results to assess the best recharging investment as discussed in Chapter 7.

Chapter 5 identified the low quantity of PIVs registered in the NE region in 2018 and confirmed that the market was at the first innovators stage of adoption with affluent customers. The region's relatively low household wealth and proportion of homes without off-street parking suggested that most NE PIV owners could recharge at home with little need to use the public recharging estate, so it is unsurprising that NECYC utilisation was low.

2018				
Location type	Qty of charge points	Charge Events(CE) per CP per day	Median energy per CE (in kWh)	Median duration per CE (in mins)
Commercial	43	0.239	6.15	137
Public off-street	159	0.416	6.06	142
Public on-street	13	0.200	7.38	186
Transit	30	2.361	7.81	30
Workplace	68	0.362	7.09	204
Access type				
All Public	215	0.368	6.11	143
Employees	68	0.362	7.09	204
Transit	30	2.361	7.81	30
Charge point type				
Fast	248	0.369	6.37	151
Rapid	30	2.361	7.81	30
Slow	35	0.351	6.49	188

Table 6.2 – 2018 charging characteristics of NECYC estate

Following the long duration but low energy results obtained for slow and fast chargers in sections 6.3.2 and 6.3.3, the correlation between energy delivered and charge event duration was found to be very low for all categories. In addition, scatter plots identified some impossible charge events beyond PIV recharging capabilities circled in Figure 6.28, with high energy but durations close to zero. Consequently, the NECYC dataset was refined further to identify impossible recharging events where the calculated recharging rate exceeded maximum charger power, removing a further 0.93% of the dataset (mostly slow charger events). A large population of 397,520 NECYC recharging records remained for analysis which is summarised in Table 6.3.

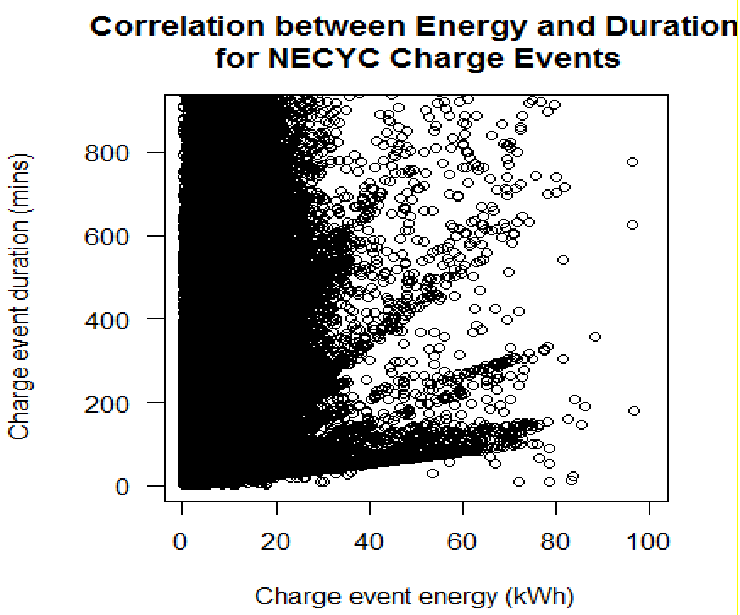


Figure 6.28 – Energy and duration correlation

NECYC Dataset - Charge event summary (n=397,520)						
	Location Types					
Charge point Type/Power	Commercial	Public off-street	Public on-street	Transit	Workplace	
Slow 3kW	10,457	8,522	1,546	0	15,867	**36,392**
Fast 7kW	33,441	111,537	8,071	0	76,384	**229,433**
Fast 22kW	0	5,936	1	0	1	**5,938**
Rapid 50kW	0	0	0	125,757	0	**125,757**
	43,898	**125,995**	**9,618**	**125,757**	**92,252**	**Totals**

Table 6.3 – NECYC charge events by Charger and Location type

Examining the scatter plots for each charge point type provided further insight into NECYC use. Firstly, for slow chargers the majority of slow charge events (n=36,392, r=0.277) delivered energy below 10 kWh, as Figure 6.29 shows, providing evidence for DNOs operating the grid who must manage load to ensure continuity of electricity supply. Secondly, the low correlation coefficient r=0.277 indicated there was little linear relationship between energy and duration, but the large concentration of low energy but high duration charge events confirmed that users were connected to a charger for longer than the active recharging duration, supporting the supposition that parking is the primary purpose at slow chargers. Thirdly, the charge events falling between the two lines on the correlation chart suggest that some chargers were wrongly labelled as slow instead of fast chargers in the source data.

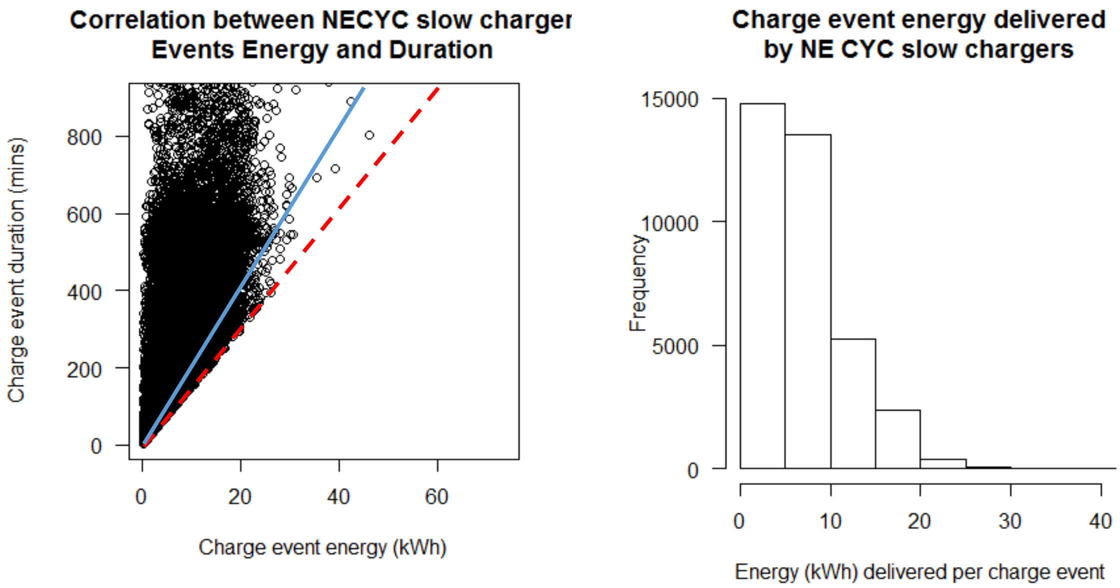


Figure 6.29 – Energy and duration correlation for NECYC slow chargers

The fast charger data was split into 7kW and 22kW subsets to investigate utilisation. The poor correlation and dense clustering at low durations on 7kW fast chargers evident in Figure 6.30 (n=229,433; r=0.216) suggested that most users were connected for longer than the active recharging duration, mimicking the behaviour on slow chargers. The dense cluster of charge events up to the solid blue line indicates PIV users with only 3kW recharging capability which is unsurprising since most PIVs sold in the UK by 2018 had only 3kW charging capability. The data between the two lines indicates PIV charging at up to 7kW in line with newer PIV models. The largest frequency of 7kW fast charge events delivered between 5–10 kWh of energy, making them a more attractive investment proposition than slow chargers where the highest frequency occurred in the 0–5 kWh range.

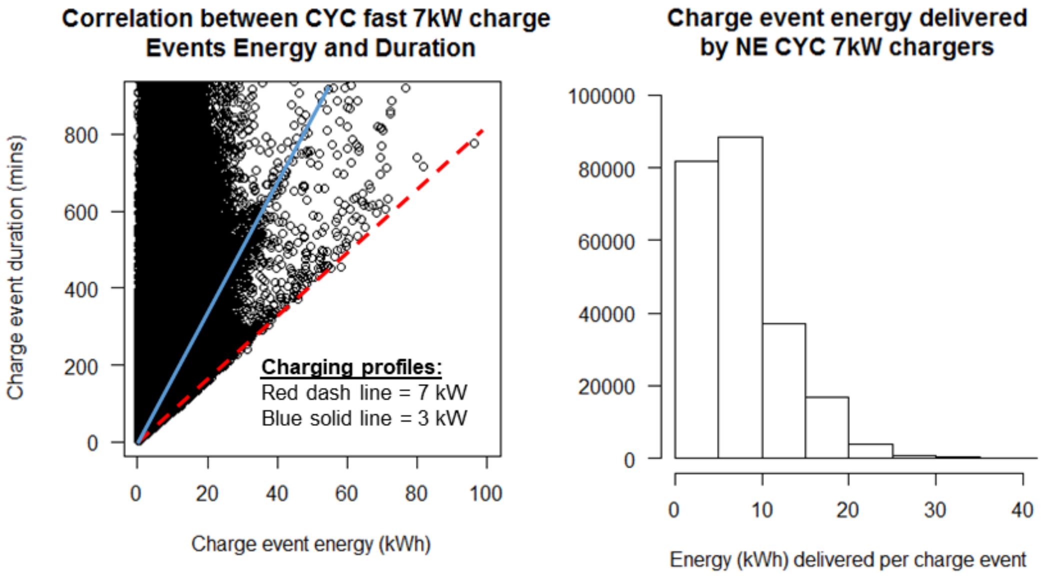


Figure 6.30 – Energy and duration correlation for NECYC 7 kW Fast chargers

22kW fast chargers provide three phases of power, enabling up to three PIVs to recharge at once, or one PIV with greater than 7kW recharging capability. The 22kW charger data (n=5,938, r=0.0539) presented in Figure 6.31 also shows many high duration low energy charge events, again suggesting primary parking use. Although far fewer than the slow or 7kW fast charge events studied, most 22 kW charge events delivered below 5 kWh energy. 3kW vehicle recharging events are clustered up to the green dot-dashed line representing the majority of PIVs sold to date, the solid blue line identifies 7kW vehicles and the red dashed line represents the few 22kW recharging events of the latest PIV models.

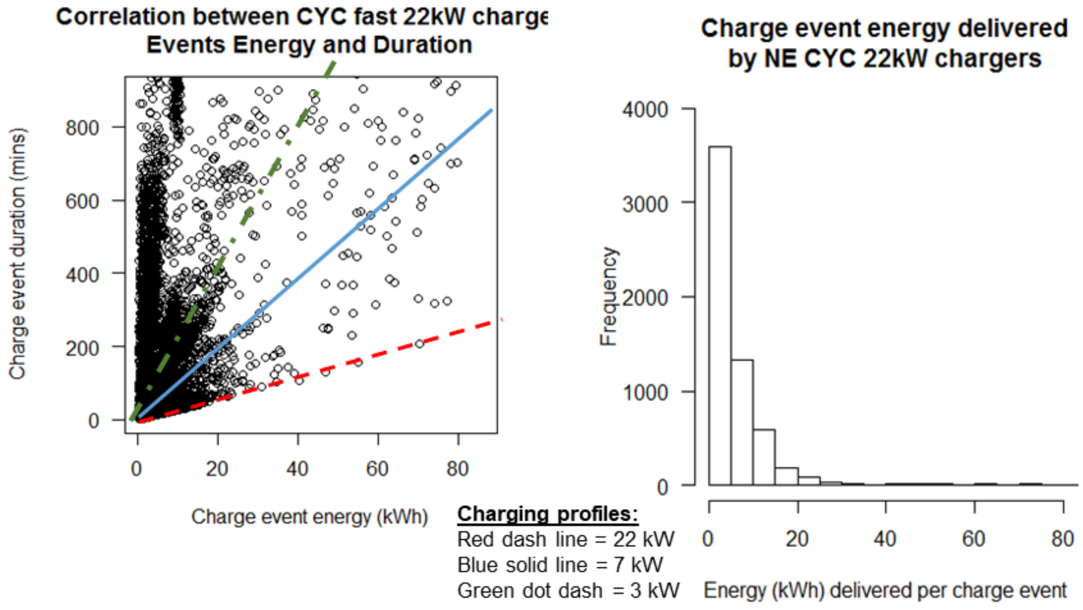


Figure 6.31 – Energy and duration correlation for NECYC 22kW Fast chargers

The energy and duration correlation results by location type are presented in Appendix K. All publicly accessible and workplace locations indicated a density of high duration, low energy events suggesting primary parking use rather than recharging need and only off-street locations exhibited 22kW charging rates where space allowed for three recharging bays per charger to increase availability.

Since transit locations only contained rapid chargers, the correlation between energy and duration for rapid charge events in transit locations (n=125,575, r=0.1355) is displayed in Figure 6.32. Transit charge events were clustered below 60 minutes and the highest frequency of energy delivered was in the range 5–10 kWh, confirming that rapid chargers are used primarily to meet recharging need not parking need, unlike slow and fast charger use.

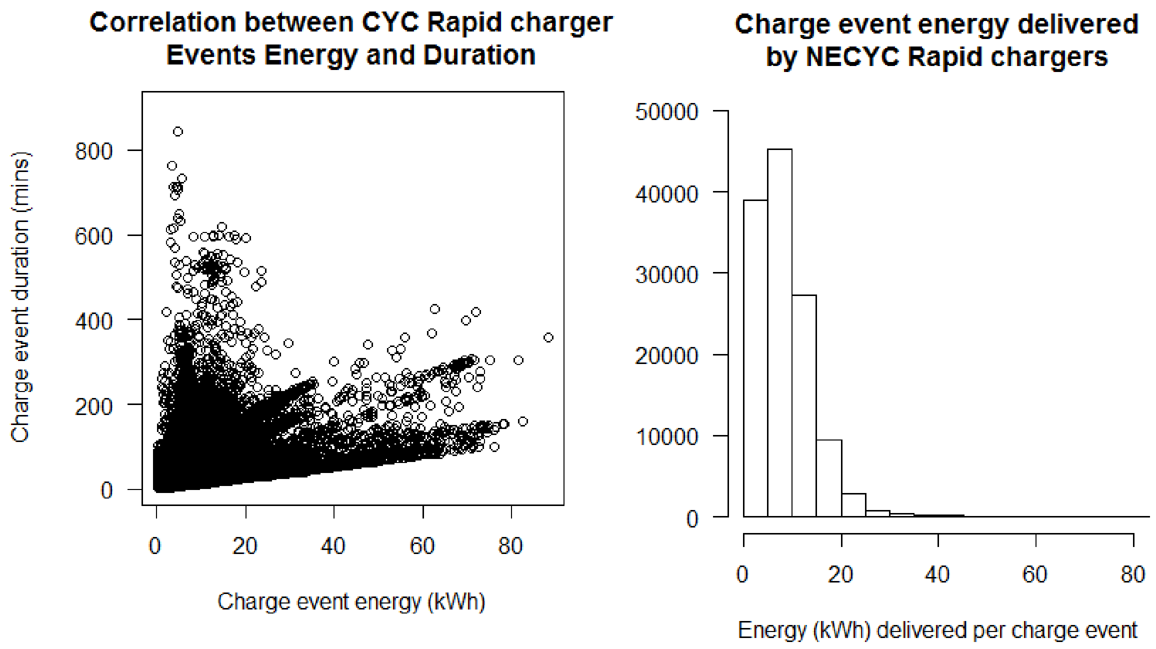


Figure 6.32 – Energy duration correlation for NECYC Rapid charge events

The correlation findings indicate that the availability of the NECYC recharging estate was limited by the primary use of slow and fast chargers as parking places rather than recharging facilities. Free PIV parking incentives at charge points which encourage this behaviour should be removed if the recharging financial business model is to be successful. Indeed, levying parking fees in addition to the recharging service could support future investment in the recharging estate.

The study has so far considered independently three variables which were found to significantly affect recharge event energy: location, access and charger type. To investigate whether these variables also act in combination with each other to affect the energy delivered, two-way ANOVA tests were performed. Since Rapid charger events have a 1:1 relationship with Transit access and location variables, they were removed from the data in order to study a subset of slow and fast charge events.

A two-way ANOVA test was conducted on the two levels of Charger type (slow, fast) and two levels of Access type (All Public, employees) to investigate the hypothesis:

H_0 : Charger Type does NOT interact with Access Type

A statistically significant interaction was discovered between the effects of Charger and Access type on energy delivered ($F(1)=349.4$, $p<2e-16$) as shown in Figure 6.33. Fast chargers recorded 19% higher mean energy with employee access than with public access, although the difference was only 3% for slow chargers. In terms of the financial business case, providing fast chargers in workplaces with employee access was therefore likely to achieve higher energy sales than in publicly accessible locations.

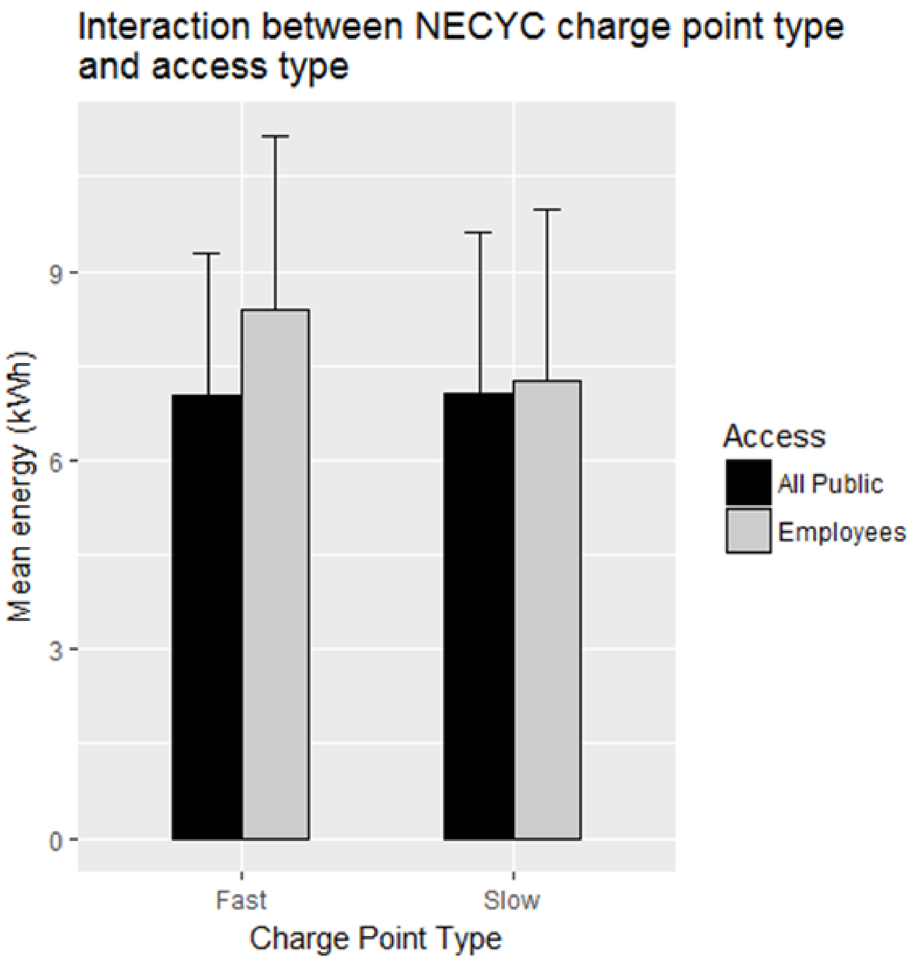


Figure 6.33 – The interaction between NECYC charger and access types

A two-way ANOVA test on the two levels of Charger type (slow and fast) and four levels of Location type (Commercial, on-street, off-street and workplace) was then conducted. A statistically significant interaction between the effects of Charger and Location type on energy delivered [$F(3)=158.9$, $p<2e-16$] was also discovered as shown in Figure 6.34. This test confirmed that providing fast or slow chargers in workplaces was likely to deliver the highest mean charge event energy of all location types. Fast chargers showed little difference in mean energy (0.45 kWh) between the three public access locations (commercial, on-street and off-street), whereas slow chargers exhibited greater differences and in the reverse order to fast chargers, with on-street locations recording the highest publicly accessible mean energy at 8.17 kWh and commercial locations the lowest.

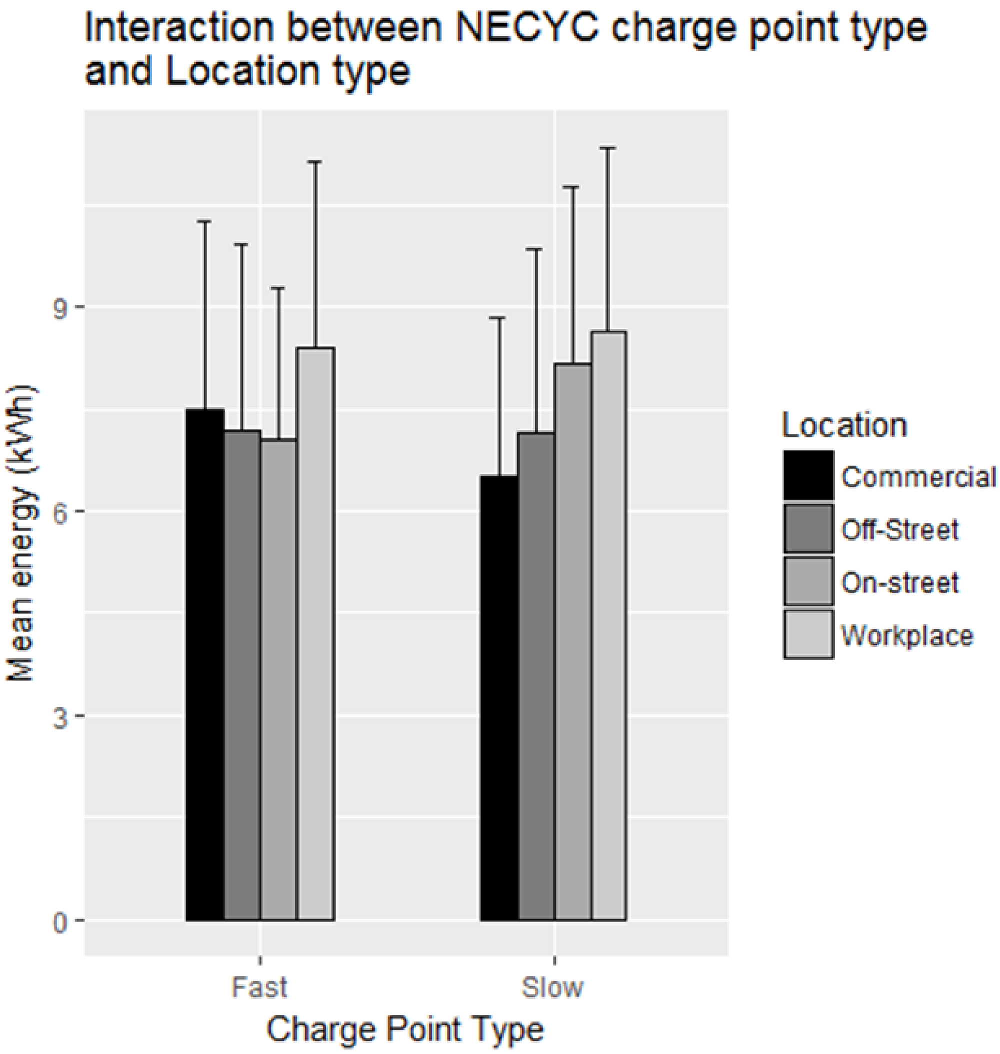


Figure 6.34 – The interaction between charger and location type

By 2018 NECYC utilisation remained below one daily charge event per charger, except in Transit locations where rapid chargers delivered 2.36 daily events, with the highest median energy and shortest duration. Poor correlation between energy and duration confirmed that users were connected to fast and slow chargers for longer than the active recharging duration, limiting availability. The three variables: charger, location and access type were found to act in combination affecting energy delivered. ANOVA tests indicated that providing fast chargers for employees in workplaces would generate the highest mean charge event energy of non-rapid charging facilities.

6.4 Users Discussion

Unique users of the NECYC estate increased each year as shown in Figure 6.35, in line with the increasing PIV adoption in the area demonstrated in Chapter 5. Increasing users may reflect increasing PIV mileage and consequently recharging demand, or an increasing reliance on the NECYC charging estate rather than alternative recharging solutions. A comparative study of home recharging data for NE PIV drivers using the NECYC estate would be useful to qualify the proportions of home and public recharging.

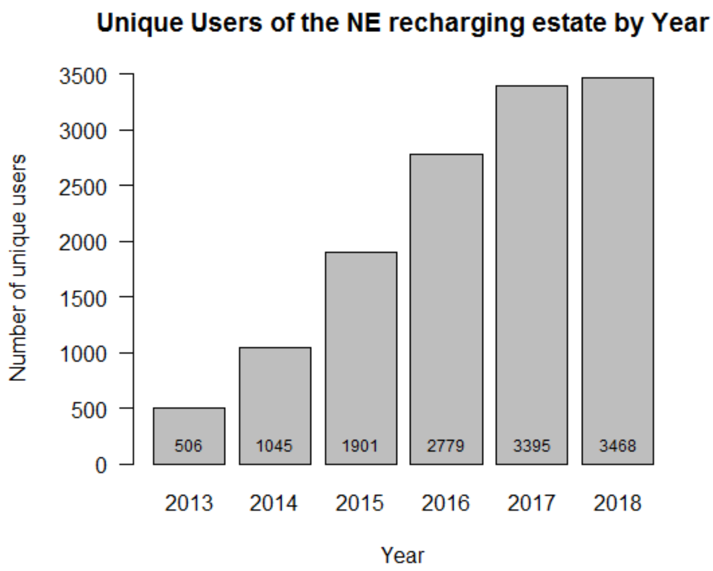


Figure 6.35 – Unique users of the NECYC estate by year

Different PIV models have different recharging capabilities as outlined in Chapter 2, providing another variable in NECYC use. Vehicle model data was missing from 22.4% of the source data and a further 7.1% of records stated “Multiple vehicles available”, so a unique PIV subset containing 70.5% of the original dataset was created. Figure 6.36 shows the increasing trend of unique PIV models using the estate, mirroring the increasing range of EV models for sale in the UK.

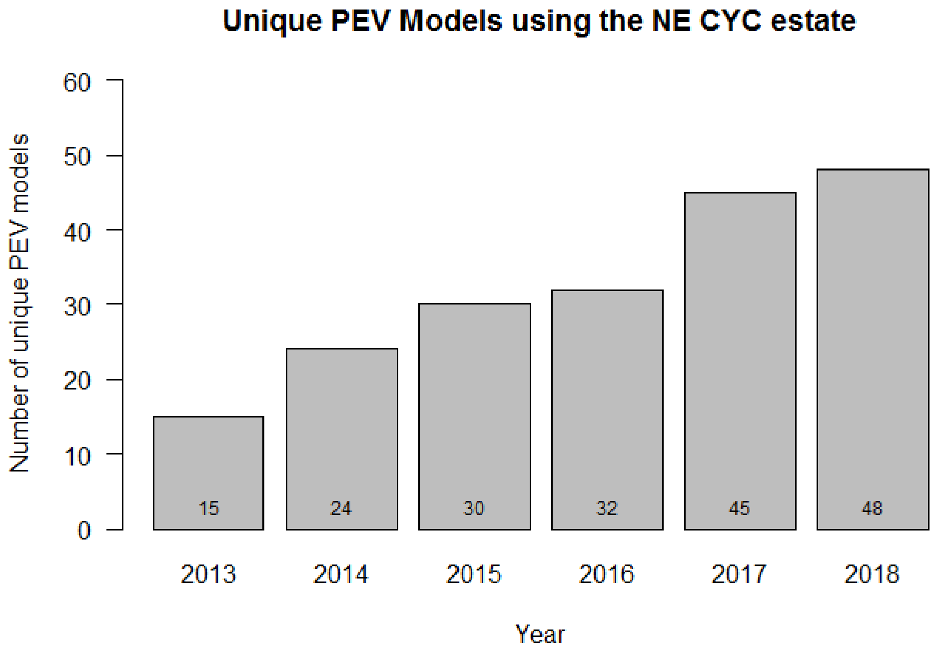


Figure 6.36 – Unique PIV models using the NECYC estate by year

Chapter 5 identified that more PHEVs than BEVs are registered in the UK, however Figure 6.37 indicates that the majority of NECYC energy was delivered to BEV models. Both BEV and PHEV models were recorded using all types of charging location illustrated in Figure 6.38 which is surprising because most PHEV models cannot rapid charge. However, PHEVs can use rapid chargers at low power resulting in longer charge event durations which limits the high availability of rapid chargers expected by drivers as indicated in Chapter 4. Figure 6.39 shows that the median charge event energy delivered to BEVs (8.07 kWh) was greater than to PHEVs (5.20 kWh). Furthermore, in 2018 all charger types delivered higher median energy to BEVs than to PHEVs as illustrated in Figure 6.40, confirming BEV users’ relative importance to the recharging business case.

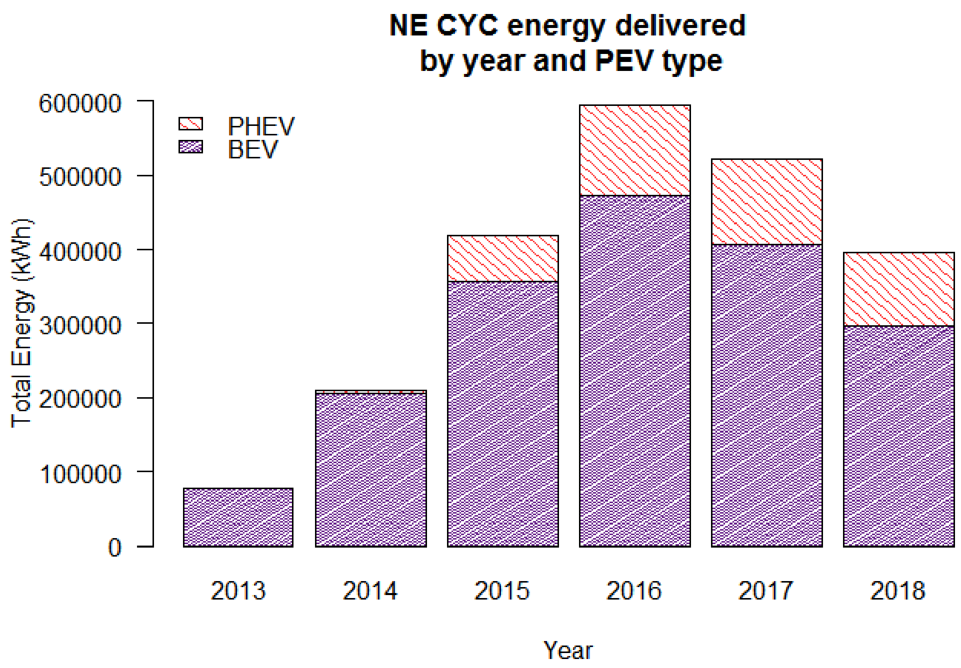


Figure 6.37 – NECYC energy delivered to BEVs and PHEVs

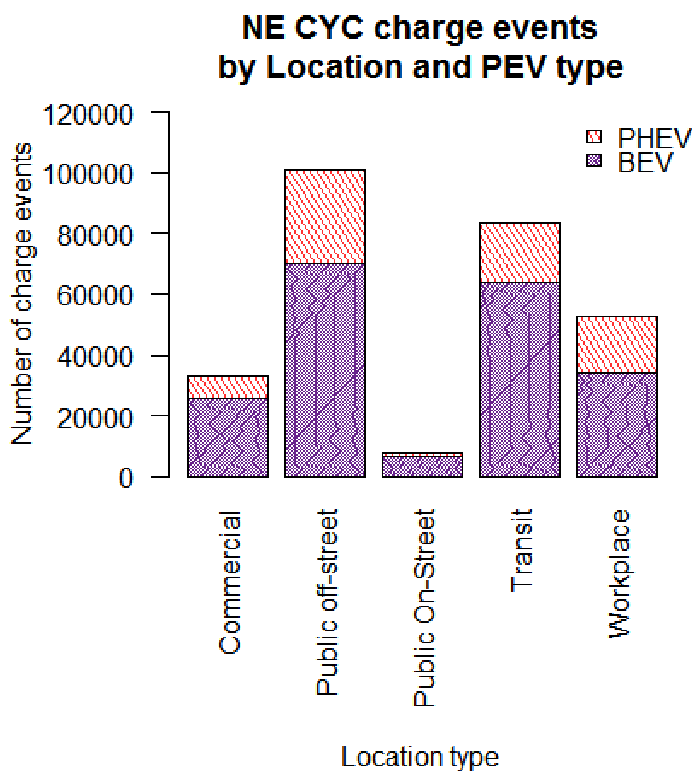


Figure 6.38 – PIV model charge events by location type

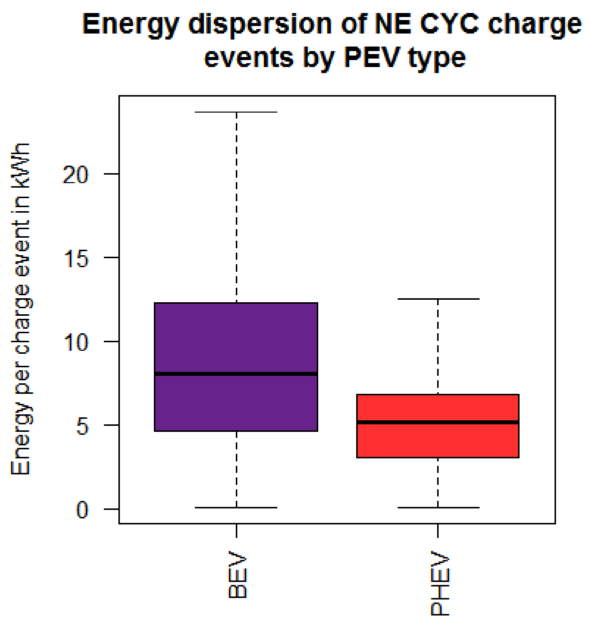


Figure 6.39 – Charge event energy delivered to BEVs v PHEVs

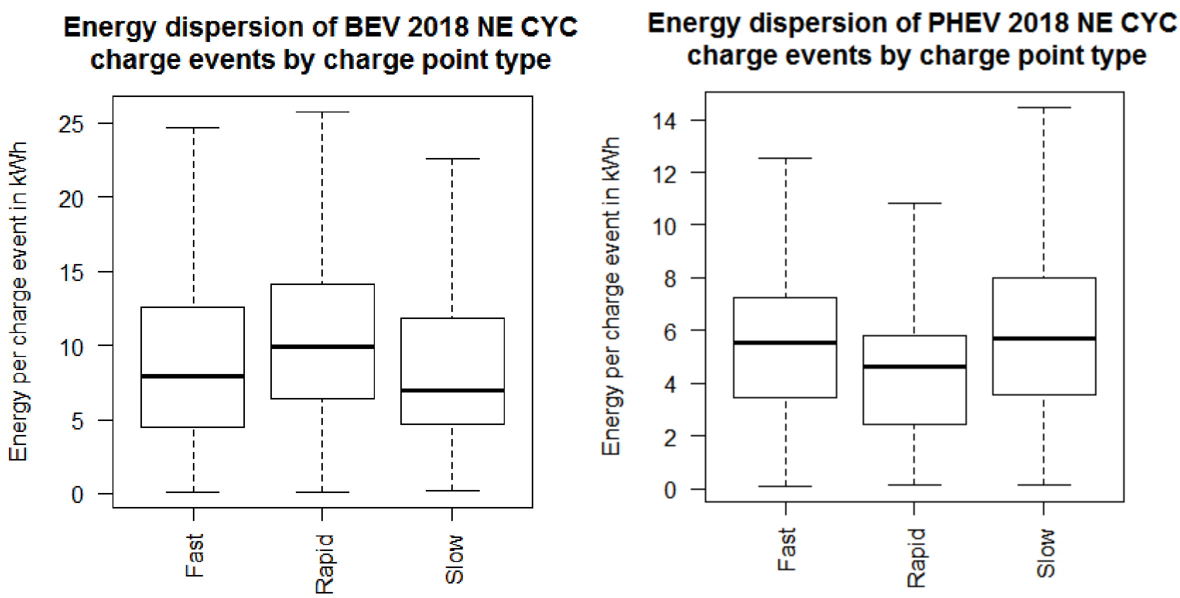


Figure 6.40 – Dispersion of median energy delivered to BEVs v PHEVs in 2018

Unique users and PIV models increased throughout the study. Both BEV and PHEV models used all types of locations and chargers, but most energy was delivered to BEVs. The median charge event energy delivered to a BEV (8.07 kWh) was higher than to a PHEV (5.20 kWh). Together these findings indicate that BEVs are more valuable to the recharging business case than PHEVs.

6.5 Analysis of Rapid Charger Use

Section 6.3 has identified that the most financially viable business opportunity may lie in the provision of rapid chargers, which section 4.2 has shown are favoured by PIV drivers and confirms user preferences identified in Chapter 2 (Carroll, 2010; Carroll, 2011; Element Energy, 2013). This section presents a comparison of rapid charger use in transit locations between the regional NECYC and national Electric Highway (EH) recharging estates and investigates the effects of fees on rapid charging behaviour. In order to compare use, a subset of NECYC rapid charging data was extracted, covering the same four-year period as the EH data from September 2013 to September 2017. The NECYC comparative rapid charging subset contained 89,142 charge events for 42 unique chargers, all located in publicly accessible Transit locations.

6.5.1 *Analysis of Electric Highway estate composition*

The EH recharging estate was funded by both private investment and public (OLEV and EU) funding and is now owned by the private organisation Ecotricity, Britain's first 100% renewable energy supplier, who is responsible for its operating costs and future development. The EH estate analysed contained 285 rapid chargers located in 179 publicly accessible Transit locations along the UK road network. 44% of sites contained one charger, 49% two chargers and 7% contained three chargers to provide greater availability and user confidence. DC CHAdeMO connectors made up the largest proportion (45%) of the estate, followed by 35% AC and 20% CCS connectors which were described in section 2.8.5. The EH dataset contained two subsets: 94 free-to-use rapid chargers studied from September 2013 to July 2016; and the entire estate of 285 rapid chargers studied between August 2016 and September 2017 when recharging fees were applied. Five sub-categories of Transit site emerged from the EH analysis: transport interchanges; retail sites; motorway service areas; leisure sites and fuel filling stations. The majority of EH chargers studied were located at MSAs, as shown in Figure 6.41.

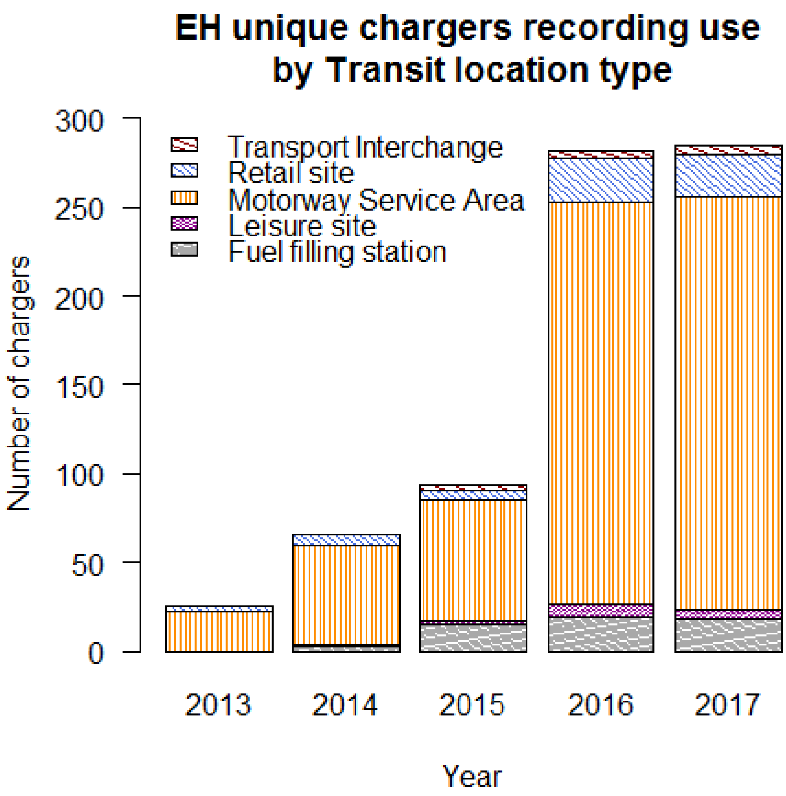


Figure 6.41 – EH chargers by Transit sub-category

The EH estate contained 285 publicly accessible rapid chargers at 179 Transit locations, the majority at Motorway Service Areas and most sites contained two rapid chargers. All EH chargers were privately owned by Ecotricity.

6.5.2 *Analysis of Electric Highway use*

The EH dataset provided a large population of 282,972 rapid recharging events for analysis, after 22% of incomplete records were removed by data cleansing. EH charge events increased each year, however Figure 6.42 identifies three periods of major fluctuation. The sharp fall in observed charge events between January and August

2016 resulted from incomplete data caused by the end of public funding data obligations. From July 2016 data was provided for the entire EH estate, causing a sharp increase in events studied, closely followed by the introduction of recharging fees which may account for the second steep fall in events. Recharging fees were subsequently changed in July 2017 and another steep drop in use was noted. The implications of recharging fees will be studied further in section 6.5.4.

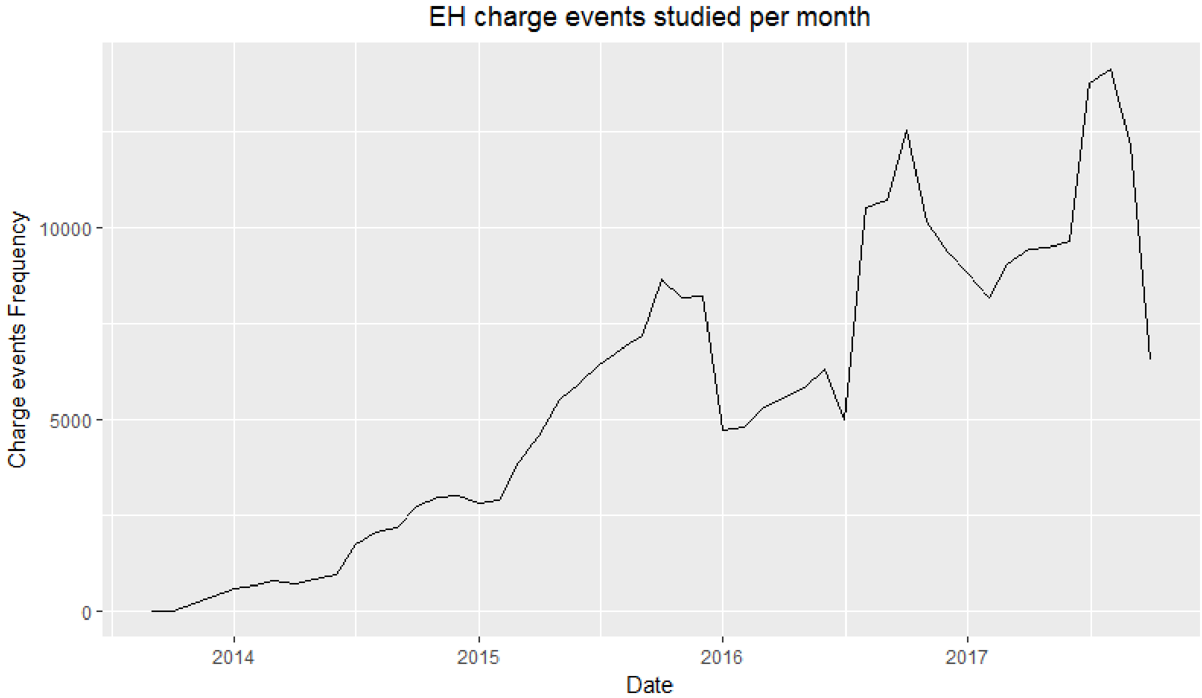


Figure 6.42 – Monthly charge events studied on The Electric Highway

Figure 6.43 demonstrates that the majority of recharging events took place at MSA sites, where the majority of chargers were located and that use was relatively stable by day of the week, across all transit location sub-categories, concurring with the relative stability of NECYC rapid charge events identified in section 6.3.4.

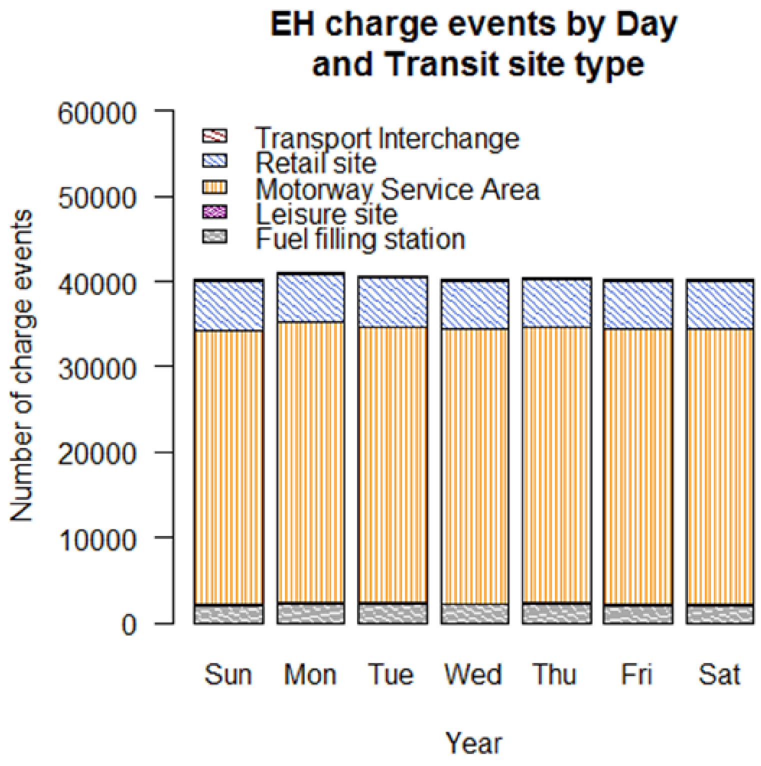


Figure 6.43 – Use of EH chargers by day of the week

The NECYC energy analysis in section 6.3 suggested that recharging estates wishing to make a financial return should focus on rapid charger provision in Transit locations, because they demonstrated the highest charge event energy and utilisation figures in the estate. To investigate how Transit site type affects the energy delivered per rapid charge event, Figure 6.44 indicates that the median charge event energy increased for the last three years of study on all types of site, with the exception of the few Transport Interchange sites where the median energy figure remained much lower and fell sharply. This suggests that Transport Interchanges may not be profitable sites for rapid chargers and the low and heavily skewed median energy in Figure 6.45 confirms that conclusion. By contrast, fuel stations and MSAs demonstrate high and centralised median charge event energy figures, which have risen for the last three years, indicating that they may be more valuable rapid charging locations.

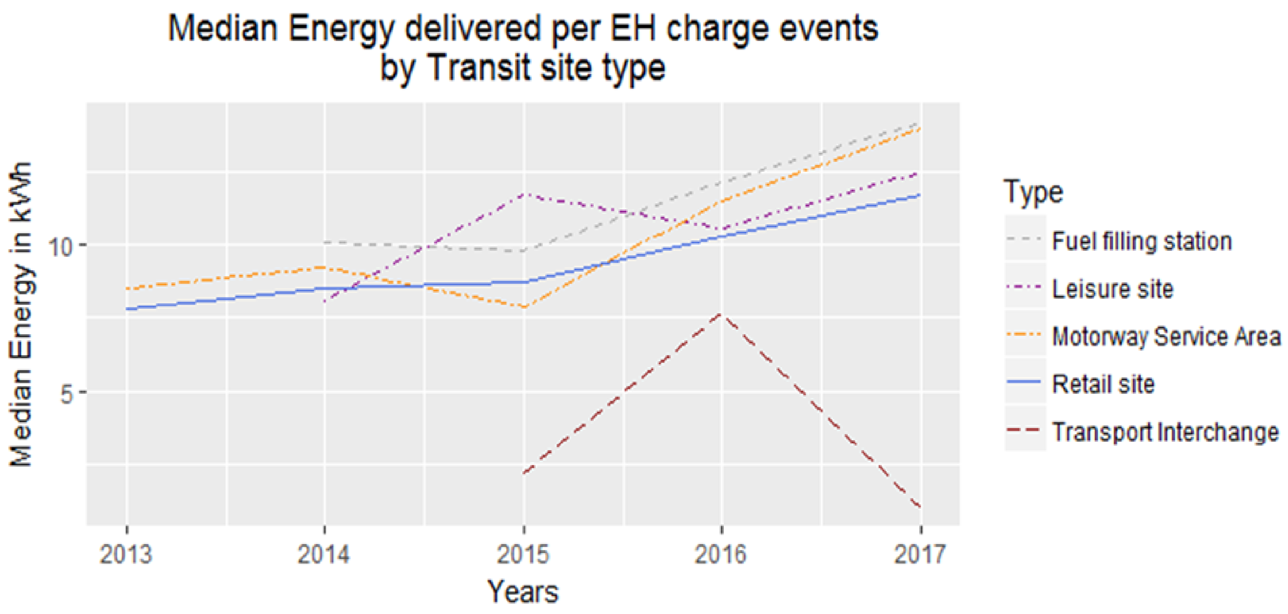


Figure 6.44 – EH Annual median energy delivered per charge event

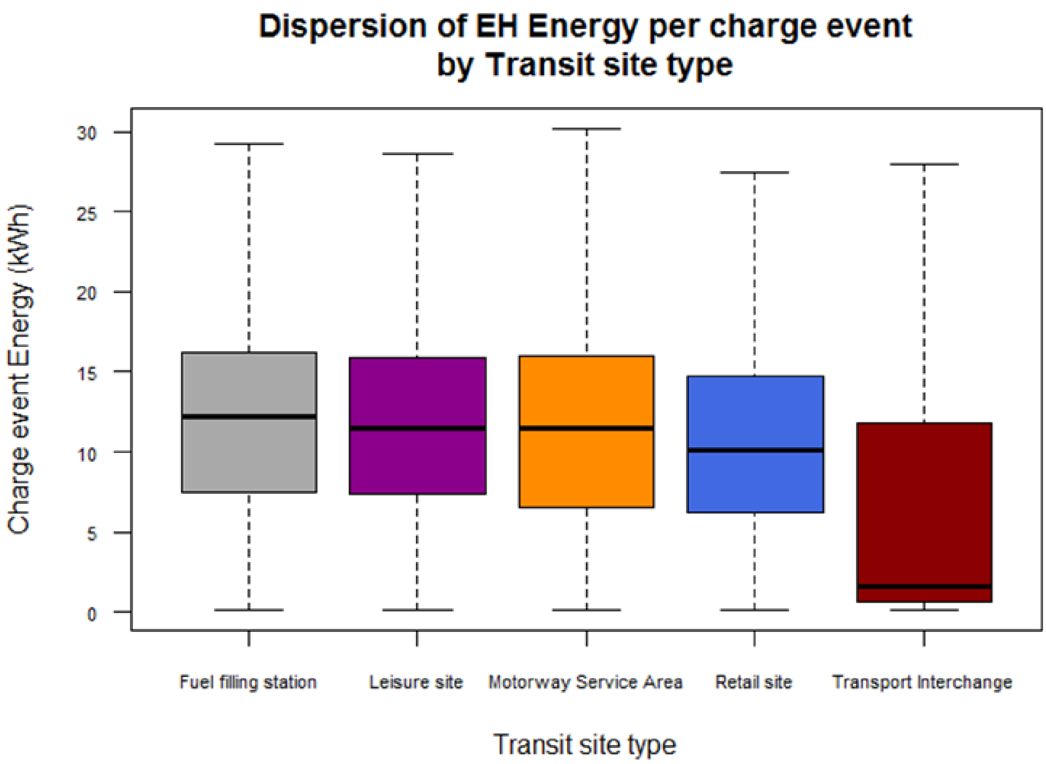


Figure 6.45 – Dispersion of EH charge event energy by Transit site type

Figure 6.46 demonstrates the marked increase in median charge event duration from 2016, reaching 31.9 minutes in 2017 with reduced variability, reversing the previously reducing trend. However, 2016 and 2017 data coincided with the introduction of fees and were heavily skewed towards lower durations, suggesting that an automatic stop was applied by EH shortly after 30 minutes. Furthermore, Figure 6.47 indicates greater variability at retail and transport interchange sites than the most-used MSA sites. Together these results suggest that MSAs could be the best sites for rapid chargers.

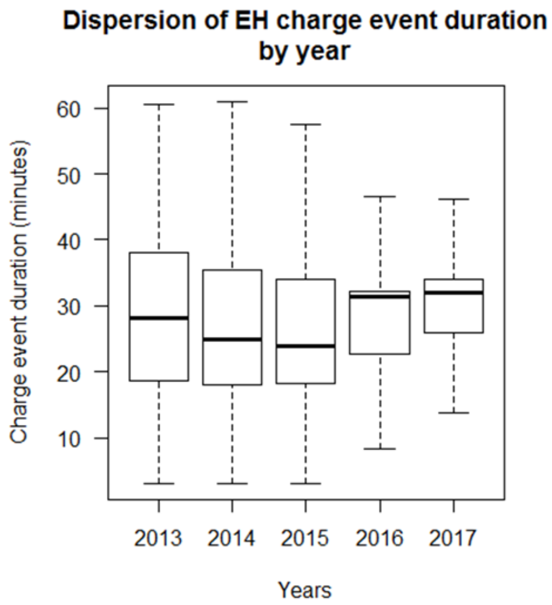


Figure 6.46 – Dispersion of EH annual median charge event duration

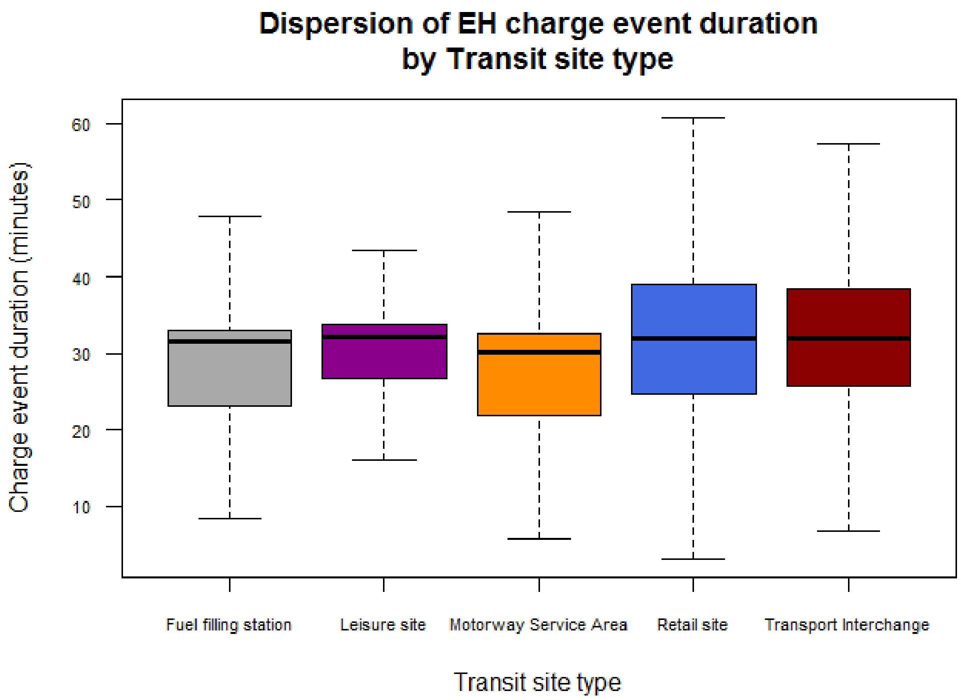


Figure 6.47 – Dispersion of EH median duration by transit site type

To investigate peak time requirements, Figure 6.48 shows that the peak in EH demand occurred around midday and then remained relatively stable throughout the afternoon for all transit location types, similar to the NECYC rapid charger profile. Demand then fell progressively through the evening, but some overnight charge events were evident at MSA sites providing higher utilisation opportunity than sites with no overnight access.

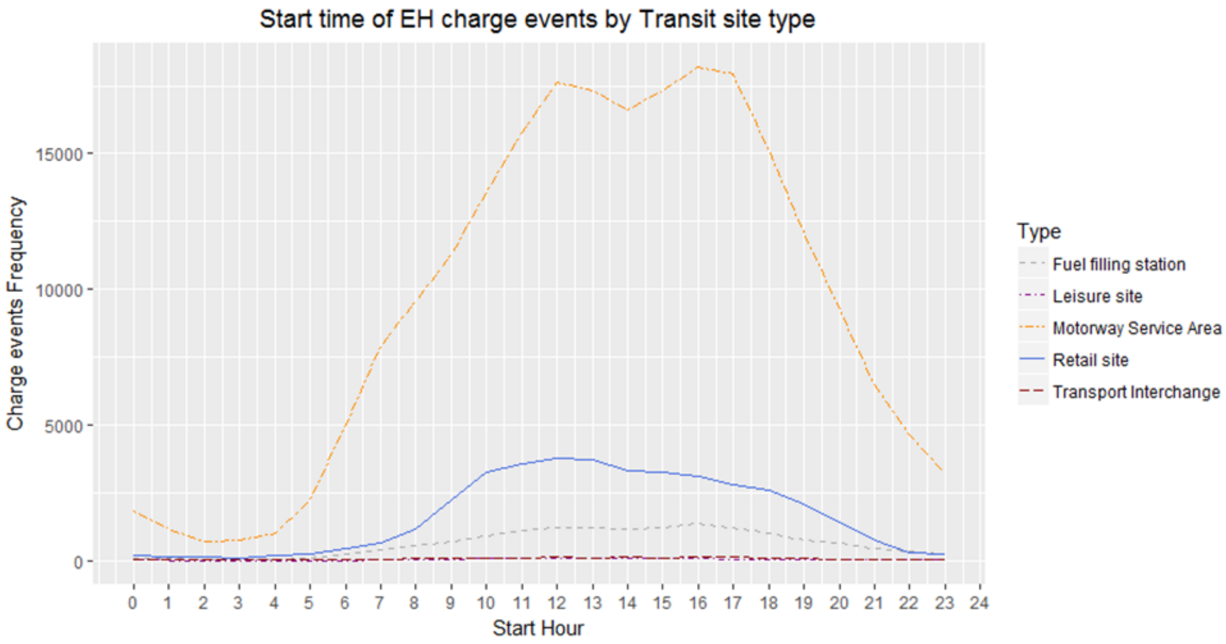


Figure 6.48 – EH time of use plot by Transit site type

The correlation between EH plug-in duration and energy delivered was very low (r=0.1155), confirming no linear relationship existed. However, the scatterplot in Figure 6.49 shows multiple clusters emerging, reflecting the bespoke rapid recharging profiles of different PIV models.

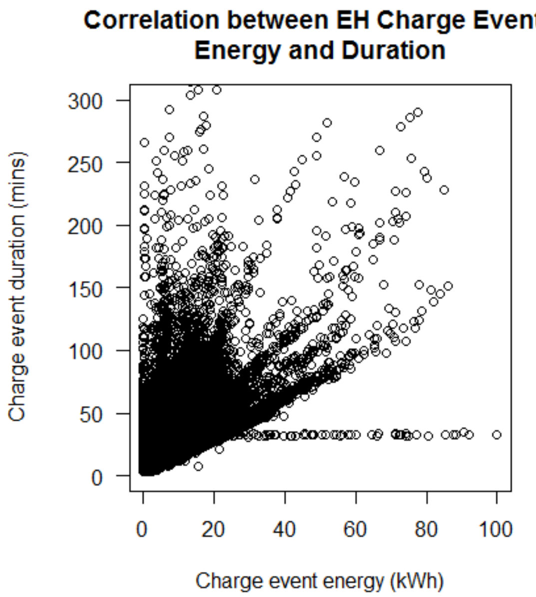


Figure 6.49 – EH correlation between energy and duration

Most EH rapid recharging events delivered between 5–10 kWh of energy, but investigations by transit site type identified that the highest proportion of fuel filling station charge events were in the 10–15 kWh range as demonstrated in Figure 6.50, which may be useful information for DNO capacity planning considering the continuing roll-out at fuel stations.

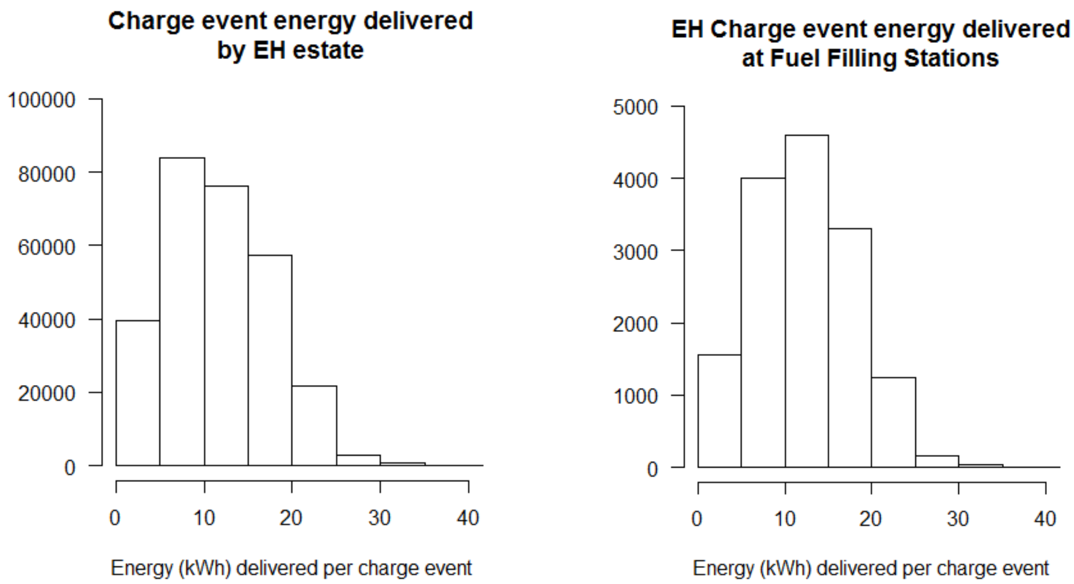


Figure 6.50 – EH charge event energy histograms

In the final year of EH study, 2017, fewer recharging events took place each day than with the NECYC rapid chargers, limiting the ability to make a financial return on investment, however recharging fees were in place the effects of which are discussed in section 6.5.4. Table 6.4 summarises EH use in 2017, showing that whilst Retail sites had the highest utilisation, MSA sites were close behind with the highest quantity of chargers, median charge event energy and shortest duration, suggesting MSAs are the best transit site for rapid charger investment.

Electric Highway study - 2017 Results (290 days)				
Transit site type	Qty of charge points	Charge Events(CE) per CP per day	Median energy per CE (in kWh)	Median duration per CE (in mins)
Fuel filling station	18	1.062	14.20	32.0
Leisure site	5	0.332	12.50	32.3
Motorway service area	233	1.246	14.00	31.8
Retail site	24	1.492	11.70	32.2
Transport Interchange	5	0.346	1.00	32.3

Table 6.4 – EH recharging estate utilisation 2017

Content analysis was undertaken using the connector type to identify PIVs using the EH recharging estate. 22% of the dataset did not contain connector information so were excluded from this investigation. Figure 6.51 indicates that DC CHAdeMO connectors delivered the majority of EH charge events, despite comprising only 45% of the estate. This result reflects the dominance of UK PIV sales with the CHAdeMO rapid charging connector, including the Nissan LEAF manufactured in NE England.

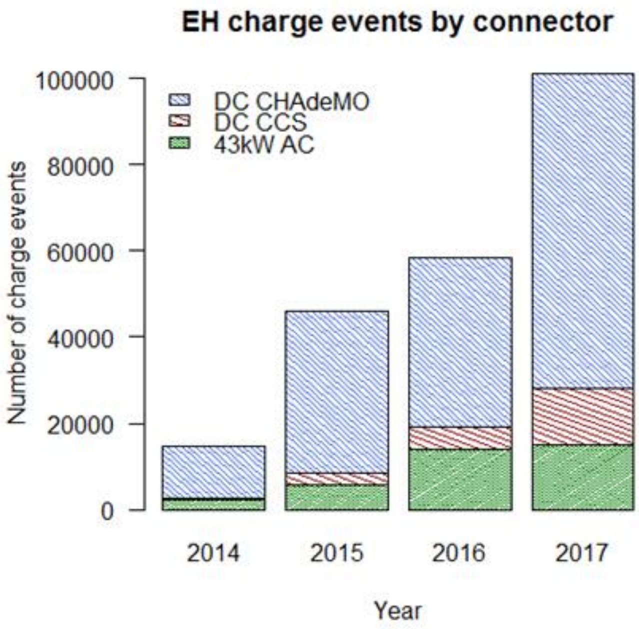


Figure 6.51 – EH charge events by connector type

Figure 6.52 shows that the vast majority of EH energy was delivered to BEVs, with higher median energy and higher median duration heavily skewed downwards in Figure 6.53, which confirms the importance of BEV over PHEV models to the rapid charging business case suggested by the NECYC analysis.

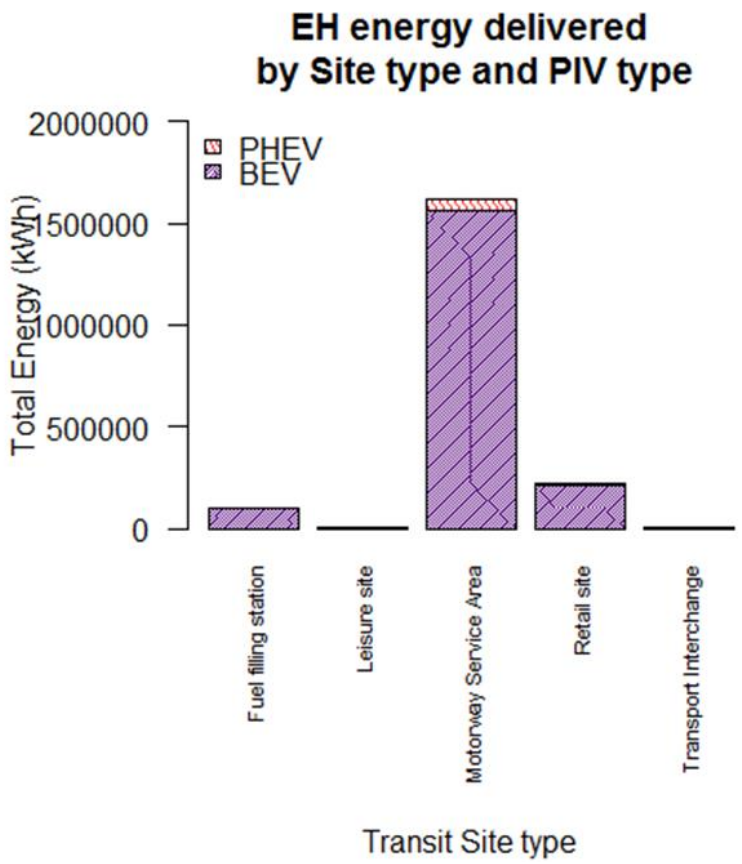


Figure 6.52 – EH energy delivered by PIV model

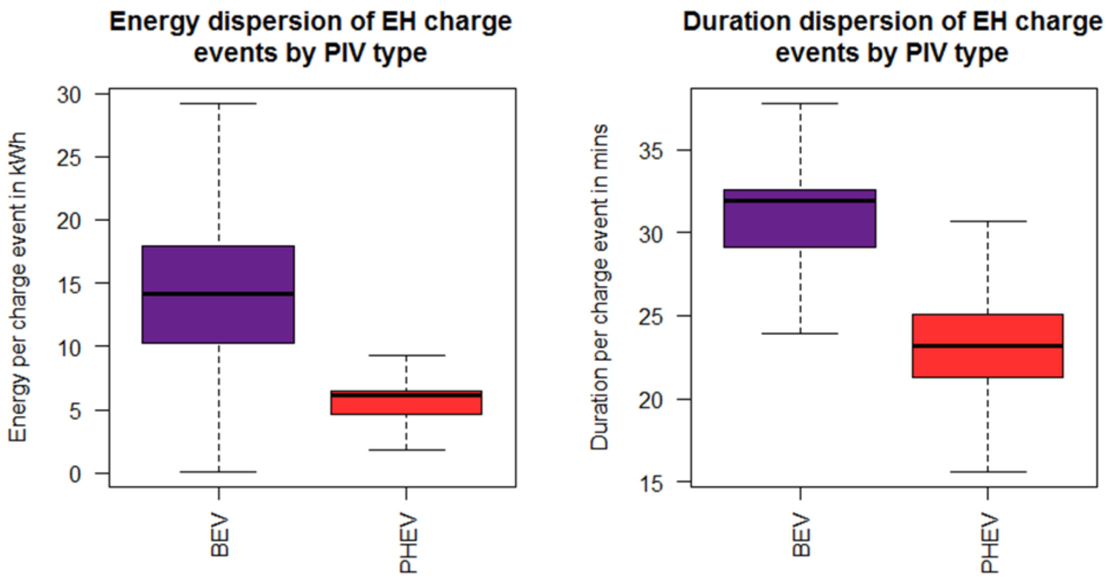


Figure 6.53 – EH energy and duration dispersion

Comparing the EH and NECYC rapid recharging behaviour results to the 2017 national LA rapid charger use reported (DfT, 2018a) yielded some interesting findings summarised in Table 6.5. Firstly, NECYC rapid chargers comprised only 8% of the total LA chargers studied but provided 30% of the charge events. Five of the top ten most used chargers were located in the NE region, including the highest 2017 utilisation of 6.23 daily charge events recorded in Stockton-on-Tees. Secondly, investigation into the commercial situation revealed that fees were applied to most LA rapid chargers outside the NE region, whereas the NE chargers were free to use. The 2017 median energy delivered by the NECYC rapid chargers (7.38 kWh) was lower than the national average of 9.32 kWh and the median duration (27 minutes) was slightly lower than the national figure. Considering these statistics alongside the higher NE daily utilisation suggested that NE drivers used rapid chargers to top-up quickly because they were free to use, whereas drivers in other areas used rapids only when necessary and deemed to be good value. Investigation into LA rapid charger locations revealed a prevalence of public car parks and leisure locations in urban centres which differed from the dominant EH locations on main highways. 2017 EH analysis provided a significantly higher median energy than the LA rapids at 13.7 kWh, with only slightly longer duration at 32 minutes. Importantly, fees were levied on EH throughout 2017 enabling a better comparison with national LA rapids than NECYC. This indicates that rapid chargers at Transit locations on main highways were more heavily utilised than rapid chargers in urban centres.

2017				
Rapid charger networks	**Quantity rapid chargers studied**	**Charge events (CE)**	**Median energy per CE (in kWh)**	**Median duration per CE (in mins)**
DfT LA	237	108,746	9.30	29
NECYC	30	37,061	7.38	27
EH	285	101,104	13.70	32

Table 6.5 – Rapid charging characteristics across three networks

EH charge events increased each year and the majority took place at MSA sites. MSAs provided the best rapid charging investment opportunity in 2017 with relatively high utilisation (1.25 charge events/day) and median charge event energy (14 kWh), combined with the lowest duration (31.8 mins). Double the median charge event energy was delivered to BEVs than to PHEVs. EH delivered higher charge event energy than either LA or NECYC rapid chargers, even with fees applied.

6.5.3 *Discussion of free-to-use rapid recharging*

To study comparative recharging behaviour using free-to-use rapid chargers, subsets were created for the period 2013 to 2015 from the regional NECYC and national EH datasets. The EH free-to-use subset contained 91,116 rapid charge events recorded between 2/9/2013 and 31/12/2015 by 97 unique chargers, whereas the NECYC subset contained 18,870 events from 38 unique chargers. Both composition and use differed between each free-to-use rapid recharging estate. The majority of EH chargers were located at MSAs followed by retail sites and fuel filling stations, whereas most NECYC rapid chargers were located in public car parks, leisure sites and workplaces attributed to OLEV grant funding awarded to local authorities who set up the NECYC estate on publicly owned land. Figure 6.54 illustrates that most EH events occurred at MSA sites which also formed most of the estate, whereas most NECYC events occurred at retail sites comprising only 13% of the estate. However, retail, leisure sites and public car parks together recorded 90% of the 2015 NECYC charge events in roughly equal proportions. Transport Interchange sites played a very small role in both estates.

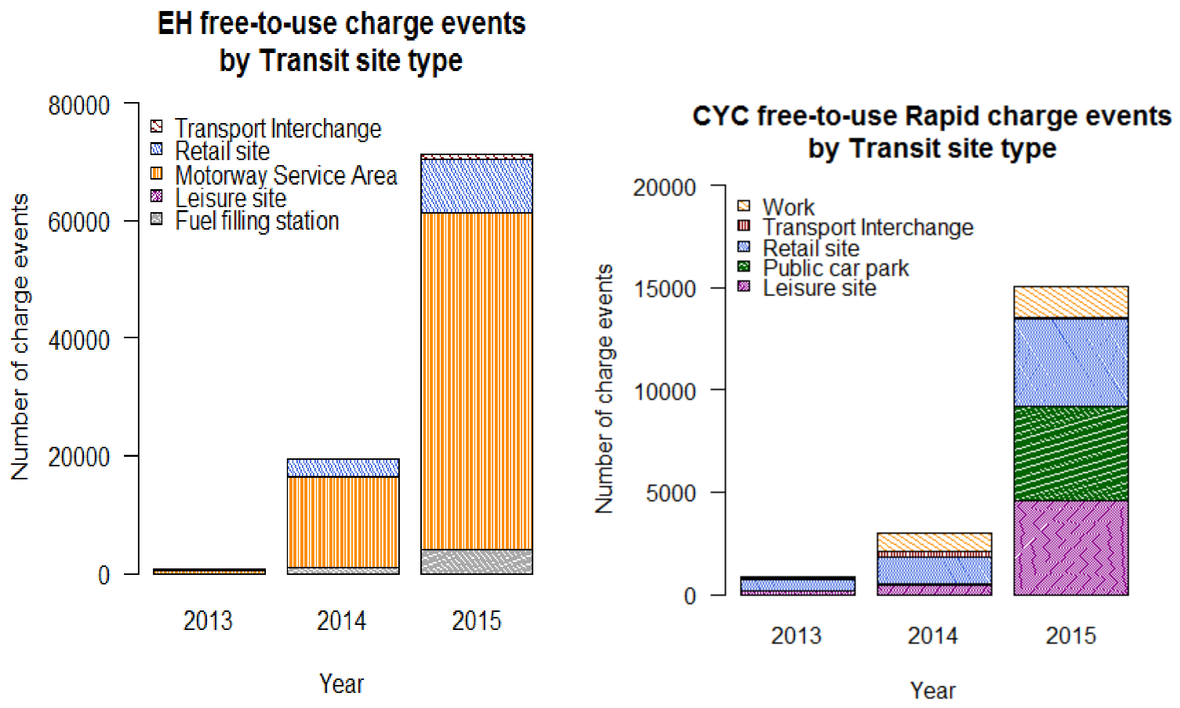


Figure 6.54 – EH v CYC rapid free-to-use charge events by Transit location type

The median rapid charge event energy delivered was consistently slightly higher on the EH than NECYC estates as summarised in Table 6.6, with more variability in the above median energy records, whereas NECYC contained more below median readings. Hence, energy sales on the EH estate are likely to provide a better investment opportunity than on the NECYC estate.

	Median charge event Energy (kWh)	
Year	**EH**	**NECYC**
2013	8.20	7.31
2014	9.10	7.66
2015	8.10	6.60

Table 6.6 – Comparison of free-to-use rapid charge event energy

The median duration of charge events on the EH estate was consistently slightly below that of the NECYC estate as shown in Figure 6.55. The variability and skew towards higher durations reduced on EH whereas it increased on NECYC which may indicate an increasing problem with excessive parking duration on the NECYC rapid chargers. Table 6.7 summarises the median durations of charge events on each estate.

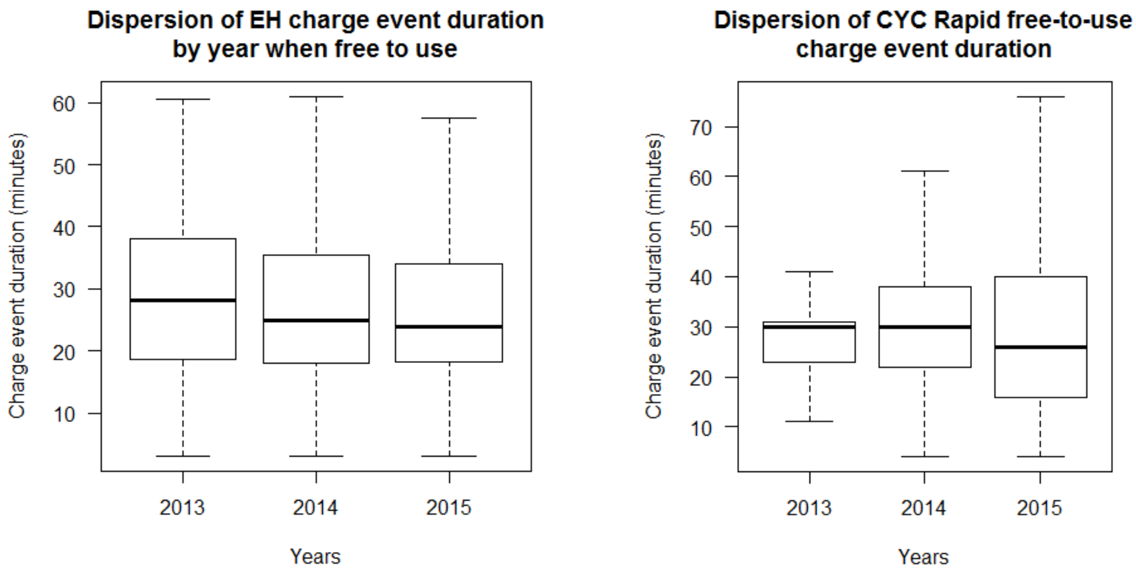


Figure 6.55 – Comparison of duration dispersion on rapid chargers

	Median charge event Duration (mins)	
Year	**EH**	**NECYC**
2013	28.10	30.00
2014	25.00	30.00
2015	24.00	26.00

Table 6.7 – Comparison of charge event duration on free-to-use Rapid chargers

The utilisation of each estate in the free-to-use period increased each year, but to a much higher median of 94.7 charge events per charger per month on EH in 2015, compared with only 43.5 on NECYC as shown in Figure 6.56. NECYC also experienced much greater variability in utilisation demonstrated by the tails in Figure 6.56, indicating that EH had a more predictable level of use which is important for revenue estimates and future growth plans.

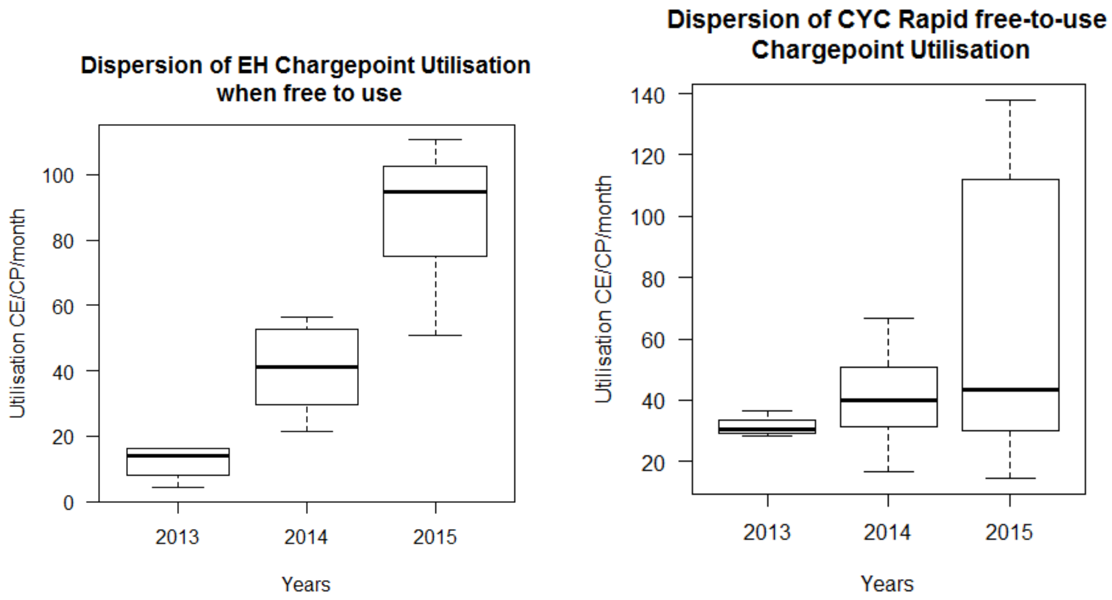


Figure 6.56 – Comparison of Utilisation on free-to-use Rapid chargers

EH data did not contain PIV information before 2016, therefore comparing free-to-use use by PIV type was not possible. However, the NECYC rapid chargers delivered the majority of charge events to BEVs, which had higher charge event energy and durations than for PHEVs using the estate, as illustrated in Table 6.8.

	NECYC free-to-use Rapid chargers	
PIV type	**Median charge event energy (kWh)**	**Median charge event duration (mins)**
BEV	7.91	31.00
PHEV	4.45	22.00

Table 6.8 – Use of NECYC Rapid chargers by vehicle type

EH delivered more energy per charge event than NECYC rapid chargers, with lower median duration and variability. Utilisation increased each year on both estates, although EH achieved more than double the utilisation of NECYC rapid chargers in the free-to-use period.

6.5.4 *Discussion of fee implications for rapid charging*

Content analysis was undertaken to compare use of the EH estate when free-to-use, with fee 1 and with fee 2 in place. Figure 6.57 illustrates the drop in utilisation experienced following the introduction of fees, with 2015's median 94.7 monthly charge events per charger falling to only 34.9 for the nine months of 2017 studied.

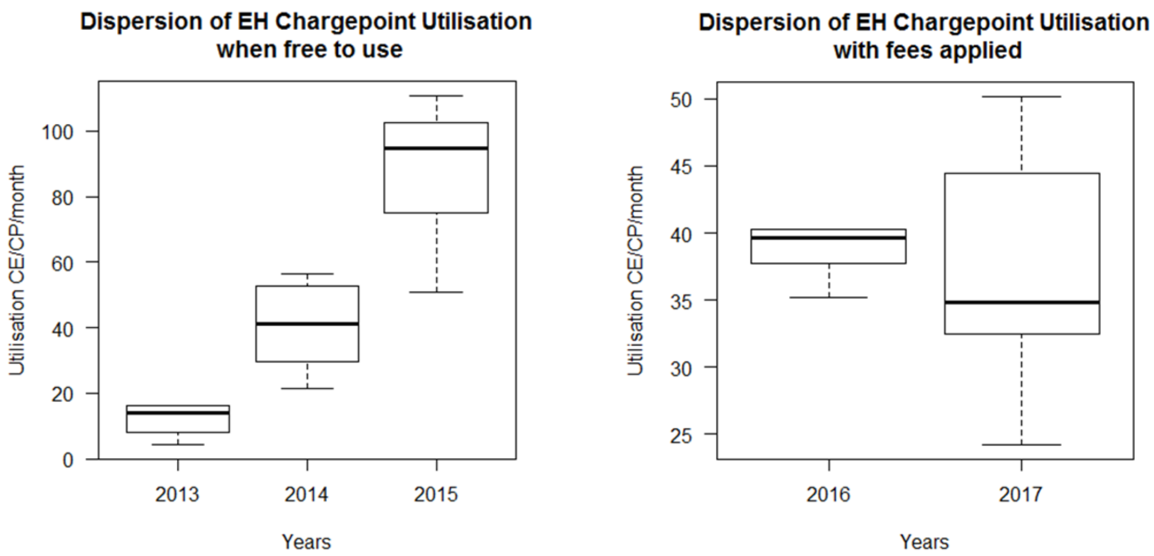


Figure 6.57 – EH monthly charge events without and with fees applied

Inspecting utilisation for each fee separately identified that utilisation recovered considerably when fee 2 was introduced, as shown in Figure 6.58, suggesting that users were happier with an energy-related tariff than a fixed tariff which supports drivers' feedback reported in Chapter 4. Further work could investigate whether utilisation continues to increase with fee 2.

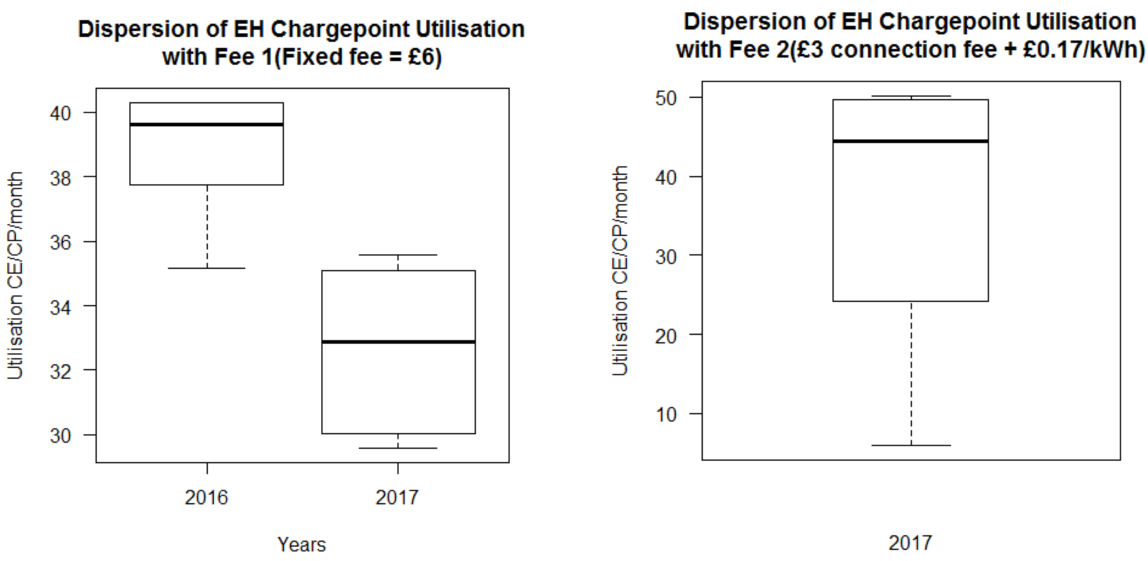


Figure 6.58 – EH monthly charger utilisation with fee 1 and fee 2 applied

The median charge event energy increased following the introduction of fees, from below 10 kWh when free-to-use to a median of 13.7 kWh in 2017 as shown in Figure 6.59, suggesting that users valued the service more when they had to pay for it. However, little difference was found between the median energy delivered under each fee, rising only slightly from 13.5 to 13.9 kWh from fee 1 to fee 2 with increasing variability which may indicate vehicles with larger batteries or longer journeys using the EH estate in 2017.

Median charge event duration rose following the introduction of fees, as shown in Figure 6.60, reversing the trend experienced in the free-to-use period. The introduction of fees caused a large reduction in the variability of charge event duration, suggesting users maximised the value of the fixed £6 fee. The impact of fees on both energy and duration are beneficial to the business case because energy delivery increased and variability decreased providing more certainty.

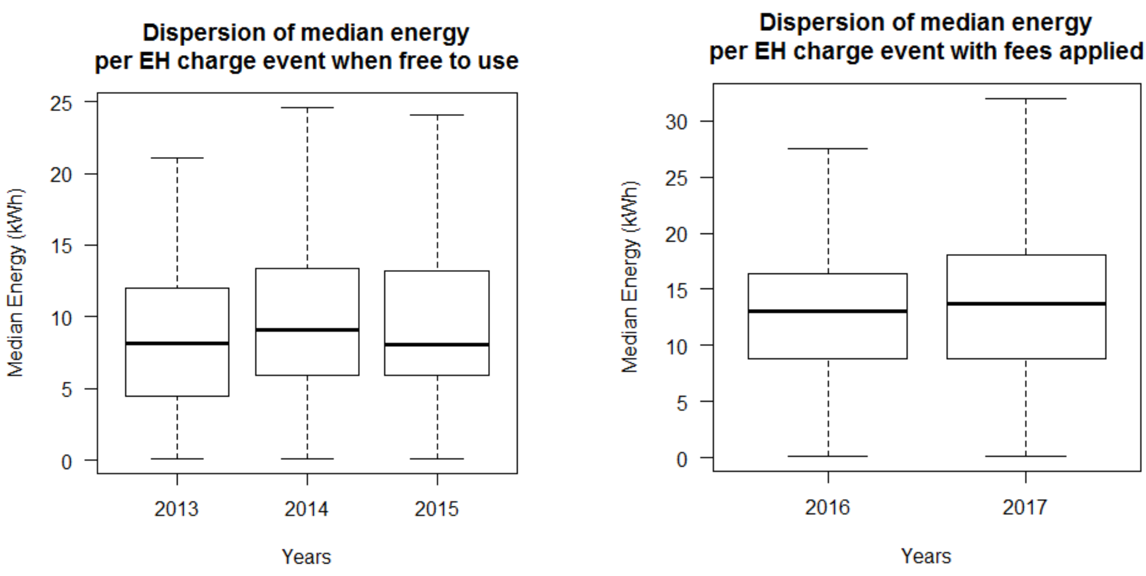


Figure 6.59 – Comparison of charge event energy before and after fees were applied

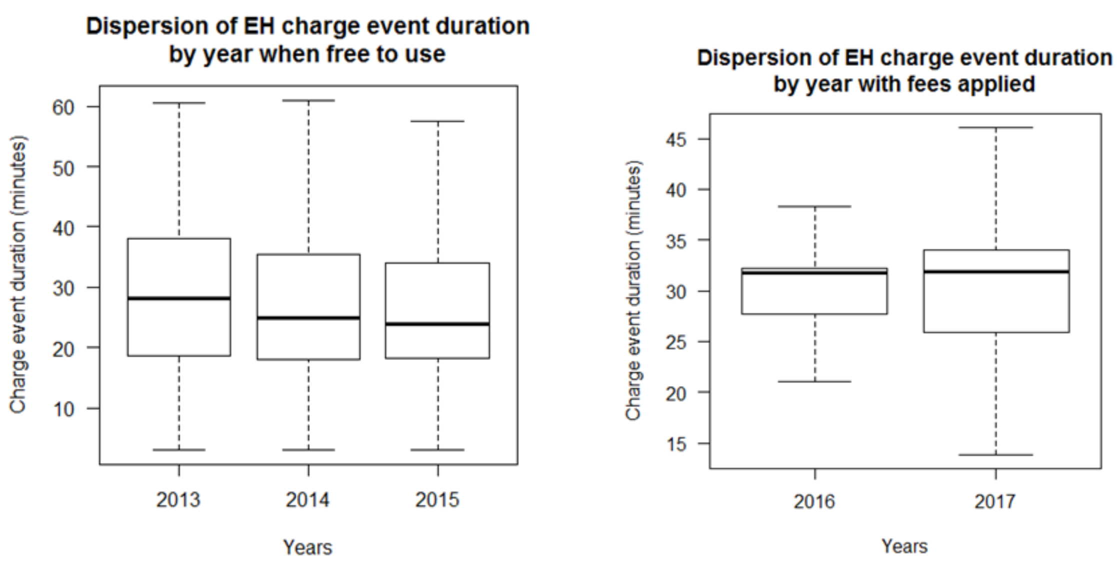


Figure 6.60 – Comparison of EH charge event duration without and with fees

Under fee 1, which was fixed for 30 minutes, more charge events were evident in the lower than higher duration quartile as shown in Figure 6.61, suggesting that some users ended charge events before the maximum 30 minutes allowed, regardless of cost. The heavily right-skewed median and very small upper quartile confirm that an automatic stop may have been applied by EH at about 32 minutes. With the introduction of fee 2 based on energy delivered, the stop appears to have been lifted enabling the median duration to rise to a well-centred figure of 34.9 minutes but allowing variability to rise again in line with the rise in energy delivered.

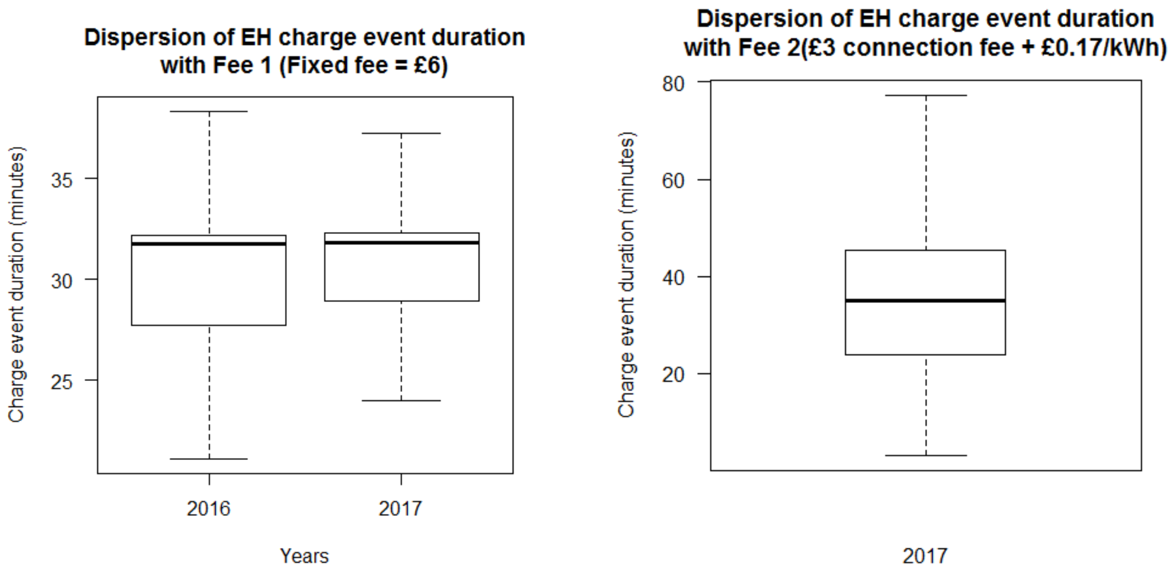


Figure 6.61 – Comparison of EH duration with fee 1 and fee 2 applied

The introduction of fees could have discouraged PHEV drivers from using the EH estate, considering the low median charge event energy delivered to PHEVs discussed in section 6.5.2. However, the change from fee 1 to fee 2 had little effect on BEV and PHEV charge event characteristics as shown in Table 6.9.

	EH with Fee 1 (£6 fixed fee)		EH with Fee 2 (£3 conn + 17p/kWh)	
PIV type	Median charge event energy (kWh)	Median charge event duration (mins)	Median charge event energy (kWh)	Median charge event duration (mins)
BEV	14.00	31.80	14.80	36.30
PHEV	6.10	23.30	6.10	22.90

Table 6.9 – Comparison of BEV v PHEV charge events with Fee 1 and Fee 2

The introduction of fees increased median charge event energy delivered and reduced variability in duration, generating revenue from electricity sales whilst also increasing the availability of the estate. Utilisation of the estate roughly halved with the introduction of fee 1, but recovered considerably with fee 2, indicating users were happier with an energy-related tariff than a fixed fee.

6.6 Summary of Findings

The goal of this chapter was to identify the characteristics of supply and demand for public recharging services to address aim 1, by analysing nine years of public recharging data to complement the PIV adoption results in Chapter 5 and drivers' requirements identified in Chapter 4. The supply study considered quantity, ownership, type, accessibility and location of charge points in the regional NECYC and national EH recharging estates. The dependent demand variables energy and duration were found to be affected by charger, access, location and PIV type, as summarised in Figure 6.62. The energy and duration results provided in this chapter address the need for recharging behaviour information identified in Chapter 2 and will be used to investigate the financial business model for public recharging in Chapter 7. The regional NECYC results can be used to inform local sustainable transport plans regarding expansion, ownership and operation of public recharging infrastructure. The implications of applying fees for public recharging coupled with drivers' willingness-to-pay results in Chapter 7 can be used to inform recharging operators' business plans.

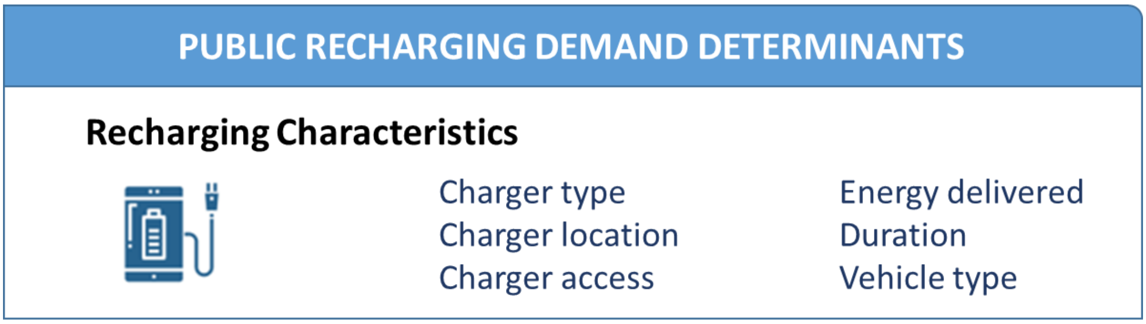


Figure 6.62 – Characteristics of public recharging demand

A total of 761 unique charge points were identified in the NECYC estate in NE England, at 332 unique sites including commercial, public on-street and off-street, workplace and transit locations, 70% of which contained two or more charge points. 81% of the estate were fast chargers, 14% slow chargers and only 5% were rapid chargers, however supply peaked in 2016 when 506 chargers provided data, falling each year thereafter. 62% of the charge points were available for public use, 33% for employees in workplaces and 5% for transit users requiring a quick turnaround so transit locations only contained rapid chargers. Both slow and fast chargers were identified in all other types of location and public off-street locations contained the majority (40%) of chargers, whereas on-street locations contained the least at 6%. The urban area of Newcastle Upon Tyne contained the most chargers, the most densely populated LA area in the region with the highest proportion of homes without off-street parking and relatively high PIV adoption. Conversely, the areas with lowest PIV adoption, Middlesbrough, Redcar and Cleveland, Darlington and Hartlepool, had the fewest chargers.

99 unique hosts owned charge points in the NECYC estate at a median of two charge points per host, however the 12 LA Councils together owned 60% of the chargers including all those in on-street locations and most in public off-street and transit locations. 57% of the hosts were private organisations, although academic, government and third sector organisations also owned chargers in addition to the LAs. Their environmental and grant funding motivations for charger ownership were identified in Chapter 4.

A population of 401,240 NECYC charge events was studied between 2010 and 2018 and the utilisation remained below one daily charge event per charger, except in Transit locations where rapid chargers delivered 2.36 daily events, with the highest median energy (7.81 kWh), shortest duration (30 mins) and lowest variability. NECYC annual recharging events peaked in 2016 and then fell each year reflecting the reduction in charger supply. Fast chargers delivered the majority (58.7%) of recharging events, although the small proportion (5.5%) of rapid chargers delivered 31.3% of charge events and the highest proportion of energy in the final three years of study. Workplace and public locations containing fast and slow chargers recorded longer durations than the energy delivery time, suggesting primary parking rather than recharging use which limited availability for other users. Public and employee access chargers exhibited peak start times between 7–8am, dropping to a short lower plateau in the early afternoon, then tailed off into the evening, whereas transit chargers demonstrated a relatively stable pattern of start times between 9am and 6pm. The three independent variables (charger; location; and access type) were found to act in combination affecting charge event energy delivered. Studying fast and slow charger use, ANOVA tests indicated that providing fast chargers for employees in workplaces would generate the highest mean charge event energy from non-rapid chargers.

Together the results suggest that investment in rapid chargers in transit locations may be most beneficial for revenue-focussed recharging estates, whilst investments in fast and slow chargers should focus on workplaces. BEVs were confirmed to be more valuable to the recharging business case than PHEVs, so recharging network operators should target BEV over PHEV users.

A comparative study of 285 rapid chargers on the EH recharging estate owned by Ecotricity, at 179 sites close to main highways, covered a population of 282,972 recharging events. Rapid chargers were found to deliver higher charge event energy on the national EH estate than on regional NECYC or DfT reported LA estates, even with fees applied, suggesting that EH's main highway locations were preferable to NECYC and LA urban centre sites. The EH analysis identified that MSA sites provided the best rapid charging investment opportunity with relatively high utilisation and median charge event energy, combined with the lowest charge event duration of all transit location types studied. EH rapid charger utilisation in the free-to-use period was more than double that on the NECYC estate, with more energy delivered per charge event, lower median duration and variability.

The introduction of EH recharging fees increased median energy delivered per charge event and reduced variability in duration, generating revenue from electricity sales whilst also increasing the availability of the estate. However, the introduction of fixed fee 1 roughly halved utilisation of the estate from the free-to-use period, but the change to fee 2 caused some recovery indicating users were happier with a variable energy-related tariff than a fixed fee. The change from fixed fee 1 to variable energy fee 2 and the removal of the 30-minute duration limit allowed the duration to increase but with reduced variability, providing more certainty for the business case.

Chapter 7. Recharging Business Models

The first purpose of this chapter is to address hypothesis 2 of aim 1: *Revenue generated by public charge point owners is not sufficient to match their total financial investment*. This chapter uses financial data from the NEPIP and RCN case studies described in section 3.8 with the recharging behaviour results from Chapter 6 to investigate the business model for public recharging infrastructure. The rapid charging business model developed during the RCN project was updated as described in section 3.7.2 to identify changes in the break-even point under the two EH fees. Following input modifications the model was used to determine the profitability of fast charger provision using NECYC recharging data and the willingness-to-pay results from the drivers' survey described in section 7.4 of this chapter.

The second purpose of this chapter is to address aim 2 by exploring stakeholders' views about the wider value of recharging infrastructure. Chapter 2 identified that e-mobility has a wider value proposition than ICE vehicles because it provides public good by reducing emissions as well as providing mobility. E-mobility requires recharging infrastructure but public recharging facilities exhibit the typical infrastructure characteristics of high up-front capital cost with long-term low revenue potential, an uncertain lifecycle because PIV technology is still developing, and complex environmental and social as well as economic value (Bryson *et al.*, 2014). The iBUILD business model framework was trialled to identify the wider elements of value created by public recharging solutions as described in section 3.7.2 and the results are presented and discussed in this chapter.

7.1 Public Recharging Business Models

This section describes the public recharging business models operated by the two example recharging networks studied, NECYC and EH, and discusses some alternative models operating in the UK.

7.1.1 *The purpose of public recharging services*

The UK government believes that recharging services are necessary to enable the changeover from ICE to PIV models (HM Government, 2018b) to reduce transport emissions, improve air quality and social well-being. The global objective is to protect the planet for future generations, but this aim has no measure of value recordable in the recharging business model. The function of all recharging services is to provide electricity to enable PIVs to travel, but the public recharging service is differentiated from its alternatives by location and accessibility characteristics. Public recharging services are accessible by the general public, whereas home recharging is located on private off-street residential land which is only accessible by the homeowner and workplace recharging is restricted to employee access only.

Public recharging services solve a number of problems in PIV operation. Firstly, drivers without access to off-street parking land at home or at work will require public recharging services in lieu of home or workplace recharging solutions. However, only a small proportion of UK drivers currently use PIVs, as explained in Chapter 5, and most of those early adopters can recharge at home as identified in Chapter 4, limiting the demand for public recharging services. Secondly, constrained power supplies limit most UK homes and workplaces to slow and fast chargers which take many hours to recharge a PIV, as illustrated in Chapter 6, restricting the convenience of PIVs compared with ICE vehicles. Therefore, alternative faster recharging services are required to enable a quick turnaround which publicly accessible rapid chargers currently fulfil. Finally, public recharging services can enable drivers to recharge whenever they are parked as a matter of convenience rather than necessity to complete the following trip.

7.1.2 *Public recharging business model roles*

Figure 7.1 illustrates the actors in the UK value chain for public recharging services using the European electricity industry’s terminology (Eurelectric, 2013) and identifies the actors performing key roles in the two networks studied in this research. Business to business (B2B) relationships exist between the many suppliers, charging station operators (CSOs) and electromobility service provider (EMSP), who then has a business to consumer (B2C) relationship with the end users, PIV drivers.

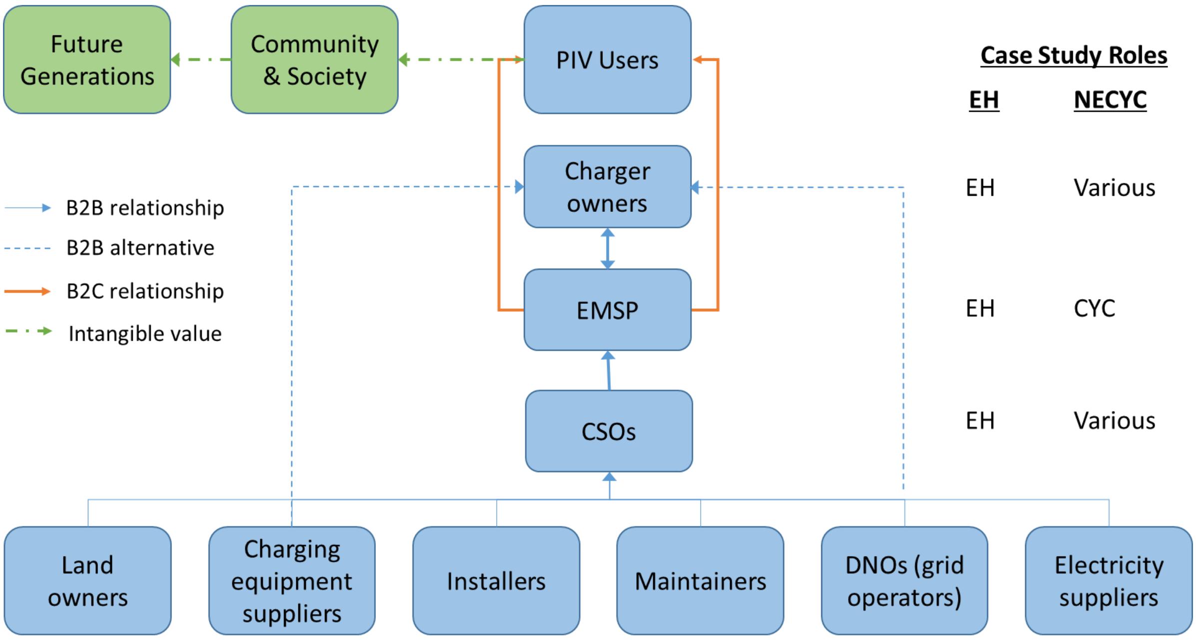


Figure 7.1 – Actors in the UK public recharging service value chain

In the Electric Highway (EH) example, EH was originally an energy supplier which diversified to act as a recharging network operator fulfilling the EMSP role by offering recharging services to PIV drivers. EH also acted as the Charging Service Operator (CSO) operating, monitoring and maintaining the chargers using their own back-office system and staff, unlike many European business models where multiple CSOs use cross-border EMSPs, e.g. Gireve[13], Hubject[14], to engage with consumers. EH owned all the chargers in its network, originating from one manufacturer enabling the development of EH's bespoke CSO systems, so both operating costs and service levels remained within EH's control in this model. EH rented land from multiple landowners including MSAs, fuel stations and retail sites on which to operate its chargers.

By contrast the NECYC example was more complicated, containing multiple charger specifications manufactured by multiple suppliers, owned by multiple organisations

[13] Further information can be found at https://www.gireve.com/
[14] Further information can be found at https://www.hubject.com/

with no relationship with consumers, instead contracting with the network operator Charge Your Car (CYC) to act as EMSP. The EMSP therefore had two types of customer: charger owners and PIV drivers, each requiring a different service. The CSO role was split: CYC performed the control and monitoring function requiring B2B relationships with multiple charging equipment suppliers; whereas the charger owners were responsible for maintenance and energy supply procured from suppliers through separate B2B relationships. This model had many inefficiencies: the EMSP required B2B relationships with multiple CSOs leading to poor network performance and customer complaints; the EMSP was dependent upon its customers for maintenance and energy rendering key service levels and costs out of its control; and charger owners required multiple B2B relationships.

7.1.3 *B2C recharging business models*

In a traditional business model, charger owners require cost-effective operation of their assets to generate revenue to offset against capital set-up (CAPEX) and operating (OPEX) costs. However, the NECYC estate was operated on a free-to-use B2C basis intended to raise awareness and consumer confidence that the switch from ICE to PIV was possible, so did not generate revenue. National and local government funding with a contribution from charger owners covered capital costs and operating costs were absorbed by charger owners from 2013, but this approach stifled maintenance and development leading to customer dissatisfaction according to the PIV driver feedback presented in Chapter 4. The EMSP attempted to raise revenue through annual operating contracts with charger owners and by levying small fixed connection fees on PIV drivers with little success given the falling use of and satisfaction with the NECYC estate discussed in Chapter 4 and Chapter 6. Consequently, the LAs who together own the majority of the NECYC estate have decided to procure a new EMSP and CSO from 2020, requiring a commercial business model with fees from the outset.

Learning from the NECYC experience, most UK EMSPs now apply a Pay-as-you-go (PAYG) B2C model, usually charging PIV users per unit (kWh) of electricity supplied, with or without an additional fixed connection fee. Alternatively, some EMSPs use a Freemium business model offering free electricity but providing premium reservation services for a fee, whilst others operate Subscription models with reduced per unit electricity prices. The Advertising business model also has revenue creation potential by displaying information to PIV users whilst recharging, however until PIV adoption increases this is unlikely to be an attractive financial opportunity for advertisers.

To address the high capital outlay associated with charger deployment some CSOs lease chargers to their customers as an alternative to outright procurement, thus retaining the asset and any associated value. The CSO is often also the charger equipment supplier so whilst this model reduces immediate equipment income it secures the installation, ongoing maintenance and operation business for that supplier.

Section 4.2 identified that PIV drivers require a reliable and convenient recharge at a price which they consider to be good value for money in comparison with the alternatives available. EH experimented with two fees during this study, changing from a free-to-use offer in 2016 to a fixed price per charge event, then to per kWh pricing in 2017 with a fixed connection fee as discussed in Chapter 6 and has since reached 30 p/kWh in December 2019. However, EH also operated a bundled services business model offering consumers cheaper recharging electricity unit prices if they also purchase home electricity from Ecotricity.

These examples demonstrate that the niche public recharging business model has many forms which must continue to change because PIV and recharging technologies are still developing and user recharging behaviour will adapt accordingly, affecting the future demand for public recharging services.

7.1.4 *B2B recharging business models*

Figure 7.1 illustrated the many suppliers in the public recharging market performing individual or multiple functions, and their different business interests lead to different B2B models. As discussed in Chapter 6 the recharging market can be divided into four segments: recharging services at destinations; at transit locations; at workplaces; and at homes where Chapter 4 identified drivers’ recharging preference lay. The opportunities and risks within each segment are likely to result in different business models. Chapter 2 described PWC’s emerging supplier business models for each segment (PWC, 2018), however they seem overly simplistic considering the existing players in the UK market. For example, Ecotricity is active in all of the business models identified: originally as a renewable energy supplier who provided specialist transit charging services through EH; then expanding into the home charging segment; and with wider interests in providing network optimisation solutions. PWC considered rapid charging to be less interesting for energy suppliers due the risks of high capital cost and low utilisation, yet this is where Ecotricity's business model originated. Engie, also an energy supplier, originally focussed on home charging solutions by partnering with multiple equipment suppliers, then diversified into destination provision and recently bought a specialist public charging operator ChargePoint Services (Engie, 2019). By contrast, traditional fuel suppliers Shell and BP have taken different approaches to the threats posed by the PIV market. Shell bought a home charging specialist (NewMotion, 2017) to diversify its revenue opportunities with homeowners and then partnered with existing suppliers to provide transit charging services in their fuel stations (Allego, 2017), generating new revenue whilst mitigating the risks of lost fuel sales. Whereas BP bought the UK's largest portfolio charging supplier Chargemaster (BP, 2018) to provide recharging facilities at their fuel stations, which quickly diversified and stacked revenue opportunities across all recharging sectors.

There are many roles in the UK recharging value chain and the two case studies differed in terms of actors and complexity. EH performed multiple roles in the rapid charging case study maintaining control of costs and service levels, whereas the multiplicity of actors and lack of control in the NE case study caused low NECYC satisfaction. EH had introduced and evolved fees whereas CYC had not. Both B2C and B2B business models are still emerging for public recharging as actors, technology and user behaviour develop but demand remains low.

7.2 Charger Owners' Attitudes to Public Recharging Business Models

NE charger owners provided basic data regarding their current and future business model aspirations in the 2015 questionnaire (Appendix E) responses, the results of which are presented in this section. The majority of respondents provided free-to-use recharging services but 14% had introduced recharging fees: three using a fixed fee regardless of energy or duration; two by energy delivered; and the sixth by duration. One reported trialling time of use tariffs in an employee car park in an attempt to spread energy demand away from peak hours. Most respondents indicated that they would consider levying fees for recharging services within the next five years and 47% already did or were planning to within the next two years. 61% of respondents believed that levying fees would have no effect on the use of their chargers. However, 43% either had not considered or had no fee intentions, suggesting a lack of business model focus on recharging services. Of the few owners levying fees, the maximum annual revenue reported was only £150 which respondents said was used to support maintenance and electricity costs in pursuit of cost-neutral operation, suggesting that charger owners were not seeking a profit making business model in 2015.

NE charger owners were asked to categorise their OPEX costs by annual value covering electricity, maintenance, back-office operation, promotion, enforcement and lost parking revenue costs and the results are presented in Figure 7.2. The majority of annual electricity costs fell into the £501–£1000 range which clearly depends upon chargepoint use, whilst most annual maintenance costs reported fell into the £101–£500 bracket which is unrelated to use. A large proportion of respondents did not provide any information regarding costs of back office, enforcement, promotion or lost parking revenue which could indicate either a lack of investment or a lack of cost data.

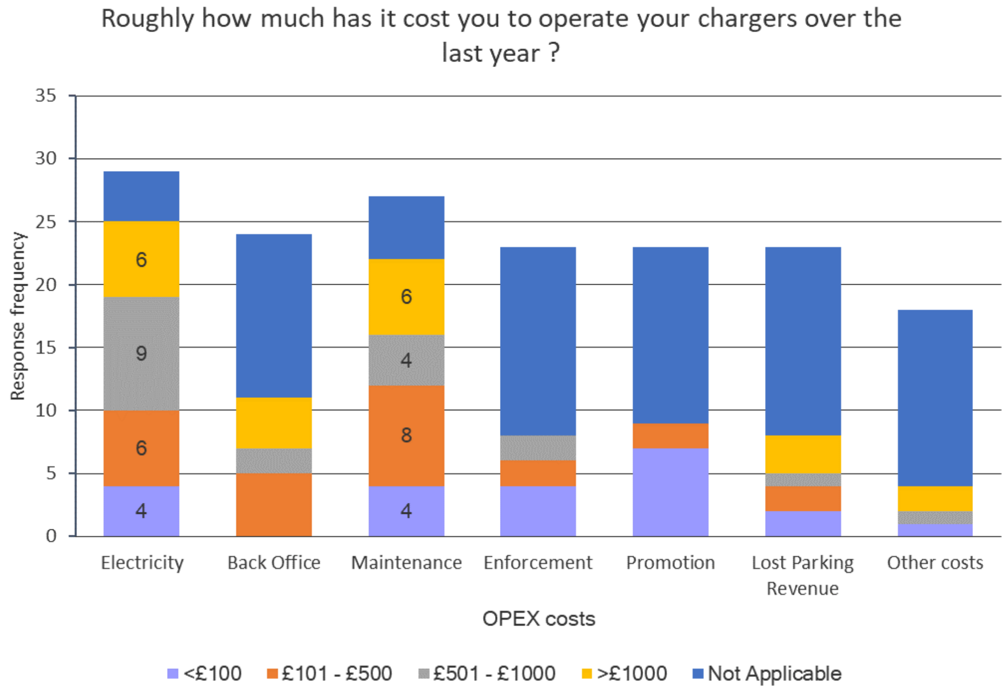


Figure 7.2 – NE charger owners' reported annual CAPEX costs (2015)

In response to an open question about the unit cost of electricity, the most frequent responses fell between 10p–15p/kWh, closely followed by under 10p/kWh originating from the large energy users such as LAs and large workplaces. Unfortunately, 54% of respondents said they never reviewed recharging cost data. Two commented that “car charging is not of a high volume and is not seen as a significant financial loss at the moment” and “Unfortunately, at the moment, monitoring all aspects of the charge points is not a priority”, indicating that recharging was not seen as an important service in 2015.

When questioned about their business reporting methods the lowest proportion of positive responses indicated preparing Social Accounts, although 37% of respondents declined to answer this question. Environmental reports received the most responses, followed by sustainable transport and health and well-being reports indicating that owners recognise the importance of demonstrating delivery against some non-financial objectives.

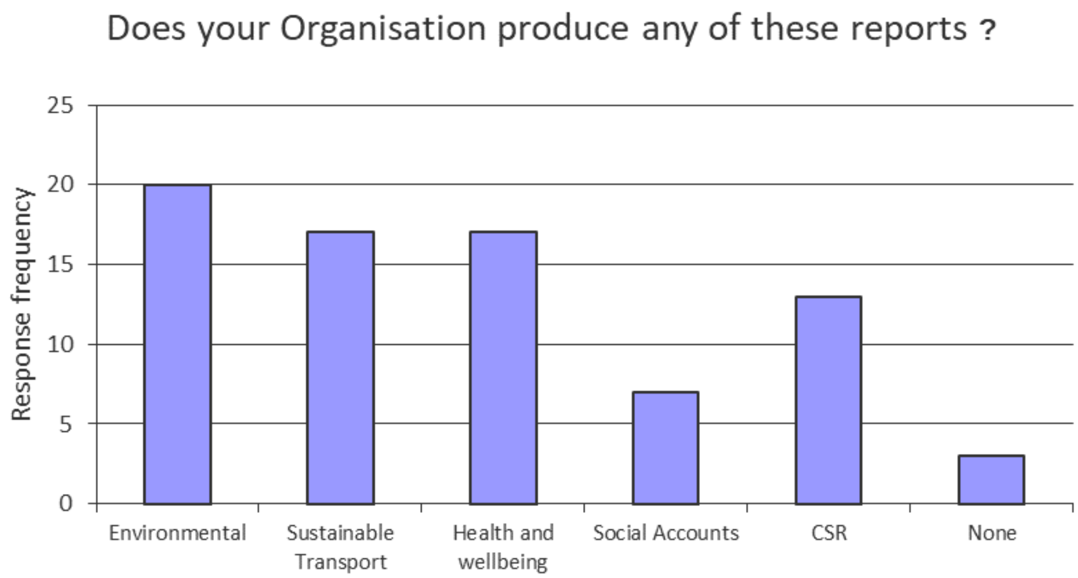


Figure 7.3 – Business performance reporting by NE charger owners

63% of charger owners indicated that charger use had increased in the last year and 84% of respondents agreed that charger use would increase in the future, however a wide disparity in timeframe was evident from one to ten years and 10% didn’t believe that public charge use would increase within ten years.

In 2015 only 14% of NE charger owners levied recharging fees, seeking only cost-neutral operation, and 43% had not considered introducing fees. Limited OPEX cost data was provided, indicating either a lack of investment or data recording, and 54% of respondents said they never reviewed recharging cost or revenue data. Together this suggests a lack of business model focus on recharging services.

7.3 Wider Stakeholders' Attitudes to Public Recharging Business Models

Data regarding stakeholders' views on the nascent recharging business case were gathered at the first iBUILD stakeholder workshop in 2014 (Appendix G) described in section 3.7.2. Attendees from EMSPs, driver groups, regulators, local authorities, consultants and academia provided their thoughts on business models for public recharging. Participants agreed that the multiplicity of stakeholders with differing objectives produced potential benefits which were difficult to define, although recharging costs were becoming more clearly understood. The panel commented that different types of public recharging (varying by charger specification, location and intended users) had different business models which must be flexible to allow for undefined future changes in PIV and recharging technologies, PIV use and customer profile as uptake increases.

The EMSP commented that consumers' willingness to pay (WTP) would guide the fees charged and that the recharging market should decide which costs and benefits the business model should encompass. The representative stressed the need for profit to invest in developments to satisfy PIV drivers' growing demands and continuing changes in technology, whilst acknowledging the price sensitivity of socially conscious early adopters. In response, the PIV drivers' representative stressed that low running costs were a fundamental component of the decision to drive electric so the psychology behind the operation of fees should be considered and drivers consulted in recharging business model creation. Interestingly, since 2014 most EMSPs have introduced recharging fees varying by charger type and location and in some cases punitive charges for excessive recharging durations.

Recharging dwell-time, location and fees were considered to be the key components of the recharging business model. However, commercial businesses providing chargers as added-value for their customers mentioned the difficulty of identifying additional services which could be sold during recharging dwell-time. In contrast, local authority officers stressed the environmental and social benefits of providing public chargers to encourage low-carbon travel, particularly into city centres and for those without the ability to recharge at home, but they did not expect significant revenue from these services.

In addition to the iBUILD workshops, ZCF designed and delivered recharging stakeholder workshops for the London Mayor's infrastructure delivery taskforce in 2018 (TfL, 2019), providing an update on attitudes to the recharging business model. The 95 attendees included stakeholders with interests in financing, sponsoring, installing, operating and using public recharging solutions in London. The discussions highlighted that energy and transport providers must work together to provide recharging services where users want them, whilst stressing the importance of increasing public recharging utilisation. However, attendees also called for better data for effective infrastructure business planning, including realistic PIV supply figures and adoption forecasts, drivers' willingness to pay, and where, when and how much PIV drivers wish to recharge in the future. Each of these factors has been investigated in this thesis. Suggestions made to increase public recharging utilisation included tools to grow the second-hand PIV market, targeting predictable fleet users and management tools to increase charger availability. Identifying good locations with predictable user demand, where power and space exists to provide multiple chargers, was identified as a value-for-money priority for London. Widening the recharging service offer was also suggested, for example by bundling services for PIV drivers or by supplying new customers with grid services to maximise revenue opportunities. The necessity of effective maintenance to increase users' confidence was stressed, including warranty and low-cost maintenance solutions. To encourage recharging infrastructure investment in London, stakeholders called for consistent long-term recharging policy, for example regarding land use, with targets and clear priorities adopted by all 32 London boroughs. It was suggested that public funding should contribute towards high capital costs such as new power connections and offset utilisation risks to ensure equality and coverage across London in situations where commercial providers are currently unwilling to invest. In recognition of public funding limitations, it was suggested that London boroughs and Transport for London (TfL) concentrate on promoting the need for and benefits of public recharging widely to residents, landowners, fleets and investors. Wider stakeholders could also contribute non-financial support including access to reliable information for business modelling and investment decisions, access to land and commitments to using public recharging facilities. The difference in stakeholders' thinking between 2014 and 2018 demonstrates the development of the recharging industry.

Wider stakeholders recognised that public recharging is a complex and uncertain niche market with multiple objectives and some benefits which are difficult to define. In 2014 LAs did not expect significant revenue from public recharging, however network operators stressed the need for profit to enable development, whilst PIV drivers cautioned that recharging fees must not infringe lower running cost benefits. By 2018, increasing public charger utilisation was highlighted as the priority, for which more reliable data on PIV supply and users' demand was required. Technology, information, policy, funding and promotion methods were identified for multiple stakeholders to contribute to increasing utilisation.

7.4 PIV Users' Willingness to Pay for Public Recharging

A successful business model needs to create value for both the EMSP and charger owner by providing a return on their investment and to the PIV driver who wishes to use the EMSP's recharging service at a reasonable price. Consequently, understanding PIV users' willingness to pay for recharging services is critical to a successful recharging business model. PIV drivers participating in the NEPIP and RCN projects were therefore asked a series of willingness-to-pay (WTP) questions in the 2016 (Appendix D) and 2015 (Appendix B) surveys respectively as described in section 3.4.1.

Using a check-all-that-apply (CATA) question to determine whether NE PIV drivers'

WTP varied by charger type identified that the majority (83%) were willing to pay for rapid recharging but some were still unwilling to pay for any public recharging service, as shown in Figure 7.4. In a later question 68% of respondents said they would pay more for a quicker recharging service, confirming that speed of recharge is an important variable in drivers' public recharging choices.

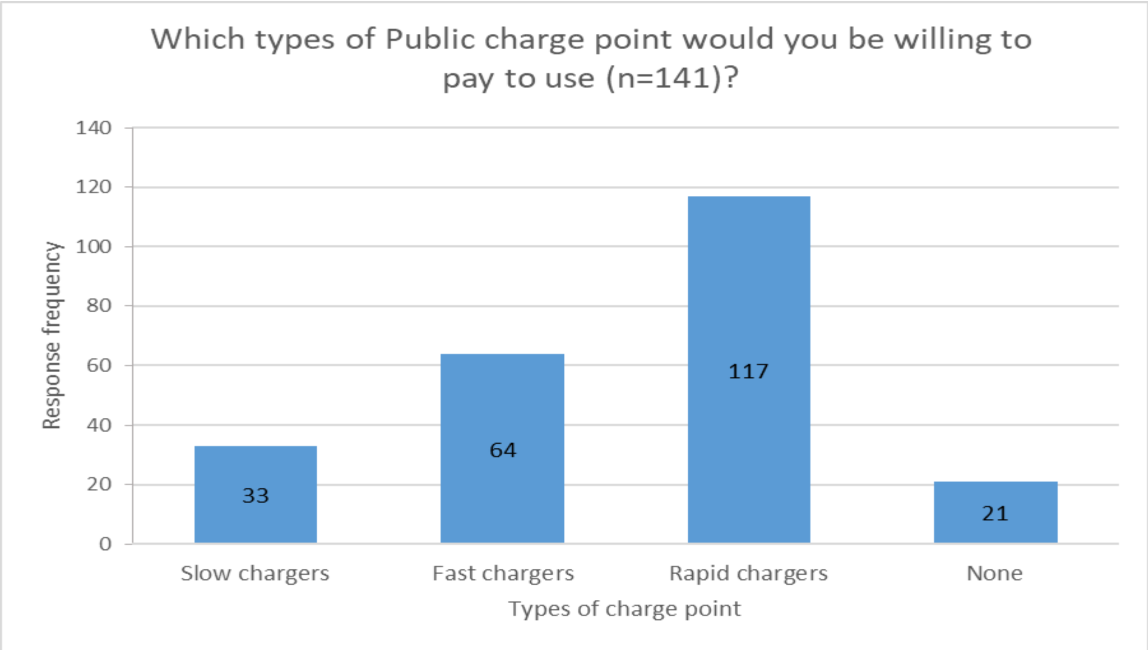


Figure 7.4 – NE PIV drivers' stated WTP by charge point type (2016)

The most popular locations where respondents were willing to pay for public recharging were motorway service areas (MSAs), as shown in Figure 7.5. At the time of this survey EH provided rapid chargers at MSAs with fee 1 applied which may have influenced responses, although there were only three MSAs in the NE region. The next most popular locations were public car parks and city centre streets which reflects drivers' use of traditional parking opportunities to recharge, where they are accustomed to paying parking fees. 41% identified fuel station locations which approximates to existing ICE refuelling behaviour and 40% identified transport interchanges, suggesting that co-benefits with multi-modal transport solutions could exist in the recharging business model.

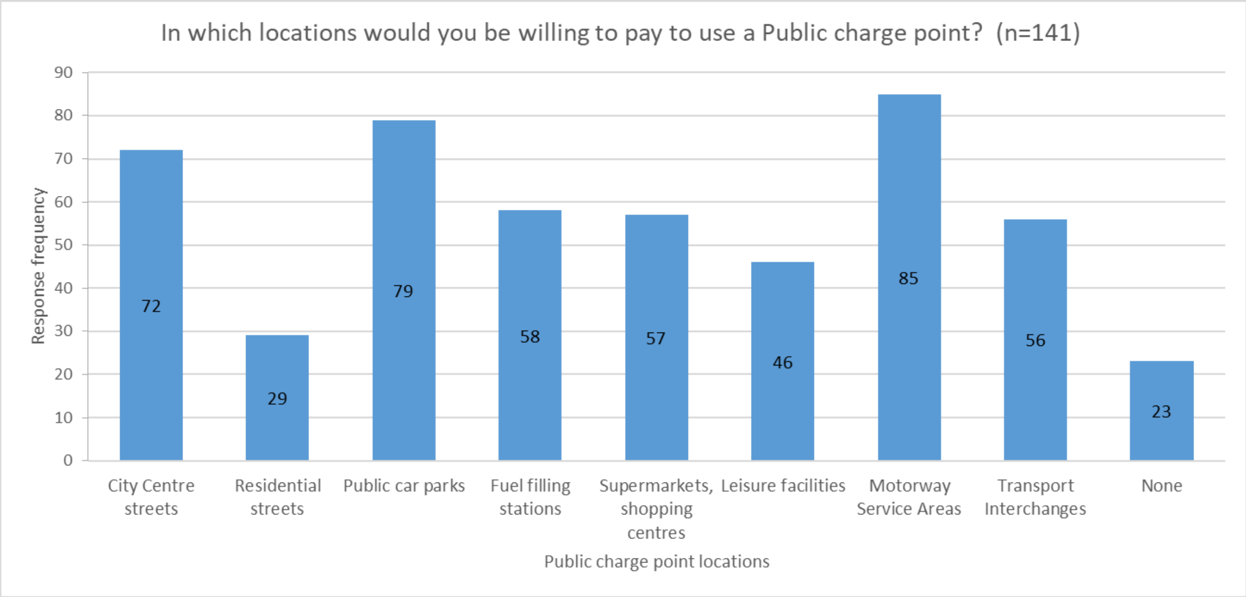


Figure 7.5 – NE PIV drivers' WTP by location type (2016)

RCN PIV drivers considered only rapid charging WTP whereas the NE drivers considered all types of public recharging, however their WTP responses were relatively similar indicating that these Early Adopter PIV consumers were willing to pay a premium for public recharging services over home recharging costs. Table 7.1 shows that both groups favoured calculating recharging payments by energy received (in kWh), similar to home electricity payments which consumers are accustomed to. No RCN respondents selected the fixed fee method, and the fact that some NE drivers did may be due to the short fixed fee trial conducted in the region during the NEPIP project. "Other" responses strayed into fee amounts.

	PIV drivers' responses	
Responses	NE drivers (n=138)	RCN drivers (n=182)
By energy (per kWh)	60.9%	67.0%
By duration	13.8%	14.3%
Fixed fee	12.3%	0.0%
Subscription	8.0%	8.2%
Other	5.1%	10.4%

Table 7.1 – PIV drivers' preferred public recharging fee methods

CATA questions were used to determine WTP for public recharging under different fee methods, to gather data for use in the financial business model investigations in sections 7.5 and 7.6. With fees based on energy use, Table 7.2 shows that the majority of respondents from both groups were willing to pay up to 16p/kWh, which they were told was equivalent to home energy cost. However, popularity diverged between the groups as the unit price increased, for example only 10.9% of NE responses indicated WTP at 30 p/kWh versus 30% of RCN responses, which may reflect a higher perceived value of rapid over fast recharging services. Interestingly, only 21.7% of NE responses favoured no fees, suggesting that the majority recognise the value of public recharging services. Yet 67.1% of NE respondents and 58.8% of RCN drivers said they would reduce or stop their use of public charge points if fees were introduced. The difference between the groups' responses may indicate that PIV drivers are more willing to pay for public rapid than fast or slow recharging services.

	PIV drivers' responses (check all that apply)	
Fee in p/kWh responses	**NE drivers**	**RCN drivers**
<16 p/kWh	90.6%	80.0%
20 p/kWh	32.6%	N/A
30 p/kWh	10.9%	30.0%
40 p/kWh	N/A	5.3%
45 p/kWh	0.7%	1.2%
50 p/kWh	2.2%	N/A
55 p/kWh	N/A	0.0%
0 p/kWh	21.7%	N/A

Table 7.2 – PIV drivers' WTP for public recharging per kWh

Since the technical characteristics of fast and rapid recharging intentionally deliver widely different recharging durations, as discussed in Chapter 6, only the NE drivers were asked about their WTP by time for fast recharging. Unsurprisingly, the majority of responses favoured the lowest fee equating to 60p per hour, however 15% accepted a fee equating to £1.80 per hour for fast charging illustrated in Table 7.3. Interestingly, 2p/minute equates approximately to home fast recharging cost, whilst 1p/minute is slightly more expensive than home slow recharging cost. Duration recharging fees may be more acceptable to drivers for slow and fast recharging services in traditional parking locations. Both groups provided WTP by duration for rapid recharging services and both favoured the lowest fee proposed, equating to £3.00 for a 30 minute rapid recharge shown in Table 7.4. However, higher proportions of RCN than NE responses accepted rapid recharging fees up to £6.00 which may reflect RCN drivers' experience using rapid chargers frequently as part of the project activity, providing a higher appreciation of rapid charger convenience and therefore value.

Fast recharging services	PIV drivers' responses (check all that apply)	
Fee by duration responses	NE drivers	RCN drivers
1p/minute = £0.60 per hour	52.5%	N/A
2p/minute = £1.20 per hour	36.0%	N/A
3p/minute = £1.80 per hour	15.1%	N/A
4p/minute = £2.40 per hour	2.2%	N/A
5p/minute = £3.00 per hour	5.0%	N/A
0p/minute	30.2%	N/A

Table 7.3 – NE PIV drivers' WTP for public fast charging by duration

Rapid recharging services	PIV drivers' responses (check all that apply)	
Fee by duration responses	NE drivers 2016	RCN drivers 2015
10p/minute = £3.00 for 30 mins	59.7%	67.1%
15p/min = £4.50 for 30 mins	25.2%	43.9%
20p/min = £6.00 for 30 mins	10.1%	18.5%
25p/min = £7.50 for 30 mins	1.4%	3.5%
30p/min = £9.00 for 30 mins	2.2%	0.0%
0p/min	29.5%	N/A

Table 7.4 – PIV drivers' WTP for Rapid recharging services

WTP responses with a fixed recharging fee regardless of energy delivered or duration also suggested that RCN drivers focussing on rapid recharging services associated higher value with public recharging than NE drivers, as illustrated in Table 7.5.

	PIV drivers' responses (check all that apply)	
Fixed Fee responses	**NE drivers 2016**	**RCN drivers 2015**
£2.00 per recharge	59.4%	75.0%
£3.00 per recharge	N/A	58.7%
£4.00 per recharge	26.8%	27.9%
£5.00 per recharge	N/A	11.0%
£6.00 per recharge	5.8%	1.7%
£7.00 per recharge	N/A	1.7%
£8.00 per recharge	1.4%	N/A
£10.00 per recharge	1.4%	N/A
£0.00 per recharge	35.5%	N/A

Table 7.5 – PIV drivers' WTP for public recharging at fixed fees

Approximately 65% of responses from both groups suggested willingness to spend up to £10 on additional services whilst recharging, as shown in Table 7.6. However, 22.1% of NE respondents declined to spend anything additional, compared with only 5.19% of RCN drivers, which may be because short durations mean drivers stay close to the PIV and most Transit locations were close to shops or refreshment services.

	PIV drivers' responses	
WTP for additional services whilst recharging	**NE drivers 2016**	**RCN drivers 2015**
< £5	35.7%	25.97%
Up to £10	29.3%	38.31%
Up to £20	7.1%	20.78%
> £20	5.7%	6.49%
£0	22.1%	5.19%

Table 7.6 – PIV drivers' WTP for additional services whilst recharging

In response to questions about related recharging services, only 31.4% of NE respondents and 32.1% of RCN respondents were willing to pay to reserve a charger. However, this response is likely due to the early stage of PIV adoption described in Chapter 5, predominance of home charging alternatives and limited queueing experience described in section 4.2. As PIV adoption grows, especially for those without the ability to recharge at home, demand for public recharging will increase and reservation services may be required in popular locations.

These WTP results limit the financial revenue available from public recharging services and additional offerings for charge point owners and operators. The most popular WTP results were subsequently used in the recharging business model to determine profitability, and the results are described in the following sections 7.5 and 7.6.

> The majority of PIV drivers were willing to pay for rapid recharging and would pay more for a quicker service, but some were still unwilling to pay for any public recharging services. Most drivers preferred the energy unit fee structure (p/kWh) at up to home energy prices, above which WTP fell significantly. Unsurprisingly, the majority of responses favoured the lowest fee in each scenario, however acceptable variable fees per kWh and by duration and per charge event fees were identified by drivers, which were used for modelling in the following sections.

7.5 Electric Highway Business Model Results

The business model constructed during the RCN project using actual capital expenditure, operating costs and use data was tested in this research using data collected during the two EH fee periods described in Chapter 6. The RCN business model was based on the provision of a single multi-standard rapid charger containing three outlets operating in a transit location along the UK highway network. The average capital expenditure (CAPEX) per charger was £36,849 without new power connections including: charger purchase and delivery with a three-year warranty; all civil and electrical installation works; commissioning to connect and test the charger; and project management services. 16 chargers required new power connections to the electricity distribution grid ranging from £1,000 to over £20,000 depending upon local conditions, which increased the average CAPEX to £42,454 for those chargers. An interest rate for the investor was applied at 5% and a charger salvage value of 20% after 15 years was used in the model following discussions with the manufacturer. Annual fixed operating costs (OPEX) were reported as £1,359.80 per rapid charger in 2015, equating to £453.27 per outlet. Fixed OPEX included: site rental fees paid by the EMSP to the landowner; back-office costs for software tools and user support activities; maintenance costs for routine checks, call-outs and stocks of spare parts; and unplanned maintenance costs estimated at 4% of the charger cost.

Many inputs to the model were found to have changed since 2015. Firstly, energy delivered by the estate fell with the introduction of fee 1 as discussed in Chapter 6, whereas the 2015 model assumed 15% annual growth. Secondly, both fees differed from the electricity cost multiple of three assumed in the model. Thirdly, the electricity price ten year growth rate fell from 5.2% to 2.1% (DECC, 2018) nearing the 2% OPEX inflation rate which limited profit opportunity. In 2015 the point estimate RCN model forecasted that rapid charger operators could return a profit in year 13 if a fee of three times the cost of electricity was applied to each recharging event, but by 2017 this forecast had fallen to year 17 due to lower than expected growth in energy prices and EH use. The change in inputs and resultant output forecasts observed in only two years between the model's creation and this review suggests that point estimate forecasts are inadequate for recharging infrastructure business planning, with insufficient levels of uncertainty accounted for in such a niche market. Further work to investigate the uncertainty of each input and to identify profitable scenario bands might be useful for potential investors and policy-makers.

To determine profitability under the two EH fees applied, the baseline was updated to reflect 2016 use data associated with fee 1, then 2017 data associated with fee 2, as shown in Table 7.7. A 2% OPEX annual inflation rate (ONS, 2019) was applied to both scenarios and the 15% annual energy growth rate was retained, acknowledging the PIV adoption required by UK policy. Network operators will periodically review cost and revenue to plan fee increases which are acceptable to users whilst maintaining business plan targets, so the electricity price growth figure of 2.1% was also applied to fees.

EH with Fee 1 (£6 fixed fee)		EH with Fee 2 (£3 conn + 17p/kWh)	
Median charge event energy (kWh)	**Monthly energy demand (kWh)**	**Median charge event energy (kWh)**	**Monthly energy demand (kWh)**
13.5	442.23	13.9	471.19

Table 7.7 – EH rapid charging characteristics under each fee structure

With fee 1 applied, a fixed fee of £6.00 per recharge, use fell resulting in a year 15 profitability forecast which matched the useful life of the charger. With fee 2 applied, a £3.00 fixed connection fee plus a variable fee of £0.17 per kWh, use recovered slightly bringing profit forward to year 14. This point estimate forecasting exercise suggests that applying fees per kWh is more likely to be a successful financial strategy than fixed fees per charge event.

The favoured WTP fees described in section 7.4 were also applied to the rapid charging business model to determine profitability, using fee 2 charge event energy and duration characteristics as the baseline, with 2% OPEX inflation and 2.1% increase in energy costs and fees applied. The fixed fees acceptable to PIV drivers were all lower than the £6 fixed fee 1 already modelled, so no further fixed fee scenarios were run. Running the highest acceptable variable energy fee of 30p/kWh through the model resulted in profitability by year 17, which was beyond the rapid charger's useful life. Finally, running the highest acceptable duration fee of 20p/minute resulted in profitability by year 12. This exercise indicates that the most profitable rapid charging business model for network operators involves charging fees calculated by duration, however drivers do not favour this mechanism as identified in section 7.4.

The year 13 rapid charger profitability forecast predicted in 2015 with fees at three times the cost of electricity fell to year 17 by 2017. With EH's fixed £6.00 fee 1 applied this improved to year 15, although few drivers found this fee acceptable. Fee 2, a £3.00 connection fee plus £0.17 per kWh, became profitable by year 14. PIV drivers' highest acceptable energy fee of 30p/kWh only showed profitability beyond the rapid charger's useful life. Levying rapid recharging fees by duration provided the most profitable business model, although drivers did not favour this model. However, point estimate models did not incorporate sufficient uncertainty for recharging infrastructure business planning at this time.

7.6 NECYC Business Model Results

The RCN model was then used to investigate financial return scenarios for NECYC fast chargers which require much lower capital investment than rapid chargers. NEPIP data indicated an average CAPEX of £5,393 for a dual outlet fast charger installed in locations from public streets to workplaces between 2010 and 2013 including: equipment with a two-year warranty; civil and electrical construction works; and grid connection services. The annual OPEX was £73.54 per outlet in 2013 including: routine maintenance and call-out services; back-office operation; and customer support services. No rent costs were levied since hosts owned the chargers installed on their land. From 2014 individual hosts became responsible for OPEX costs but little cost data was available as discussed in section 7.2, so inflation at 2% was applied to OPEX in the model. Indeed 29% of NE charger hosts reported that they either had no maintenance contract or were unaware of one in the 2015 survey. A 5% interest rate was adopted for the investor and 2018 NECYC use data reported in Chapter 6 and summarised in Table 7.8 was used as the baseline for this fast charger profitability investigation.

NECYC 2018				
Charge point type	Qty of charge points	Charge Events(CE) per CP per day	Median energy per CE (in kWh)	Median duration per CE (in mins)
Fast	248	0.369	6.37	151

Table 7.8 – NECYC 2018 fast charging characteristics

Firstly, the profitability of offering public fast charging at a fee comparable to home electricity cost in NE England was investigated. The latest domestic electricity unit cost published was found to be 16.24 p/kWh for 2017 (BEIS, 2018) and 2% annual inflation was applied to this figure. The results did not indicate a profitable outcome within 20 years which is way beyond the charger's useful life, so public recharging facilities cannot be offered at home electricity prices if a financial return is required. The WTP responses described in section 7.4 were then applied to the fast recharging business model with 2% annual inflation applied to both OPEX and fees and the profitability results are summarised in Table 7.9.

Fast Charging - Point forecast year of profitability					
Fee per kWh (+2% annual inflation)	Profit Year	Fee per minute (+2% annual inflation)	Profit Year	Fixed fee per charge event (+2% annual inflation)	Profit Year
20p/kWh	Year 21	1p/minute	Year 17	£2.00	Year 15
30p/kWh	Year 16	2p/minute	Year 10	£3.00	Year 11
3 x electricity cost	Year 14	3p/minute	Year 7	£4.00	Year 9

Table 7.9 – Public fast charging business model results

Recognising that PIV drivers preferred fees to be calculated by energy delivered in kWh, profitability was determined at various fees above the home electricity equivalent. The highest acceptable fast recharging energy fees reported by NE PIV drivers were: 20p/kWh which did not return a profit until year 21; and 30 p/kWh which provided a profit in year 16. However, the 2019 market price for the quicker rapid charging service was 35p/kWh, so it is unlikely that PIV drivers would pay a similar price for public fast charging services. Finally, a fee equivalent to three times the electricity cost was applied for comparison with the rapid charging results, indicating a profit could be made on fast chargers in year 14. However, this is beyond the useful life of NECYC's fast chargers and the salvage value is likely to be zero due to the speed of PIV and recharging technology change.

Modelling fast charging duration fees ranging from 1p to 3p/minute identified that the 2p/minute fee was found to be profitable in year 10 and the 3p/minute fee in year 7. Whilst this result seems the most attractive fee for financial investors, it presents challenges for the EMSP who wishes to maximise utilisation of the recharging facilities. As explained in Chapter 6, NECYC fast recharging activities display longer durations than the energy delivery time, so setting recharging fees by duration should be linked to the value of parking in the area rather than to energy delivery. Duration fees risk turning the recharging facility into a parking service rather than an energy solution provided to meet policy objectives, but could mitigate some opportunity cost of lost parking revenue. However, changing use of commercial parking bays to recharging use will likely produce lower revenues until PIV adoption increases, causing landowners to charge high rent costs to EMSPs.

Fixed fast charge event fees acceptable to PIV drivers were modelled at £1 to £4. The £1 fee per charge event was applied because a short trial of this tariff was carried out by the NEPIP project in 2014 but did not provide profit until year 29. The highest acceptable £4 fixed fee reported was found to be profitable by year 9.

These results suggest that most of the fees found acceptable by PIV drivers do not provide EMSPs with a profit within the useful life of fast chargers, so public funding is required to continue and increase public provision until utilisation increases. The NECYC estate was installed between 2010 and 2013 so the oldest chargers are nearing the end of their assumed 10-year useful life. To adopt a commercial business model for future operation further investment will be required to upgrade or replace charger assets and effective maintenance contracts will be needed to ensure that PIV drivers receive a reliable public recharging service.

Fast public recharging facilities cannot be offered at home electricity prices if a financial return is required. NE PIV drivers' highest acceptable fast recharging energy fee of 30 p/kWh provided a profit in year 16, whilst fees equivalent to three times electricity cost improved to year 14. The highest acceptable fixed fast recharging fee of £4 was profitable by year 9. Charging fees by duration provided the earliest profit for fast charging: at 2p/minute in year 10; and 3p/minute in year 7. This fee strategy could mitigate some opportunity cost of lost parking revenue but risks turning the recharging facility into a parking service rather than an energy solution.

7.7 Recharging Incentives Discussion

Long payback periods with major up-front capital investments are typical of infrastructure projects (Bryson *et al.*, 2014) and this coupled with low use forecasts renders them unattractive for profit-motivated investors (Foxon *et al.*, 2015). In the 2014 iBUILD workshop transport specialists CENEX stated that public funding would be required to operate public recharging networks until mass PIV adoption took place, which was likely to be many years away.

As discussed in section 7.2, capital grants were reported as a key motivator for NE hosts choosing to provide public recharging facilities. Figure 7.6 shows that grants were also the second most important motivator for adding more chargers in the future. These responses indicate that hosts recognise the importance of utilisation to the business model and understand that low PIV adoption will constrain demand, resulting in calls for grant funding until demand increases. Low NE PIV adoption forecasts reported in Chapter 5 and NECYC's falling utilisation reported in Chapter 6 suggest that low demand will continue for many years, so grant funding will continue to be beneficial to improve the public recharging business case for some time to come.

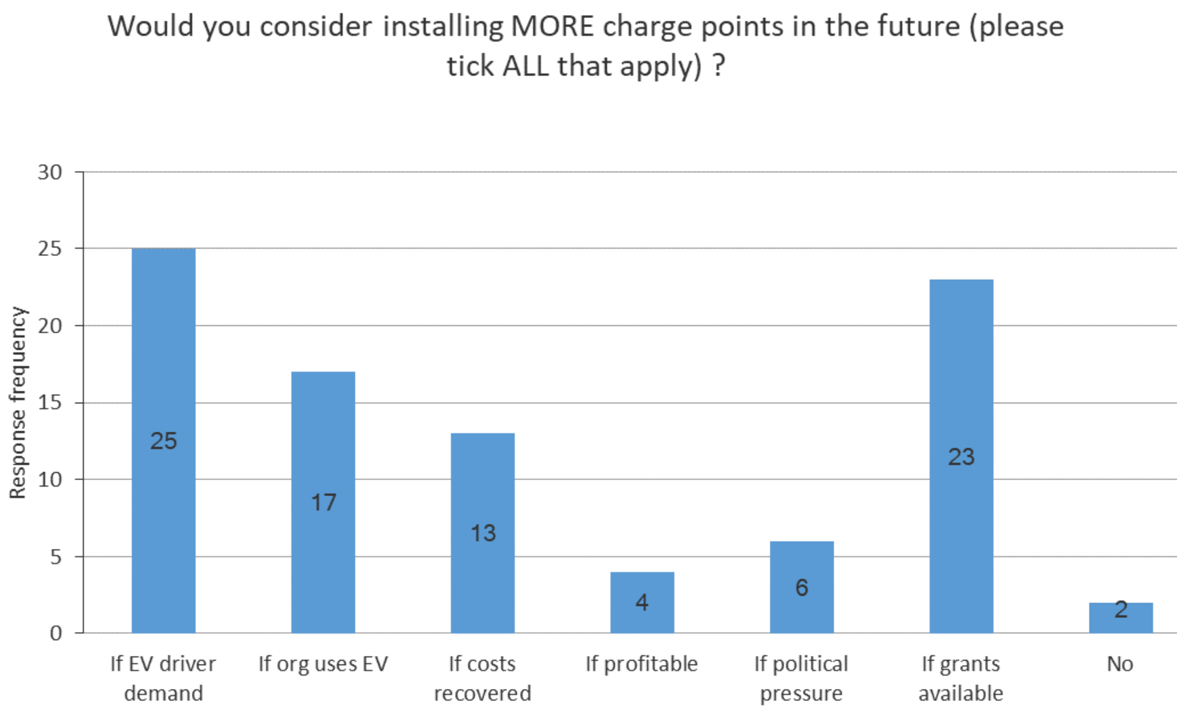


Figure 7.6 – NE CP owners' attitudes to further charger provision (2015)

In response to questions about recharging incentives, NE PIV drivers preferred free parking and recharging packages closely followed by free recharging as shown in Figure 7.7. This response is unsurprising since the majority of recharging facilities in the region were free-to-use at the time and most LAs offered free parking whilst recharging. However, almost half of respondents (45%) indicated that free parking for PIVs was not important, which may give LAs reassurance to re-introduce parking fees to curb opportunity costs of lost parking revenue caused by converting commercial parking into dedicated recharging bays with low demand. Notably, respondents also recognised the financial benefits of congestion charge exemptions and the practical benefits of using priority bus lanes, neither of which were offered in the area at the time nor directly affect recharging behaviour. This confirms that PIV drivers consider recharging as only one part of holistic PIV value, so awareness programmes could focus on co-benefits to encourage future PIV adoption.

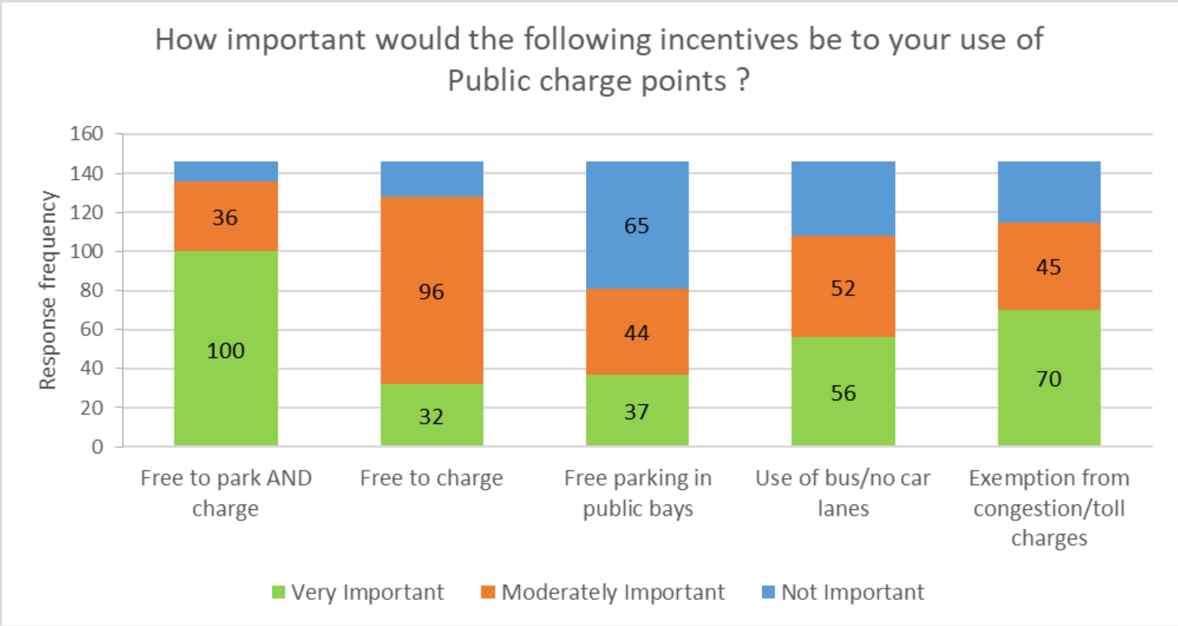


Figure 7.7 – NE PIV drivers' attitudes to public recharging incentives (2016)

In response to an open question requesting suggestions for incentives to increase use of public recharging services, 74% of respondents said no further incentives were required. Most comments called for increased availability especially in city centre car parks and for greater reliability rather than direct incentives. However, suggestions for financial incentives included buy-one-get-one-free and incentivised subscription schemes to make public recharging competitive with home recharging cost. Subsequently, in response to policy requirements many public recharging operators have introduced Pay-as-you-go (PAYG) fees which do not require pre-registration, but a few operate subscription schemes with below average energy tariffs, e.g. BP Chargemaster. Technical suggestions included a national access tool, national payment scheme with standardised fees, free charging cables and reliable real-time availability tools. Some commercial development has taken place since, including contactless access and payment systems and Zap-Map's real-time availability. Regulatory suggestions included limiting the duration of use, penalising users for overstay and penalising non-PIV drivers for parking in recharging bays. Recharging back-office and parking enforcement systems are now technically capable of delivering these solutions although they may not be commercially viable whilst public recharging demand remains low. Further work could study the impact of these incentive developments on public recharging behaviour in the future.

In October 2018 Newcastle Upon Tyne LA reintroduced city centre car park fees for PIVs and ZCF conducted further research in 2019 to investigate the impact on public charger use. Analysis of recharging data from the affected car parks for six months before and after the change found that, although total recharge events fell, average charge event energy increased, and duration decreased, so the total energy delivered remained almost the same. Therefore, the reintroduction of parking fees increased charger availability and reduced opportunity cost of lost parking revenue without affecting energy delivery, suggesting it is a successful business model strategy. Figure 7.8 confirms this using 2019 NE PIV drivers' survey data: although 45% of respondents said they'd either stopped or were using public chargers less than when parking was free, 48% said their use had remained the same.

Continuing recharging data analysis would be useful further work to monitor whether increased availability results in increased charger utilisation. Adding PIV driver interviews to investigate how increased public charger availability affects relative recharging behaviour in homes, work and public places would also be beneficial, however until the maintenance of NECYC recharging estates improves to minimise charger downtime this is unlikely to produce useful insights.

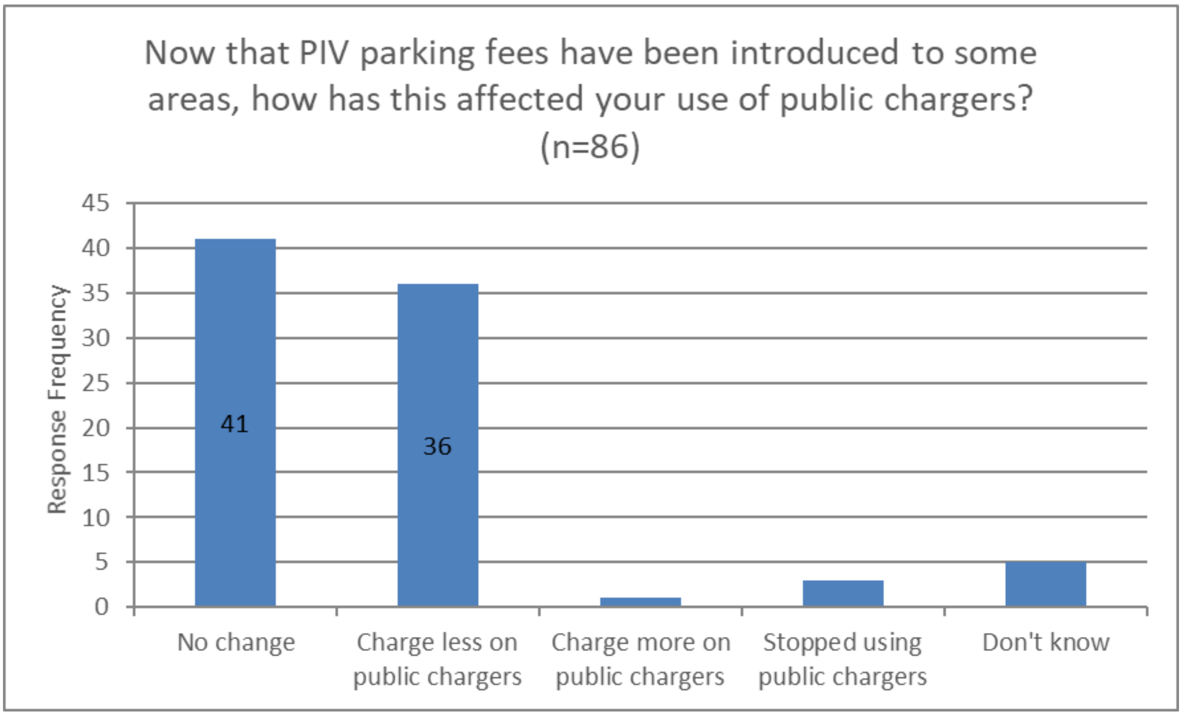


Figure 7.8 – Effect of parking fees on NE drivers public recharging (2019)

Continued financial incentives are likely to be required for recharging infrastructure until PIV adoption increases. Capital incentives were key to NE hosts' public recharging provision. Free parking and recharging packages were the most popular recharging incentives for NE PIV drivers, although non-financial co-benefits such as priority travel lanes were also identified. The reintroduction of PIV parking fees in Newcastle city centre car parks increased charger availability without hindering energy delivered. Many of the financial, technical and regulatory suggestions made by PIV drivers in 2016 have since been implemented.

7.8 Recharging Value Discussion

The second iBUILD workshop delivered in 2017 used the infrastructure value framework (iBUILD, 2018) to identify the relative value of three different recharging solutions for PIV drivers without the ability to recharge at home, as described in section 3.7.2. Chapter 2 identified that diverse stakeholders are required to create successful transitions (van de Kerkhof and Wieczorek, 2005; Bakker *et al.*, 2014), so stakeholders from local authorities, EMSPs, energy suppliers, DNOs, regulators, fleet operators, vehicle dealerships, consultants, academia and drivers were brought together to consider the outcomes, enablers, constraints and business models for public recharging solutions.

Firstly, the stakeholders' desired outcomes for solving this problem were determined and the associated enablers and challenges identified, addressing the need to understand varied stakeholder interests identified in Chapter 2 (Bakker, 2014). The participants agreed on two outcomes: increasing PIV uptake to reduce air quality problems; and increasing convenient, lower-cost mobility choices, indicating both social and environmental value. However, their priorities differed reflecting their different roles in public recharging in line with previous studies (Bakker *et al.*, 2014; Fischer and Newig, 2016). Fleet operators and vehicle dealerships focussed on enabling personal users, private hire and delivery drivers who take vehicles home at night to convert to PIV. The DNO and energy providers focussed on balancing demands on the grid through more efficient energy use. Whilst the LA representatives added the desire to build profitable businesses and local economies with healthy environments whilst meeting residents' needs. However, everyone agreed that all stakeholders must work together to achieve the major behavioural changes in both travel and energy use required to meet the two outcomes.

The participants identified the following constraints facing solutions for drivers without home recharging capability: the cost of recharging infrastructure deployment and continuing operation including maintenance; the lack of demand and poor financial business case for investment; the lack of grid capacity and costs of increasing power supplies; the pace of change in PIV battery technology outstripping recharging technology developments; conflicting land use policies and widespread ownership; and stakeholders' limited willingness to change the status quo. Stakeholders mentioned the difficulty of using limited public funds appropriately, balancing public recharging provision in affluent residential areas without off-street parking where the propensity to buy PIVs could be high, against the risk of social exclusion in less affluent residential areas if appropriate recharging facilities are not provided.

Some common themes ran throughout the enablers' discussion for alternative residential recharging solutions: political will, regulation and legislation; diverse PIV and recharging technologies; clean energy generation, increased grid capacity and energy storage solutions; good locations where drivers wish to recharge; the need for widespread education; and continuing public funding. The likelihood of increasing PIV supply and reducing cost as more second-hand models become available also featured in discussions about recharging demand, leading to a call for government to lobby PIV manufacturers for higher supply volumes, especially those manufacturing in the UK. Suggestions were also made that Section 106 planning agreements could be used by LA planners to encourage land use for recharging infrastructure in new developments such as supermarkets, business parks and residential areas. From the drivers' perspective the need for chargers close to home which are accessible and reliable 24 hours per day, with customer support services and acceptable prices, were reported as essential criteria to operate PIVs confidently. The relative benefits and costs of different recharging speeds were also discussed, but fast recharging facilities with long durations overnight were stated as adequate for most close-to-home requirements. Drivers commented on the difficulties caused by multiple recharging networks with unclear pricing, different access and payment methods and called for standardisation across the NE region.

Secondly, the participants were presented with three alternative recharging solutions for residents: on-street slow or fast chargers; rapid chargers; and EVFS and were asked to identify the value captured by who, where and when in each scenario. For this discussion an EVFS was defined as containing at least four rapid chargers plus additional consumer and operator facilities, as an alternative to on-street slow, fast chargers or individual rapid chargers. EVFS consumer facilities could include a shop, information and waiting areas, whilst operator facilities could include renewable energy generation and energy storage facilities. Table 7.10 summarises the many values identified by participants for the EVFS solution, with the type of value created and who could benefit. Stakeholders also commented that many PIV drivers could benefit from strategically located EVFS, not just those without home charging facilities, therefore increasing revenue opportunity. EVFS could also provide the convenience and certainty required by PIV business operators for whom minimising non-productive time is important, and for those wishing to extend journeys beyond the battery range without having to stop for many hours to recharge. With current rapid charging technology EVFS operators have the opportunity to sell additional products and services to PIV drivers waiting approximately 30 minutes to recharge.

EV Filling Stations - containing >4 rapid chargers + additional services		Types of value						
Value generated	To who?	Social	Environmental	Economic	Health	Cultural	Aesthetic	Political
Cheaper vehicle running costs	EV drivers			✓				
Convenience - a quick recharging service	EV drivers	✓				✓		
Recharging confidence - high availability and reliability	EV drivers	✓				✓		
Security whilst recharging	EV drivers	✓				✓		
No exhaust emissions and reduced noise from EV	Community, government, local businesses		✓		✓			✓
Revenue from operation of recharging services	EVFS owner & operator, maintenance & energy suppliers			✓				
Revenue from EVFS deployment	EV charging suppliers - equipment, installation, DNO			✓				
Deployment - Economies of scale	EVFS owner			✓				
Spread of deployment & operating costs	EVFS owner			✓				
Revenue from additional service sales e.g. shop, café, air/water, deliveries	EVFS owner & operator, concession operators			✓				
Revenue from advertising	EVFS owner & operator			✓				
Increased use of associated EV businesses	EV dealers, rental, car-share, MaaS operators, community transport	✓		✓		✓		
Additional business opportunities e.g. green transport contracts	Vehicle operators e.g. taxis, delivery and service organisations, business drivers		✓	✓	✓	✓		
Green energy opportunities - generation & use	EVFS owner & operator, concession operators, DNO, energy suppliers, academics, government		✓	✓	✓	✓		✓
Energy storage opportunities	EVFS owner & operator, concession operators, DNO, energy suppliers, academics, government		✓	✓	✓	✓		✓
EV Education and awareness	Community, local government, EV manufacturers	✓		✓		✓		✓
Regeneration of the area	Community, local government, local businesses		✓	✓			✓	✓
EVFS design	Community, local government, local businesses						✓	
No fuel delivery tankers	Community, local government, local businesses		✓		✓			
Brand Value	EVFS owner & operator, concession operators			✓		✓		
EVFS use data	EVFS owner & operator, government, academics			✓		✓		✓

Table 7.10 – EV Filling Station value map

The benefits reported for rapid chargers as alternatives to on-street fast chargers were broadly similar to those for EVFS, however more focus was placed on the difficulty of finding good residential locations with space for rapid chargers without having to buy costly new power connections from the DNO. Instead, multiple rapid chargers were proposed in car parks close to residential areas to achieve deployment economies of scale, but without providing added services. This model will be trialled across the North East region in 2020. The opportunity for community cohesion funding was also suggested for this operating model in rural areas, similar to community energy and broadband project funding in hard to reach areas.

Participants identified fewer values associated with on-street residential fast chargers than for rapid or EVFS solutions summarised in Table 7.11. In addition to the value generated by increased PIV use identified for all scenarios, the on-street scenario benefitted from: cheaper deployment and operating costs for the owner; cheaper recharging fees for the driver; and combined parking and recharging functionality close to home, increasing convenience for PIV drivers. However, on-street recharging fees were debated regarding whether home energy prices or commercial rates should apply and what the role of local authorities and regulators should be in price setting considering social equity responsibilities. Participants agreed that commercial rates would be necessary to enable charger maintenance and growing provision to meet increasing demand but suggested that LAs could cap prices and fill gaps where commercial operators were unwilling to provide chargers. This suggested approach aligns with the fixed term public ownership models proposed for hard to reach areas (San Roman *et al.*, 2011; Platform for Electromobility, 2018), although NE stakeholders suggested LA rather than DNO charger ownership which may constrain deployment based on the Netherlands' experience described in section 2.8.3 (Bakker, 2014).

The majority of values identified for each residential recharging solution were economic, which was unsurprising given the current focus on commercial business models. Since cultural value relates to the way society acts and social value is the quantification of the relative importance people place on the changes they experience in their lives (Kay, 2011), these two value categories were considered together. Combined cultural and social benefits received the second highest scores in all scenarios, indicating stakeholders' appreciation that public recharging solutions can change behaviour and have an impact on society's norms to improve the local environment. Many benefits were thought to create multiple types of value, indeed environmental and health benefits often appeared together, but neither were highly weighted in the benefits identified for either solution. A further study is proposed focussing on one solution using prescriptive value definitions to build on these initial findings, before defining a suitable method of capturing wider value outcomes of public recharging.

On-street residential slow and fast AC chargers		Types of value						
Value generated	**To who?**	**Social**	**Environmental**	**Economic**	**Health**	**Cultural**	**Aesthetic**	**Political**
Cheaper vehicle running costs than ICE	EV drivers			✓				
Convenience - closer to home than rapid or EVFS	EV drivers	✓				✓		
Convenience - long dwell-time parking and recharging	EV drivers	✓		✓		✓		
Lower recharging fees - than rapid or EVFS	EV drivers			✓				
No exhaust emissions and reduced noise from EV	Community, government, local businesses		✓		✓			✓
Cheaper deployment costs - than rapid or EVFS	Charger owner			✓				
Cheaper operating costs - lower use than rapid or EVFS	Charger owner			✓				
Revenue from advertising	Charger owner & operator			✓				
Increased use of associated EV businesses	EV dealers, rental, car-share, MaaS operators, community transport	✓		✓		✓		
Additional business opportunities e.g. green transport contracts	Vehicle operators e.g. taxis, delivery and service organisations, business drivers		✓	✓	✓	✓		
EV awareness	Community, local government, EV manufacturers	✓		✓		✓		✓
Brand Value	Charger owner & operator			✓		✓		
Charger use data	Charger owner & operator, government, academics			✓		✓		✓

Table 7.11 – On-street fast chargers value map

Participants stressed that the on-street fast charger scenario suffered from many disadvantages or disbenefits presented in Table 7.12. LA participants discussed criticism received from residents that converting already scarce parking to PIV charging bays would reduce public service for the majority of non-PIV owners. Residents' concerns were also reported regarding the risks of increasing disturbance and vandalism in residential areas. Furthermore, LA representatives raised streetscape concerns about adding more infrastructure to cluttered residential streets. PIV driver participants provided examples of the difficulties experienced by multiple residents attempting to share a single on-street charger and expressed concern that the number of chargers required per street would be impossible to provide once all vehicles were PIV. From the DNO's perspective, two major risks were declared. Firstly, power available on residential streets may be insufficient to support charger demands, in spite of the programme to reduce lamppost power consumption through the introduction of LED bulbs. Secondly, the risk of on-street recharging beginning during peak energy demand times (5–7pm) was reported as high, negatively impacting on the DNO's main function to protect energy supply for all. However, energy suppliers proposed employing time of use pricing for on-street recharging to financially incentivise PIV drivers to recharge outside peak times, which Chapter 2 identified could change recharging behaviour (Caperello *et al.*, 2013) to shift energy demand (Schey *et al.*, 2012; Azadfar *et al.*, 2015).

Recharging hubs containing many fast chargers in off-street locations close to residential areas were suggested as alternative solutions for drivers without home charging capability. However, questions were then raised about how far residents were prepared to walk from home to recharge, risks of safety and security overnight, and the availability of suitable sites with the required power supply. Further work is required to evaluate these constraints.

Appropriate indicators must be developed to measure each element of non-financial value for use in an alternative business model reflecting the ultimate reason for public recharging provision, transport emissions reduction. The discussion about acceptable distance between charger and home raises the potential of proxy measurement tools, for example using a time value method, which might also be appropriate to distinguish between different recharging solutions using the variables charger, access and location type. Further work is required to define and agree suitable indicators to record the wider values of public recharging provision.

On-street residential slow and fast AC chargers		Types of disbenefit						
Disbenefits	To who?	Social	Environmental	Economic	Health	Cultural	Aesthetic	Political
Recharging confidence - lower availability than rapid or EVFS	EV drivers	✓				✓		
Low security whilst recharging	EV drivers	✓				✓		
Low security - higher vandalism risk than EVFS, additional maintenance costs	Community, local government	✓		✓		✓		
Reduces scarce parking for non-EV driving residents	Community, local government	✓				✓		✓
Enforcement required - increases operating cost	Community, local government	✓		✓		✓		✓
Reduces pavement space and accessibility for pedestrians	Community, local government	✓				✓		✓
Streetscape concerns - aesthetic	Community, local government	✓					✓	✓
Low utilisation risk - overnight only	Charger owner & operator			✓				
Revenue from operation of recharging services - lower than EVFS or rapid	Charger owner & operator, maintenance & energy suppliers			✓				
Revenue from charger deployment - lower than EVFS or rapid	EV charging suppliers - equipment, installation			✓				
Risk of Grid overload - peak time of use 5-7pm	DNO, energy suppliers	✓	✓	✓				
Green energy opportunities - limited by space	Charger owner & operator, DNO, energy suppliers, academics, government		✓	✓	✓	✓		✓

Table 7.12 – Disbenefits of on-street fast chargers for residents' use

The many public recharging stakeholders had different priorities but agreed on the outcome of increasing PIV adoption to reduce emissions, indicating social and environmental value. Evaluating three options for public residential recharging solutions highlighted many elements of social, environmental, health, cultural, aesthetic and political value in addition to economic value, but some benefits were difficult to define, and disadvantages were also identified.

7.9 Summary of Findings

The first goal of this chapter was to address hypothesis 2 of aim 1: *Revenue generated by public charge point owners is not sufficient to match their total financial investment*. The free-to-use business model operated by NECYC and EH generated zero revenue, leaving charger owners with the costs of operation without sufficient budget, resulting in poor maintenance and customer dissatisfaction, proving hypothesis 2.

Using the RCN model to compare profitability estimates for EH's two fees levied during the study provided year 15 and year 14 profitability estimates, indicating that per energy unit fees could be more successful than fixed charge event fees. Applying drivers' WTP results found that the highest acceptable energy unit fee (30p/kWh) was not profitable within the rapid charger's 15-year life. By contrast, the highest acceptable duration fee of 20p/minute gave a profit in year 12, indicating that applying fees by duration could be the most profitable rapid charging business model for charger owners. However, the majority of PIV drivers surveyed preferred to pay by energy received (p/kWh) and would pay more for a quicker recharging service, indicating a preference for rapid recharging services. Testing the 2015 RCN model with 2017 data caused a four-year shift in profitability suggesting that point estimate models are currently inadequate for recharging infrastructure business planning due to high levels of uncertainty, so these profitability results must only be used for comparative purposes.

Applying the RCN model to NECYC fast recharging with NE PIV drivers' WTP results found that calculating fees by duration also provided the earliest profit forecast. Fast recharging duration fees at 2p/minute were found to be profitable in year 10 and at 3p/minute in year 7. This business model approach could mitigate some opportunity cost of lost parking revenue but risks turning the recharging facility into a parking service rather than an energy solution. However, 21.7% of responses were unwilling to pay for public recharging services and the majority preferred to pay less than home recharging costs. The model concluded that neither rapid nor fast public recharging services can be offered at home electricity prices if a profit is required. Recognising drivers' preference to pay by kWh energy unit, the highest WTP for fast recharging energy fees reported by NE PIV drivers (30 p/kWh) only provided a profit in year 16, making it unattractive to potential investors.

The two case study business models differed in terms of actors, complexity and control and the more complex multi-stakeholder NECYC case study experienced poor service levels and customer dissatisfaction. The less complex RCN case study, with its controlling actor EH, provided evidence of evolving B2C recharging business models in response to changes in demand and profitability. B2B public recharging business models are still evolving with the growing number and variety of actors in the supply chain, but PWC's presentation of emerging recharging B2B business models seems overly simplified in terms of the UK market.

The 2015 survey of NE charger owners' attitudes to recharging identified a lack of business model focus. Most offered a free-to-use recharging service, the few who charged fees sought only cost-neutral operation, and most respondents said they never reviewed recharging cost or revenue data. Charger owners called for continued capital grants and drivers also valued recharging incentives, so financial incentives will continue to be required until PIV adoption increases. However, the introduction of PIV parking fees in Newcastle Upon Tyne increased charger availability without hindering energy delivery, which suggests this is an acceptable approach to reduce opportunity costs associated with the public recharging business model.

The second goal of this chapter was to address aim 2 by exploring stakeholders' views about the wider value of recharging infrastructure. Stakeholders demonstrated differing attitudes depending upon their role and objectives for public recharging. In 2014 LAs did not expect significant revenue from public recharging, however network operators stressed the need for profit to enable development, whilst PIV drivers cautioned that recharging fees must not infringe low PIV running cost benefits. By 2018, most stakeholders agreed that increasing public charger utilisation was a priority for the business case, requiring more reliable data on PIV supply and users' demand. Technology, information, policy, funding and promotional methods were suggested for stakeholders to contribute to increasing utilisation.

Diverse recharging stakeholders attending the iBUILD workshop agreed that the outcome of public recharging solutions for those without the ability to recharge at home was to increase PIV uptake to reduce air quality problems, however their priorities differed reflecting their different roles in public recharging. Multiple constraints and enablers were identified requiring actions from all parties, although political and regulatory support was a recurring theme. Using the iBUILD infrastructure value framework to evaluate alternatives to home recharging identified many elements of social, environmental, health, cultural, aesthetic and political value in addition to economic value. However, disbenefits were also identified particularly for on-street residential recharging solutions which should also be considered in recharging business model planning.

A number of limitations and opportunities for further work were identified. Check-all-that-apply (CATA) survey questions provided results that were difficult to interpret, so alternative question styles are required for future surveys. The rapid charging behaviour data used in the RCN business model is now out of date and use has reportedly recovered to free-to-use levels by the end of 2019. Continuing to monitor EH cost, revenue and use data would enable a longitudinal study of the evolving rapid charging business case as PIV adoption increases, rapid charging competition increases, and recharging behaviour normalises under commercial conditions.

Chapter 8. Conclusions

The justification for public recharging infrastructure provision currently suffers from a lack of information regarding demand, recharging behaviour, costs and value, and the financial business case is widely considered to be poor. The purpose of this research was therefore to identify the factors affecting the public recharging business model and to explore whether non-economic value could be used to justify increasing provision in this niche market. This thesis contributes to the body of knowledge by presenting the results of a longitudinal study of public recharging behaviour in NE England, coupled with the results of surveys and focus group activities conducted with PIV drivers, charger owners and diverse recharging stakeholders in the region. This chapter provides a summary of the research findings and their implications for public recharging infrastructure, commenting on the limitations and opportunities for further research.

UK government policy seeks to end the sale of ICE vehicles by 2035 and encourages the adoption of ULEVs as a sustainable substitute, however Chapter 5 of this thesis indicates that UK ULEV adoption lags behind the CCC's adoption targets. Furthermore, ULEV adoption targets do not exist at local authority level, so targets were created for the NE area in Chapter 5 to enable local sustainable transport planning.

The limited availability of public recharging infrastructure is cited as a barrier to ULEV adoption as discussed in Chapter 4, however there are no forecasts available for the public recharging infrastructure required to facilitate ULEV adoption in local areas. In addition, meagre data is available on ULEV use and recharging behaviour, making recharging infrastructure investment strategy development difficult. Local area data is particularly required, which emphasises the importance of the analysis of nine years of NE area public recharging data reported in Chapter 6 and NE stakeholders' opinions discussed in Chapters 4 and 7.

The implications of fees on public recharging behaviour are also researched in Chapter 6 whilst the financial business model is then explored using empirical recharging data and drivers' willingness-to-pay data in Chapter 7. Finally, stakeholders' views on the wider values of public recharging infrastructure are discussed in Chapter 7 to initiate further work on alternative business models. The findings of this research indicate that financial considerations remain the primary focus for recharging stakeholders, and that whilst environmental and social benefits are acknowledged they are not yet being used to drive recharging infrastructure provision. Consequently, this thesis has addressed two aims:

Aim 1: To identify the demand and supply determinants for continuing and increasing recharging infrastructure provision in public places.

Aim 2: To explore stakeholders' views about the wider value of recharging infrastructure to inform the development of new business models.

8.1 Demand Determinants for Public Recharging

To address the first research aim, three studies were undertaken to identify the factors affecting demand for public recharging services: a qualitative survey of drivers' requirements for public recharging services; a longitudinal study of public recharging behaviour over nine years in NE England; and an analysis of PIV adoption figures in the region. Figure 8.1 summarises the factors found to affect demand for public recharging services.

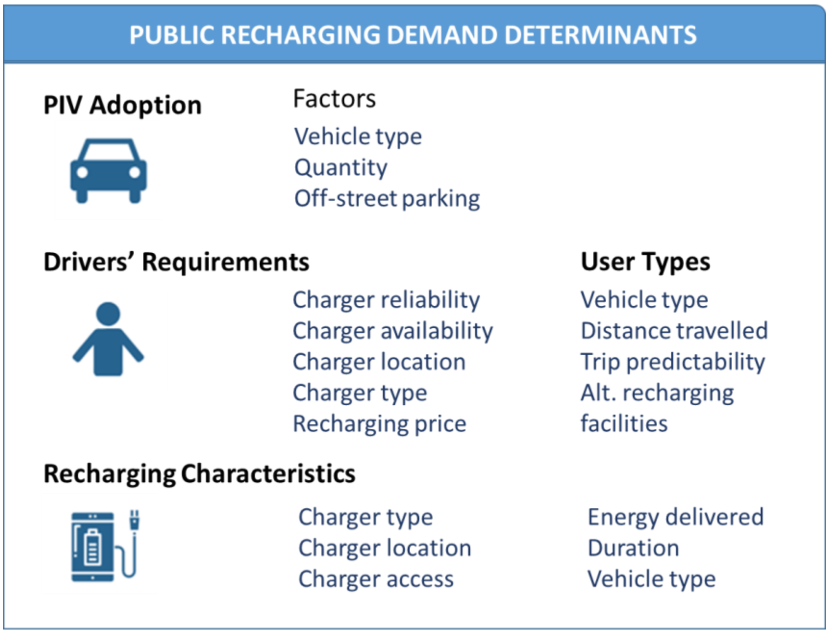


Figure 8.1 – Factors affecting demand for public recharging

The demand study results were used to test the first hypothesis: *the majority of recharging will take place at home or at work leaving little demand for public recharging facilities.* The NECYC public recharging estate actually delivered the majority (61.8%) of the calculated energy required by PIVs registered in the region in 2018, disproving hypothesis 1. However, a number of factors were found to affect public recharging demand in the region to address aim 1 which are discussed in the following sections.

Aim1	**Identify the demand and supply determinants for continuing and increasing public recharging infrastructure in public places**
Hypothesis 1	Majority of charging will take place at home or at work, with little demand for public recharging facilities
Result	**FALSE** - 61.8% of the energy required by NE registered PIVs in 2018 was delivered by the public charging estate
Objectives	**Contributions to knowledge**
A - Drivers requirements	Reliability, Availability and Location most important factors in drivers' public recharging decisions. Rapid chargers in transit locations were the preferred public charger type. NE has above UK average annual mileage, suggesting above average PIV energy demand.
B - Vehicle requirements	Highest PIV adoption evident in affluent NE areas without residential off-street parking, providing good opportunity for public recharging provision. PIV used public recharging much more than PHEV, so PIV are more valuable to business case .
C - Public charger use	Utilisation of NE rapid chargers was higher than fast or slow chargers. Fast and slow charger availability was limited by overstay. Charger type, location and access characteristics acted in combination affecting energy demand.

Table 8.1 – Hypothesis 1 contributions to knowledge

8.1.1 *PIV adoption*

The demand study identified PIV adoption as one factor determining recharging demand in response to the first aim of this research, however UK policy addresses ULEV rather than PIV adoption. UK ULEV adoption was very low, reaching only the early adopter stage at 3.14% of all new car sales in 2019 despite almost ten years of government incentives, so the CCC's 9% 2020 target was deemed to be unachievable. Local area ULEV adoption targets were missing to inform local area strategy and to monitor progress, so NE LA targets were calculated as a proportion of CCC UK targets based on vehicle populations.

All NE LA areas were found to have PIV adoption below the national average. The analysis identified that most UK regions with above average contributions to the UK PIV fleet also have high GDHI, **suggesting that affluence is an important factor in PIV adoption**, matching the early adopter profile identified by the Diffusion of Innovations theory (Rogers, 2003). **All NE LA areas have below average GDHI which may explain the below average PIV adoption** and the least affluent NE LA areas show the lowest adoption in the region. This finding contradicted previous preference studies suggesting that income was not a significant predictor of PIV adoption (Carley *et al.*, 2013; Bailey *et al.*, 2015).

PIVs include both BEV and PHEV models. Concerns have been raised that PHEV drivers use the internal combustion engine rather than the battery for the majority of mileage. This thesis **provides evidence that PHEVs use public recharging facilities much less than BEVs, supporting this conjecture, and demonstrates how vehicle type affects demand in the public recharging business case.** BEV users were responsible for the majority of charge events and energy delivered by both NECYC and EH recharging estates, so recharging network operators should encourage increased BEV over PHEV use. The dominance of PHEV over BEV sales makes the UK a less attractive market for recharging investors than countries with dominant BEV adoption, which is an important policy message for government.

Urban NE LA areas with above average homes without off-street parking have the highest percentage of PIV adoption. NE PIV drivers' surveys identified residential areas as a preferred location for public chargers, demonstrating a demand for public recharging in lieu of home charging, so residential areas without off-street parking should be a focus for recharging roll-out. The **NE LA areas with highest PIV adoption also have the most public recharging** infrastructure, whereas the areas with lowest PIV adoption have relatively few public recharging facilities.

8.1.2 *Drivers’ requirements*

PIV drivers’ requirements were identified as the second factor determining recharging demand in response to the first aim of this research. The NE region contained many drivers with up to eight years’ PIV driving experience, which **added mature PIV drivers’ travel and recharging behaviour insight** to the early UK trials using drivers’ with limited PIV experience reported in the literature (Caroll *et al.*, 2010; Carroll *et al.*, 2013; Robinson *et al.*, 2013; Bunce *et al.*, 2014). Most PIV drivers participating in this study drove BEVs and said the majority of their recharging was carried out at home with little need for public recharging, consistent with previous research (Skippon and Garwood, 2011; Morrissey *et al.*, 2016; California Air Resources Board, 2017). However, the majority (42%) of 2019 respondents recharged only a few times each week, reflecting growing confidence in PIV range and recharging capabilities over the study period. **Reliability, availability and location were identified as the most important factors in public recharging decisions**. Locations close to regular routes, work, homes and destinations with facilities were preferred, but by 2019 **transit locations providing a quick recharge became the preferred type of location for public chargers**. In addition, RCN participants identified PIV range as the biggest barrier to mass adoption and called for more rapid chargers in transit locations such as MSAs, petrol stations, supermarkets and shops.

8.1.3 *User types*

The type of PIV user was closely linked to their recharging requirements, providing a third factor determining recharging demand. PIV distance driven creates demand for energy which recharging infrastructure supplies, so the NE region is likely to have **higher recharging demand than the UK average** due to above average annual car mileage. Literature suggests that high mileage could be a barrier to PIV adoption (Achtnicht *et al.*, 2012; Egbue and Long, 2012; Graham-Rowe *et al.*, 2012) whilst PIV range remains below ICE vehicles. However, the proportion of NE PIV drivers reporting travelling above 10,000 miles per year increased between the 2016 and 2019 surveys, suggesting an increased confidence in PIV range and recharging capabilities. The majority of national PIV drivers in the RCN study also reported above average mileage and the desire to extend journeys quickly using rapid chargers. Annual car mileage was highest in NE metropolitan areas where vehicle ownership was lower than the national average, limiting the impact of PIV adoption on local transport emissions reduction. Hence **local sustainable transport plans should focus on areas where the greatest emission savings can be achieved**.

PIV travel patterns were found to affect recharging demand because unpredictable daily distances and routes increased recharging risk. Taxis and light goods vehicles travel further than private cars and may need to recharge during a shift or extend journeys beyond battery range. Therefore, reliability, availability and cost were identified as key public recharging criteria for businesses using PIVs, alongside the availability of alternative recharging options at homes and workplaces.

The affluent innovator and early adopter PIV personal consumers are likely to have off-street parking at home and therefore the option of home recharging. 93% of NE respondents could park off-street at home and 86% were able to park at work, indicating a high availability of alternatives to public recharging solutions in the NE region. However, as PIV adoption increases, users without the ability to park off-street at home will rely upon cost-effective public recharging solutions in easily accessible locations.

8.1.4 *Recharging characteristics*

The charger, access and location type were found to affect the energy and duration of charge events, in response to the first aim of this research. NE PIV drivers identified the need for reliable, available public chargers accessible 24 hours per day with customer support services and acceptable prices in order to operate PIVs confidently. The recharging data analysis demonstrated falling use of the mixed regional NECYC estate of slow, fast and rapid chargers from 2016, which reflects the increasing reliability and availability concerns expressed by drivers between the 2016 and 2019 surveys. Although utilisation of rapid chargers exceeded two charge events per day by 2018, fast and slow charger utilisation remained below one daily charge event and users were connected for longer than the active recharging duration, limiting availability for other users and therefore business model potential. **This local utilisation data should be used to inform future development of the NECYC recharging estate**.

The NECYC public recharging estate delivered 61.8% of the calculated energy requirement for PIVs registered in the region in 2018, disproving hypothesis 1 that only low public recharging demand exists. However, the free energy and parking incentives provided are likely to have increased use, biasing the NECYC results. The 2019 drivers' survey also recorded a higher demand (34%) for public recharging than literature suggests, although home was still reported as the preferred recharging location. Furthermore, EH analysis following the introduction of fees suggested that use of the NECYC estate will fall once public recharging fees are levied. Consequently, continued study of NECYC recharging data once fees are introduced is recommended alongside PIV registration data to reassess demand once public recharging behaviour normalises under commercial conditions.

The characteristics of charger, location and access type were found to act in combination, affecting the energy delivered by public chargers. NE PIV drivers reported a preference for short recharge durations using rapid chargers, confirmed by the NECYC recharging data where rapid chargers comprising only 5.5% of the estate delivered 31.3% of charge events. Rapid chargers generated an increasing proportion of NECYC charge events each year and delivered the highest median charge event energy and the lowest duration and variability of all charger types. Hence **investment in rapid chargers may be most beneficial for revenue-focussed** recharging network development.

Drivers reported public charger location to be the second most important use criteria, after reliability. National PIV drivers called for more rapid chargers in transit locations such as MSAs and fuel filling stations, whereas NE PIV drivers reported using chargers in short- and long-stay car parks most frequently, reflecting the dominance of slow and fast chargers in the NECYC estate. However, recharging durations for slow and fast charge events were found to be longer than the active recharging duration, limiting availability for other users. Hence **parking as well as recharging value should be reflected in the recharging business model.**

ANOVA tests indicated that providing fast chargers for employees in workplaces would deliver the highest charge event energy from non-rapid recharging infrastructure, **indicating poorer business potential for slow and fast chargers in public locations**.

The willingness-to-pay survey findings confirmed that **Innovator and Early Adopter PIV consumers were willing to pay a premium for public recharging**, but their responses **limited the financial revenue available**. Most respondents were willing to pay more for quicker recharging services, suggesting rapid chargers are favoured solutions, with national drivers indicating up to 30 p/kWh would be acceptable although NE drivers capped this at only 20 p/kWh. Furthermore, 67% said they would reduce or stop using public charge points if fees were introduced.

The recharging behaviour studies identified that rapid chargers in publicly accessible transit locations achieved the highest utilisation. Utilisation of free-to-use rapid chargers increased each year on both the regional NECYC and national EH estates. However, the EH estate's individual rapid charger utilisation was more than double NECYC's, with higher median energy, lower duration and variability which provides greater predictability for business planning. The national EH estate also demonstrated higher utilisation than any LA owned rapid charger in 2017, which may suggest that the main highway locations secured by EH are more popular with drivers than LA owned sites in urban centres. Further research could be undertaken to investigate this, given that the recharging data analysis showed location to be a key factor in recharging demand.

8.2 Supply Determinants for Public Recharging

Three activities were conducted to determine the factors affecting the **supply** of public recharging infrastructure to address aim 1: examine the motivations of charge point owners for public recharging investment; identify public recharging infrastructure deployment and operating costs; identify fees for use. Figure 8.2 illustrates the factors found to affect the supply of public recharging facilities.

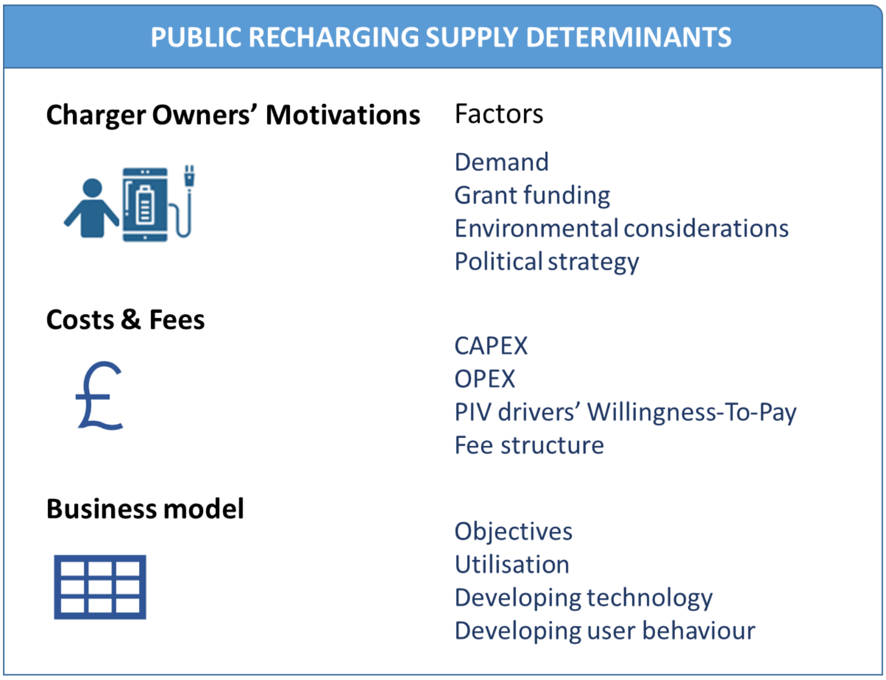


Figure 8.2 – Factors affecting the supply of public recharging infrastructure

The results were used **to test the second hypothesis**: *the revenue generated by public charge point owners is not sufficient to match their total financial investment.* **The results indicated that free-to-use operation generates zero revenue and that most of the drivers' WTP preferences were not sufficient to match total financial investment within the charger's useful life.**

Aim1	Identify the demand and supply determinants for continuing and increasing public recharging infrastructure in public places
Hypothesis 2	Revenue generated by public charge point owners is not sufficient to match their total financial investment
Result	**TRUE** - free-to-use operation generated zero revenue. PIV drivers' willingnes- to-pay thresholds were insufficent to match charger owner's financial investment
Objectives	**Contribution to knowledge**
D - charger owners' motivations	Environmental concerns and availability of funding most popular reasons for recharging provision, but recharging was a low business priority. Charger owners identifed issues of insufficient demand and unprofitability. Unwilling to provide more chargers until demand increases, or require incentives.
E - Recharging costs, fees & constraints	Charger owners' preferences shifted from cost-neutral operation to setting recharging fees and increasing utilisation. Applying fees to the EH rapid charging estate halved utilisation, but increased median charge energy and reduced duration variability, improving availability.
	Drivers' motivations shifted from cost savings to environmental benefits. Drivers recognised value in public recharging but willingness-to-pay reduced as price exceeded home energy price. Rapid chargers commanded higher fees than fast or slow chargers, and WTP was highest for rapid charges in transit locations.

Table 8.2 – Hypothesis 2 contributions to knowledge

8.2.1 *Charger owners' motivations*

NE charger owners reported **environmental concerns and the availability of grant funding as the most popular reasons for their investment in recharging** provision, but regional and political strategy were also reported as strong motivators reflecting the importance of Nissan's PIV production to the region's economy. NE charger owners recognised that recharging provision contributes to CSR, sustainable transport, carbon reduction and environmental objectives above financial goals. NE charger owners considered the existing recharging supply as sufficient to meet demand in 2015 and, recognising that charger provision was not profitable, required additional funding to increase supply. Their responses displayed a wide disparity in the expected timeframe for increased charger use, ranging from one to ten years. The accumulated NE survey findings suggest that **recharging provision currently has a low business priority** for NE charger owners with few targets set, little monitoring of cost or use, and few actions taken to increase utilisation. However, larger recharging operators outside the region indicated higher business priority and reported setting KPIs, frequently reviewing data and levying fees, whilst also calling for continued funding from government as the key stakeholder until demand increases.

8.2.2 *Public recharging infrastructure costs*

NEPIP project cost data for the NECYC estate indicated an average CAPEX of £5,393 for a dual outlet slow or fast charger installed in varied locations from public streets to workplaces, with an average annual fixed OPEX per outlet of £73.54 in 2013. Unit costs for the electricity supplied to PIV consumers varied in line with each owner's electricity contract, typically in the range of 10p–15p/kWh.

By comparison, the RCN project indicated a much higher average CAPEX of £36,849 for a triple-outlet rapid charger, but this rose to £42,454 where new power connections were required. Annual fixed OPEX was reported as £1,359.80 per rapid charger in 2015, equating to £453.27 per outlet. The higher rapid charger cost reflects its ability to recharge a 24kWh PIV from flat to 80% SOC in 30 minutes, whereas a fast charger would take three hours to deliver the same energy.

8.2.3 *Public recharging fees*

In 2014 recharging stakeholders reported diverse and opposing attitudes to public recharging fees, ranging from drivers seeking to protect the lower running cost benefits of PIVs through free public recharging, to network operators calling for profitable fees to enable network development. But by 2018 most stakeholders agreed that setting fees and increasing utilisation were priorities to maintain and grow public recharging networks, and to encourage PIV adoption as a result. More reliable PIV supply and user recharging data were identified as key enablers to grow sustainable public recharging networks and Chapter 6 provides considerable NE area recharging data to inform future growth.

The 2015 survey of NE charger owners identified that most offered a free-to-use recharging service. The few who charged fees sought only cost-neutral operation and LAs, who provided the majority of NE recharging infrastructure, did not expect to make significant revenue from public recharging. Nonetheless, almost half of respondents indicated that they were considering imposing recharging fees within two years, but the subsequent recharging data analysis provided no evidence of this occurring.

61% of NE respondents believed that imposing fees would have no effect on the use of their chargers, however the introduction of fees across the EH rapid charging estate in 2016 caused utilisation to halve from the free-to-use period. The subsequent change from EH fixed fee 1 (£6) to an electricity unit fee 2 (£0.17/kWh + £3 connection) enabled utilisation to recover somewhat, indicating that users preferred an energy-related tariff to a fixed fee. Whilst severely reducing EH utilisation, the introduction of fees increased the median energy delivered and reduced the variability in duration compared with the free-to-use period, which increased the availability of chargers in addition to generating revenue. However, the heavily skewed fee 1 duration data suggests that an automatic stop was used at approximately 32 minutes to achieve the increase in availability. The stop appears to have been removed with the change from fee 1 to fee 2 in June 2017, since median duration and variability increased with little change in median energy delivered, and consequently utilisation recovered to approximately 2014 figures.

Over the course of this research, the most important factor in NE drivers' decisions to transition from ICE vehicles to PIVs changed from cost savings to environmental benefits. Financial incentives were reported as only a minor consideration, yet over half the 2016 respondents said that they would reduce or stop using public chargers if fees were introduced, and the fall in EH network use observed following the introduction of fees confirmed this likely behaviour change.

Most PIV driver survey respondents recognised the value of public recharging services by indicating their willingness to pay a fee, preferably calculated by energy received (in kWh) similar to home electricity payments. Most respondents were willing to pay a price equivalent to home electricity costs but WTP decreased as the electricity unit price increased above home price. However rapid chargers commanded a higher fee than slow or fast chargers, indicating a higher relative value to consumers. Short dwell-time transit locations where rapid chargers are provided were the most popular locations where drivers were willing to pay.

8.2.4 *Public recharging financial business model*

Public recharging was found to be an uncertain market with low demand, evolving technology and user behaviour, social and environmental benefits which are difficult to define, and multiple stakeholders with diverse objectives, which the iBUILD's extended business model canvas (Foxon *et al.*, 2015) encapsulates. Therefore, the business model must evolve as the actors, technology and user behaviour develops. The business models operated by the two case studies differed in terms of actors, complexity and control, and the less complex EH operation demonstrated evolving B2C business models responding to changes in demand and profitability. However, most of the NECYC charger owners showed little action towards profitable recharging operation.

The recharging behaviour studies demonstrated that rapid chargers in transit locations accessible by the public achieved the highest utilisation and were therefore likely to provide the best financial opportunity. EH analysis suggested that MSAs were the best rapid charging locations for investment, with relatively high utilisation (1.25 charge events/day) and median charge event energy (14 kWh), combined with the lowest charge event duration (31.8 mins) in the estate. BEV users took double the median charge event energy of PHEV users and were responsible for 90% of the EH charge events, indicating that BEV customers are more valuable to the recharging business model than PHEV users.

However, point estimate models were found to be inadequate for recharging infrastructure business planning in this uncertain and evolving market, so the model was only used to compare profitability estimates for different fee structures in each of the case studies. **The free-to-use public recharging incentive operated in the NE throughout this study does not appear to have increased PIV adoption in the region,** which remains one of the lowest in the UK. The majority of NECYC charger owners charged no fees, generated zero revenue and were therefore unable to recover their capital or operating costs.

In contrast, the EH rapid charging estate transitioned from a free-to-use offer through two fee structures. The hybrid fee 2 (17p/kWh + £3 connection fee) forecasted a profit by year 14, inside the charger's useful 15-year life, and produced higher utilisation than fixed fee 1 (£6). Drivers reported preferring fees calculated by energy (p/kWh), but the highest acceptable electricity fee (30p/kWh) was not forecasted to be profitable within the rapid charger's life. Whereas the highest acceptable duration fee of 20p/minute gave a profit in year 12, so **applying variable fees by duration could provide the most profitable rapid charging business model for EMSPs**. Applying fees by duration also provided the earliest profit forecast in the NECYC fast charger case study. Duration fees could maintain availability by discouraging users from connecting for longer than needed and could mitigate some opportunity cost of lost parking revenue. However, PIV drivers did not favour the duration fee structure which also risks turning the recharging facility into a parking service rather than an energy solution.

Neither rapid nor fast public recharging services can be offered at home electricity prices if a profit is required within the 15-year charger life. The model predicts that a rapid charging fee of 39p/kWh must be levied to make a profit, which matches the highest rapid charging price in the UK market in 2019. The public fast recharging business model is even more challenging. Energy unit fees at three times the cost would need to be charged to be profitable within the fast charger's life, equating to 34p/kWh currently. However, NE drivers only reported willingness to pay a maximum of 20p/kWh, and drivers are unlikely to pay a price almost equivalent to rapid recharging for a much slower service.

Financial incentives are likely to be required for public recharging infrastructure until PIV adoption increases. Charger owners reported the need for continued capital grants and drivers valued recharging incentives. However, the introduction of PIV parking fees in Newcastle Upon Tyne increased charger availability without hindering energy delivery, indicating an acceptable way to reduce opportunity costs associated with the fast public recharging business model.

The research **has confirmed the hypothesis that revenue generated by public charger owners is not currently sufficient to match their total financial investment within the charger's life**. Imposing recharging fees by duration would be more beneficial for charger owners' financial business cases, but drivers prefer fees calculated by energy unit (p/kWh). The model predicts that rapid recharging fees at 39p/kWh rising annually with energy costs are required to make a profitable financial business case, but this is above drivers' reported WTP. A starting fee of 34p/kWh must be imposed to make fast chargers profitable, which is above drivers' WTP where both cheaper and faster alternatives exist.

8.3 Wider Value of Public Recharging

To address the second aim of this research, stakeholders' views about the wider value of recharging infrastructure were explored using questionnaires and workshop activities. Public recharging infrastructure was found to generate social and environmental value as well as economic value, however further work is required to determine appropriate value indicators for measurement and use in a non-financial business model approach.

Aim2	**Explore stakeholders' opinions on wider value of public recharging infrastructure to inform development of new business models**
Objectives	**Contributions to knowledge**
A - Stakeholders' opinions on wider value of public recharging	Desired outcomes of public recharging = increasing PIV uptake to improve air quality and increase low-emission mobility choices. Social and environmental value is generated by public recharging infrastructure, in addition to economic value. PIV drivers value convenience = the combination of reliability, location and availability. Wider stakeholders priorities differed depending upon their roles and objectives within the system.
	To improve business case, target recharging provision in areas where biggest emission savings are available e.g. residential areas without off-street parking and urban centres. Target customers without home parking and unpredictable long distance drivers.
B - Identify use of wider value in alternative business models	Further work required to determine value indicators for social and environmental value associated with public recharging e.g. health, social and environmental consequences of travel choices. Stakeholders suggested using linked financial incentives and penalties to change drivers' travel and recharging behaviour.

Table 8.3 – Aim 2 contributions to knowledge

In 2015 NE charger owners recognised that recharging provision contributed to objectives beyond financial measures, namely CSR, sustainable transport, carbon reduction and environmental objectives. However, few operated PIVs within their businesses, gaining only indirect social benefits of employee and public service provision rather than the direct cost and environmental benefits available through PIV use. A wide disparity in the expected timeframe for accelerated PIV adoption and recharging demand was evident, indicating the **need for further education regarding PIV benefits to encourage adoption by both business and personal users**, consistent with previous research (Krause *et al.*, 2013; Bühler *et al.*, 2014; Bailey *et al.*, 2015).

PIV drivers' environmental values were evident in their reported rationale for PIV adoption, their desire for green electricity and home PV adoption. Driver survey responses coupled with recharging data analysis indicated that **public recharging value lies in the combination of reliability, location, accessibility and availability** factors which together provide convenience for PIV drivers. However, drivers awarded the NECYC estate a very poor satisfaction score in 2019, confirming that poor reliability and availability affected their perception of public recharging value.

Therefore, identifying users who are likely to adopt PIV models and where they need the convenience of public recharging is critical to successful public recharging business models. Affluent personal consumers and taxi, private hire and local delivery drivers were identified as potential users of public recharging services. All **drivers without home charging capability and business drivers with unpredictable daily distances and routes were identified as key customer segments** using the iBUILD extended business model canvas terminology (Foxon *et al.*, 2015).

At the 2014 stakeholder workshop it was **proposed that alternative methods could be used to encourage PIV adoption based on the health, social and environmental consequences of consumers' transport choices**, but little progress is evident by 2020 in this regard. Financial incentives such as grants and penalties such as taxation were seen as the primary influencers at the time and remain the dominant policy instruments in 2020. Stakeholders identified interdependencies between transport and energy sectors likely to cause conflict between energy supply and drivers' desire for recharging flexibility. Furthermore, stakeholders advised that effective education and communication of PIV value in all its forms was necessary alongside reasonable recharging fees to encourage drivers to change their travel behaviour. Consequently, the stakeholders recommended defining and then accounting for all the environmental, social and economic benefits of public recharging in order to propose a holistic approach to recharging business models.

The iBUILD infrastructure value framework (iBUILD, 2018) was subsequently used in 2018 to identify the benefits of public recharging. Stakeholders defined the **desired outcomes of public recharging as: increasing PIV uptake to reduce air quality problems; and increasing convenient low-cost low-emission mobility choices.** A consensus emerged that major behavioural change in both travel and energy use was required to achieve these outcomes, so **vehicle users and areas with the highest emissions should be targeted first.** But stakeholders' priorities differed depending upon their roles and objectives. Local authority officers stressed the environmental and social benefits of public recharging provision to encourage low-carbon travel but commented on the limited public funds available and risks of social exclusion. Conversely, the grid operator (DNO) focussed on balancing demands on the energy system with more efficient energy use, and the recharging network operator (EMSP) sought to increase profitability.

The stakeholders identified many constraints to recharging solutions for drivers without the ability to recharge at home. The cost of recharging infrastructure deployment and operation coupled with low demand and resulting poor financial business case featured strongly in discussions. However, the risks of widespread land ownership and conflicting land use policies, changes in PIV battery technology and stakeholders' resistance to change were also mentioned. Enablers focussed on identifying locations where drivers wish to recharge, encouraging land use for recharging, using green energy and energy storage solutions with diverse recharging technologies. **Stakeholders therefore confirmed the importance of charger location, reliability and availability identified in the demand study**. In addition, stakeholders called for continuing public funding alongside political will, regulation, legislation and widespread education to increase both PIV supply and adoption, to generate demand for public recharging services. LAs were encouraged to concentrate on promoting the need for PIVs and the benefits of public recharging to residents, landowners, fleets and investors, whilst wider stakeholders could provide information for business modelling and investment decisions, access to land and commitments to using public recharging facilities.

Using the iBUILD framework to evaluate various public recharging solutions for drivers without the ability to recharge at home **identified social, environmental, health, cultural, aesthetic and political values in each solution**. The EVFS solution generated the most value responses, whereas the on-street fast recharging solution provided the least, instead focussing on the limitations of space and energy capacity, **so constraints must also be considered in the public recharging business model.** Economic value received the most responses which is unsurprising since financial considerations are the focus of business today, but cultural values came second and overlapped with social and environmental value reports indicating their importance in stakeholders' core beliefs. A **wide range of beneficiaries were identified** including the customers and suppliers of the financial business model: drivers; PIV manufacturers; and recharging suppliers. But beneficiaries also included government, local businesses and local communities benefitting from cleaner air, less noise and regeneration of areas. Most of the values identified will provide continuing benefit to stakeholders many years into the future.

The **complexity of the holistic system** was confirmed by stakeholders highlighting **interdependencies and conflicts** between sectors, businesses and government departments which cause barriers to long-term policy commitments. These findings suggest that **diverse stakeholders must work together using a whole-systems approach** to encourage the changes in travel behaviour needed to achieve the overarching emission reduction objectives, consistent with socio-technical transitions research (Farla *et al.*, 2012; Bakker, 2014; Avelino and Wittmayer, 2016; de Haan and Rotmans, 2018).

8.4 Limitations and Future Work

This thesis has identified that stakeholders recognise some non-financial value in public recharging infrastructure, however few NE charger owners targeted or reported on non-financial measures. Further research will be required to investigate how the non-financial values of public recharging may be captured and accounted for using a sustainable accounting approach. Both social accounting and integrated reporting approaches appear to offer possibilities, but a new study is required to investigate these options.

8.4.1 *Public versus home charging activity*

This study analyses only public recharging data but drivers reported that most recharging was performed at home, so public recharging demand depends upon the alternative recharging facilities available to PIV drivers. Therefore, **a study of complementary vehicle-side PIV recharging data is recommended in NE England to include recharging events in all locations**.

The NE region contains many mature PIV drivers, including those with and without home chargers, whose recharging behaviour has adapted over many years, providing a rich source of data. A subset of BEV drivers without home charging facilities could be targeted to focus on the behaviour of key customers for public recharging operators. Furthermore, PHEV drivers' recharging behaviour could be quantified to validate concerns about low battery use to support the government's recent vehicle incentive changes and future policy.

8.4.2 *Changing PIV and charger technology*

Further work is required to explore how recharging behaviour changes as PIV and charger technologies continue to improve. PIV models with higher capacity batteries are now coming to market which may increase the mileage of PIV drivers and change the frequency and energy characteristics of public recharging behaviour. For example, how will the recharging behaviour of drivers with increased range provided by 60kWh PIV batteries differ from that of early adopters with 24kWh PIV batteries? Consequently, **continued monitoring of public recharging energy by PIV model using the NECYC estate is recommended to update the business case.**

Furthermore, ultra-high power chargers up to 350kW are now coming to market. Although relatively few premium PIV models can currently use this ultra-high power service, this capability is likely to become popular in future PIV models. Studying the locations, use-cases, infrastructure costs and fees levied for ultra-high power changing and its impact on demand for existing fast and rapid public charging services will be necessary to inform future business cases.

8.4.3 *Effects of NE recharging fees*

The EH analysis demonstrated how introducing fees affects the use of a national rapid charging estate. The majority of LA owners of the NECYC estate are currently considering applying fees, so the EH lessons should assist in their decisions. **Continuing analysis of NECYC recharging data is recommended to monitor the effect of fees on utilisation and energy delivery,** to feed back into the business case and inform changes where necessary to achieve the LA owners' objectives.

The capital and operating costs provided were early-market prices up to 2015 and so should be treated with caution by potential investors since wider model choice and prices now exist. Therefore, **a review of current market recharging capital and operating costs would be beneficial** to ensure the business case contains up-to-date cost information.

Introducing fees will generate revenue to improve the reliability and availability of the NECYC estate in response to users' concerns, however users' WTP was found to be limited. Therefore, **a review of users' satisfaction** is recommended at least one year after fees are applied, focussing on price, reliability and availability.

Studying the disparity between fees levied by place, charger and user types and their relative impact on public charger utilization will also be an important input to the ongoing development of viable financial business models. Additionally, a detailed fee study could inform the emerging discussion about the just transition to zero-emission transport, which considers the varying needs of, accessibility for and impact upon all levels of society.

8.4.4 *Public charger availability*

Average recharging duration on NECYC fast and slow chargers exceeded the active energy delivery duration, limiting the availability of the NECYC estate. This disparity should be monitored once fees are introduced and if it does not reduce then owners should consider levying fees by duration rather than by energy delivered. **Both duration and utilisation should be studied over the next year in locations where**

the free parking incentive has been removed to establish whether this is an effective policy measure for increasing availability. If maximum duration rules and penalties are introduced to increase availability, then costs of and revenue from enforcement must also be added to the recharging business case.

8.4.5 *Public charger location*

Whilst this thesis has identified PIV drivers' current preferences for public charger locations, their preferences may change as PIV and charger technology improves and PIV use and recharging behaviour develops with experience. Furthermore, as PIV adoption moves into the early and late majority stages of the Diffusion of Innovations cycle, mass user preferences may differ from that of the innovators and early adopters studied here. Therefore, **engagement with majority PIV drivers is recommended** to ensure that future public charger deployment meets their needs.

This thesis also recommends that LAs focus on public charger provision in areas where the largest emission reductions can be made by encouraging e-mobility. Consequently, **local emissions data is required** to inform where new chargers are required, existing chargers may need to be moved or replaced in the future as those needs change.

8.4.6 *NE PIV adoption*

Increasing PIV model choice and capabilities and reducing prices could increase vehicle adoption rates above the forecasts produced in this thesis, so **a continuing review of PIV adoption figures is required** to inform the public recharging business model.

Furthermore, **a subsequent review of non-PIV drivers' attitudes to PIV** conversion would be useful in two years' time to investigate whether the combined incentives and awareness measures, vehicle availability and public recharging increases lead to increasing intention to adopt PIVs.

The continuing study of PIV adoption in NE England is recommended to assess whether the region's chosen policies succeed in accelerating the socio-technical transition to e-mobility. Furthermore, parallel studies of local area emissions are recommended to investigate whether PIV adoption succeeds in reducing emissions in the priority areas.

8.5 Closing Statement

This thesis presents a qualitative study of recharging stakeholders and their assessment of the value of public recharging services, complemented and coloured by a longitudinal quantitative study of PIV adoption in NE England and the recharging behaviour of those drivers. Together this information is used to investigate the public recharging infrastructure business model and the challenges it faces for increasing provision in the uncertain early stage of the socio-technical transition to e-mobility, with the ultimate aim of reducing transport emissions.

The unique longitudinal analysis of nine years' PIV adoption and public recharging data presented specific to the NE region can be used by local policy-makers to inform future local sustainable transport plans and emission reduction policies. The findings of this thesis indicate the importance of place-based recharging solutions, but no correlation was found between public charger provision and PIV adoption. However, identifying the areas and users where most emissions reduction can be achieved is necessary both for effective policy decisions and recharging investment.

Whilst point estimate forecasting models were found to be inadequate for business planning in the uncertain and evolving recharging market, the RCN model enabled comparisons to be made between different fee structures. Setting fees by duration is likely to provide quicker financial return for charger operators and maintain availability, however drivers prefer to pay by energy received. Focussing on BEV drivers with long or unpredictable daily journeys and those without alternative recharging solutions at home or work are the recommended strategies for investors. Recharging estates which retain control over key performance indicators such as maintenance are more likely to achieve customer satisfaction and be able to respond to changes in demand and profitability.

The immediate value of public recharging infrastructure for PIV drivers lies in the combination of reliability, location, availability and accessibility factors, which together provide convenience at a reasonable price. However, both drivers and charger owners recognise environmental and social value in addition to financial opportunities for recharging provision, but this is not currently represented in business plans or reports. Further research is required to investigate how non-economic values can be captured and reported using sustainable accounting techniques for public recharging providers.

The skills developed and knowledge gained during this research have informed practice and are being used in ZCF's work to help towns and cities across the UK to adapt to the challenges presented by the transition to e-mobility and to develop suitable recharging strategies. The research has also informed and influenced UK government through workshops and advice to OLEV, which is reflected in their evolution of policy and changes in research priorities. Hopefully, this research will enable PIV adoption to grow across the UK, reducing transport emissions and improving the environments we live in today, whilst protecting them for future generations to come.

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Appendix A. RCN project Initial Questionnaire

Questionnaire for Rapid Charge Network (RCN) Project

* 1. Are you a participant of the Rapid Charge Network project trial?

- Yes
- No

Questionnaire for Rapid Charge Network (RCN) Project

Personal Information and your Electric Vehicle (EV)

* 2. Your name

3. Gender

- Male
- Female

4. Age group

17-20	41-45	66-70
21-25	46-50	71-75
26-30	51-55	76-80
31-35	56-60	81-90
36-40	61-65	90+

5. Postcode

Home address

Work address

1

6. Household numbers (include yourself)

Over 17 years old ____________________

Under 17 years old ____________________

Holding a full driving licence ____________________

7. Please indicate which of the following statements describe your situation. Please tick one only.

- ○ I have bought my EV.
- ○ I am leasing my EV.
- ○ It is a company owned EV but I am the only user.
- ○ It is a company owned EV and I share it with my colleagues.
- ○ Other, please specify your reason:

____

8. When buying the EV did you consider other types of vehicles? Please tick all that apply.

- ☐ BEV
- ☐ PHEV
- ☐ Petrol
- ☐ Diesel
- ☐ CNG/LPG
- ☐ Hybrid (Petro or Diesel)
- ☐ None of the above
- ☐ Other, please specify:

____

9. Please select three most important factors from the following options that have influenced your purchase, where 1 is the most important factor.

	1	2	3
Long term cost savings	○	○	○
I was curious about innovative vehicle technologies	○	○	○
I would like to contribute to environmental and climate protection	○	○	○
Because I enjoying driving an electric vehicle	○	○	○
Appealing design	○	○	○
To maintain an eco-friendly image	○	○	○
Participation in a research project	○	○	○
Financial incentives, e.g. allowance, free parking, etc.	○	○	○
Don't know	○	○	○
Rather not say	○	○	○
Other	○	○	○

Please specify

10. How often do you use the EV for trips of various distances?

	Daily	3-6 days a week	1-2 days a week	1-3 days a month	3-11 days a year	1-2 days a year
within 5 miles (8 Km)	◯	◯	◯	◯	◯	◯
6 - 25 miles (9 - 40 Km)	◯	◯	◯	◯	◯	◯
26 - 40 miles (41 - 64 Km)	◯	◯	◯	◯	◯	◯
over 40 miles (64 Km)	◯	◯	◯	◯	◯	◯

11. Please specify how many miles you drive approximately between charges.

12. What was the distance (miles) of the longest trip you have made with the EV so far?

13. Is the EV your primary car?

◯ Yes

◯ No

14. How often does the range of your EV affect the type of trips you would like to make?

All the time	Often	Sometime	Occasionally	Never
◯	◯	◯	◯	◯

15. What is the percentage of car trips that you cannot make with your EV? Please specify.

16. What were the reasons that you could not make those trips with your EV? Please tick all that apply.

- [ ] Limited driving range of the EV
- [ ] Limited seating capacity of the EV
- [ ] The EV is not suitable for motorways
- [ ] The EV does not have enough room for luggage
- [ ] Bad weather
- [ ] Other, please specify your reason

17. How did you choose to carry out those trips instead? Please tick all that apply.

- [ ] Aeroplane
- [ ] Train
- [ ] Other car in the household
- [ ] Rental car
- [ ] Cancelled the trip
- [ ] Other, please specify:

18. How satisfied are you with the average driving range of your EV between recharging?

Very satisfied	Quite satisfied	Neutral	Not quite satisfied	Not satisfied at all
○	○	○	○	○

19. Did the EV replace another vehicle in the household?

- ○ It replaces a petrol car (under 5 years old)
- ○ It replaces a petrol car (over 5 years old)
- ○ It replaces a diesel car (under 5 years old)
- ○ It replaces a diesel car (over 5 years old)
- ○ It is an additional vehicle
- ○ The EV was my first car

Questionnaire for Rapid Charge Network (RCN) Project

20. If the EV replaced another vehicle, please specify its characteristics.

Make

Model

Engine Size

Fuel

Year

21. How many miles did you drive in a typical year with the vehicle replaced by the EV?

- 0-2,000
- 2,001-5,000
- 5,000-8,000
- 8,001-10,000
- 10,001+

22. How much have you saved in fuel costs on a monthly basis since you got the EV?

23. Are you more pleased with the EV than the previous vehicle?

- Yes I am more pleased
- Same
- I regret buying the EV
- Other, please specify:

Questionnaire for Rapid Charge Network (RCN) Project

USE OF Rapid Charge Points

Rapid Charge Points (RCPs) can recharge your car in about 30 min from 0% to 80% state of charge using either the CHAdeMO or Combined Charging System CCS 44 kW DC protocols or 43 kW AC protocol

24. How often do you charge your EV at the following locations?

	All the time	Often	Sometime	Occasionally	Never
Home					
Workplace					
Public car parks					
Private charging points (hotels, shops, restaurants, etc.)					
Other					

Please specify where:

25. Please indicate your agreement with the following statements regarding the role of Rapid Charge Points.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
I will not buy or lease the EV if there are no Rapid Charge Points	○	○	○	○	○
I cannot complete my journeys without them	○	○	○	○	○
They are more convenient than charging elsewhere	○	○	○	○	○
They are where I need them to be	○	○	○	○	○
Other	○	○	○	○	○

Please specify your "other" reason

26. If you DON'T use Rapid Charge Points, please indicate your agreement with the following statements.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
I hate to wait	○	○	○	○	○
I don't have time to wait	○	○	○	○	○
I always charge the car at home	○	○	○	○	○
I always charge my car at workplace.	○	○	○	○	○
they aren't where I need them to be	○	○	○	○	○
other	○	○	○	○	○

Please specify your "other" reason

27. If you have used a Rapid Charge Points before, what was your main motivation for using it ?

- Fast
- Free
- Available
- Curious about it
- Free parking
- Need to make a longer journey
- Other, please specify

28. Does the availability of Rapid Charge Points make you travel further with the EV?

- Yes I have / will travel further with an EV
- No I have not made longer trips with the EV
- No it will not affect how far I travel with the EV as I use a different vehicle for longer journeys.
- I do not need to travel any further
- Other, please specify

29. Does the availability of Rapid Charge Points make you travel more often with the EV?

- Yes it has made me using the EV more often
- Yes I will use the EV more often if needed
- No I have not used the EV more often
- No it will not affect how often I use the EV
- Other, please specify

30. Please indicate how often you have found that the Rapid Charge Points was not available for the following reasons

	Very often	Often	Approximately half of time	Occasionally	Never
Another EV was using the Rapid Charge Points	○	○	○	○	○
An EV finished charging but was still occupying the parking bay	○	○	○	○	○
A non-EV was occupying the parking bay	○	○	○	○	○
The Rapid Charge Points was broken.	○	○	○	○	○
Other	○	○	○	○	○

Please specify your "other" reason:

31. What do you normally do when you plug your car into the Rapid Charge Points?

- ☐ Go shopping
- ☐ Go for a drink/snack
- ☐ Other nearby facilities, e.g. Gym
- ☐ Go for a walk
- ☐ Sit in/by my car waiting for it to finish
- ☐ Other, please specify

32. How long do you normally leave your EV on the Rapid Charge Points?

- ○ I have to leave the EV on the Rapid Charge Points as long as the shopping/snack/activity takes
- ○ 31-60 minutes
- ○ 16-30 minutes
- ○ Within 15 minutes
- ○ As soon as the charging finishes
- ○ Other, please specify

33. Does the availability of Rapid Charge Points increase the likelihood of you choosing an EV as your next car?

- ◯ Definitely yes
- ◯ Probably yes
- ◯ Not sure at the moment
- ◯ Probably not
- ◯ It will not affect my choice of the next car
- ◯ Other, please specify

34. What are the top three factors you would use to recommend to your family/friends that they buy an EV?

	1	2	3
Financial incentives	◯	◯	◯
Environmental friendliness	◯	◯	◯
Easy to drive	◯	◯	◯
Availability of Rapid Charge Points	◯	◯	◯
Trying new Technology	◯	◯	◯
Being an early adopter	◯	◯	◯
Setting an example for others	◯	◯	◯
Appearance of the vehicle	◯	◯	◯
Other	◯	◯	◯

Please specify your "other" factor:

35. If you have any other comments on your experience of the EV and the charging infrastructure, we would like to know. Please write them down in the space below.

Appendix B. RCN project Business Case Questionnaire

* 1. Are you a participant of the Rapid Charge Network project trial?

- Yes
- No

* 2. Your Name

3. How often do you use the EV for the following purposes?

	Very often	Often	Approximately half of time	Occasionally	Never
Commuting					
Business					
Education (including driving someone else)					
Shopping					
Driving someone else					
Visiting friends					
Leisure					
Other					

Please specify your other purpose:

4. Where have you used rapid charge points?

	Yes definitely	That's a good idea	Not necessary
Airports	○	○	○
Rail stations	○	○	○
Bus stations	○	○	○
Park&Ride	○	○	○
Supermarket	○	○	○
My local area	○	○	○
Hotels	○	○	○
Shopping malls	○	○	○
Restaurants	○	○	○
Motorway service stations	○	○	○
Petrol stations	○	○	○
Other	○	○	○

Please specify:

5. Which rapid charge point have you used most so far? Please specify (e.g. name of location or address)

6. Why have you used that rapid charge point so often? Please tick all that apply.

○ It is close to where I live.

○ It is close to where I work.

○ It is on my way to work/home.

○ It is always available.

○ Other, Please specify:

7. What is your approximate average annual household income?

- Less than £15,000
- £15,001 - £26,000
- £26,001 - £35,000
- £35,001 - £50,000
- £50,001 - £70,000
- £70,001 +
- I prefer do not reply

8. In a typical year how much do you approximately spend on the following means of transport for personal use?

Aeroplane	
Train	
Bus	
Other car in the household	
Rental car	
Taxi	
Other, please specify:	

9. In a typical year how much do you approximately spend on the following means of transport for business purpose?

Aeroplane	
Train	
Bus	
Other car in the household	
Rental car	
Taxi	
Other, please specify:	

10. Do you know roughly how much it costs to recharge your EV from low to full at home? (please specify)

- ◯ Yes it costs me £ (please specify below)
- ◯ I guess it costs me £ (please specify below)
- ◯ No idea but I would like to know
- ◯ No idea and I do not care

Please specify the cost:

[ ]

11. How satisfied are you with the cost?

- ◯ I'm surprised by how cheap it is to recharge the car from empty to full.
- ◯ I'm happy with the cost.
- ◯ That's about right.
- ◯ I'm surprised by how expensive it is to recharge the car from empty to full.

12. Rapid charge points are free to use currently. Is this a service you are prepared to pay for in the future?

- ◯ Yes. I would pay to use Rapid Charge Network.
- ◯ Yes. Only if I have no alternative.
- ◯ No, I would charge at home
- ◯ No, I would charge at work
- ◯ No, I would look for a free charge point
- ◯ No, I would switch back to a conventional vehicle
- ◯ Other, please specify:

[ ]

13. If you would need to pay for using the rapid charge points, how would you like to be charged?

- ◯ Pay per charge and based on the time occupying the charging bay
- ◯ Pay per charge based on the energy used kWh
- ◯ Fixed fee per charge regardless of time or energy used
- ◯ Pay a set fee per month
- ◯ Pay a set fee per year
- ◯ Other, please specify:

[ ]

14. For each of the following rates (per minute) please indicate your willingness to pay:

	Yes	Likely	About 50:50	Unlikely	Certainly not
£0.10 per minute (i.e. £2.00 for 20 mins)					
£0.15 per minute (i.e. £3.00 for 20 mins)					
£0.20 per minute (i.e. £4.00 for 20 mins)					
£0.25 per minute (i.e. £5.00 for 20 mins)					
£0.30 per minute (i.e. £6.00 for 20 mins)					
£0.35 per minute (i.e. £7.00 for 20 mins)					

15. For each of the following rates (per kWh) please indicate your willingness to pay:

	Yes	Likely	About 50:50	Unlikely	Certainly not
£0.16 per kWh					
£0.31 per kWh					
£0.40 per kWh					
£0.47 per kWh					
£0.55 per kWh					

16. For each of the following rates (per charge) please indicate your willingness to pay:

	Yes	Likely	About 50:50	Unlikely	Certainly not
£2.00 per charge					
£3.00 per charge					
£4.00 per charge					
£5.00 per charge					
£6.00 per charge					
£7.00 per charge					

17. For each of the following rates (per year) please indicate your willingness to pay:

	Yes	Likely	About 50:50	Unlikely	Certainly not
£100	○	○	○	○	○
£150	○	○	○	○	○
£200	○	○	○	○	○
£250	○	○	○	○	○
£300	○	○	○	○	○
£350	○	○	○	○	○
£400	○	○	○	○	○

18. For each of the following monthly packages we have provided you with three tariffs, please indicate your willingness to pay:

	Tariff 1	Tariff 2	Tariff 3	Not my choice
Low usage (up to 4 charges or 80 kWh of energy), Tariff 1: **£10**, Tariff 2: **£15**, Tariff 3: **£20**	○	○	○	○
Medium usage (up to 10 charges or 190kWh of energy), Tariff 1: £ **25**, Tariff 2: £ **35**, Tariff 3: **£45**	○	○	○	○
Unlimited usage, Tariff 1: **£50**, Tariff 2: £ **75**, Tariff 3: £ **100**	○	○	○	○

19. If a fee was introduced along these lines, how would your use of the rapid charge points be affected?

- ○ I will continue to use the rapid charge points as I do now.
- ○ I will find an alternative way to charge for 75% of the time
- ○ I will find an alternative way to charge for 50% of the time
- ○ I will find an alternative way to charge for 25% of the time
- ○ I will stop using them.
- ○ Other, please specify:

20. Do you think you would drive more economically if you have to pay for charging your EV, because the driving range could be increased if you drive economically or decreased if you drive erratically?

- Yes.
- Maybe.
- No because I always drive economically.
- No I don't care about the charge.
- Other, please specify:

21. Where would you like to see rapid charge points being installed?

	Yes definitely	That's a good idea	Not necessary
Airports			
Rail stations			
Bus stations			
Park&Ride			
Supermarket			
My local area			
Hotels			
Shopping malls			
Restaurants			
More motorway service stations			
Petrol stations			
Other			

Please specify:

22. How often have you used the following facilities at the rapid charge points?

	Very often	Often	Approximately half of time	Occasionally	Never
Wi-fi	◯	◯	◯	◯	◯
Shops	◯	◯	◯	◯	◯
Cafe	◯	◯	◯	◯	◯
Toilet	◯	◯	◯	◯	◯
Shelter	◯	◯	◯	◯	◯
Cash machine	◯	◯	◯	◯	◯
Other	◯	◯	◯	◯	◯

Please specify the other facility:

23. How much do you spend on average when using those facilities? (Please specify the cost unit)

24. Would you be willing to pay a fee to reserve a rapid charge point?

- ◯ Yes
- ◯ Likely
- ◯ Approximately half of time
- ◯ Unlikely
- ◯ Certainly not

25. Would the benefits of being able to reserve a spot outweigh the inconvenience of reaching a charge point to find that it was reserved for someone else?

- ◯ Yes
- ◯ No
- ◯ Don't know
- ◯ Other, please specify

26. If there are more rapid charge points, will you use the EV differently?

	Yes	Likely	About 50:50	Unlikely	Certainly not
I will use the EV more often.	◯	◯	◯	◯	◯
I will make longer distance journeys.	◯	◯	◯	◯	◯
Other, please specify:	◯	◯	◯	◯	◯

Please specify:

* 27. Have you taken part in the previous Rapid Charge Network survey? (see the image on the right of your screen)

- ◯ Yes and I have given my name.
- ◯ Yes but I did not give my name.
- ◯ No I have not taken part in the previous survey.
- ◯ I am not sure.

28. Gender

- ◯ Male
- ◯ Female

29. Age group

◯ 17-20	◯ 41-45	◯ 66-70
◯ 21-25	◯ 46-50	◯ 71-75
◯ 26-30	◯ 51-55	◯ 76-80
◯ 31-35	◯ 56-60	◯ 81-90
◯ 36-40	◯ 61-65	◯ 90+

30. Postcode

Home address

Work address

31. Household numbers (include yourself)

Over 17 years old

Under 17 years old

Holding a full driving licence

32. Please indicate which of the following statements describe your situation. Please tick one only.

- I have bought my EV.
- I am leasing my EV.
- It is a company owned EV but I am the only user.
- It is a company owned EV and I share it with my colleagues.
- Other, please specify your reason:

* 33. Would you like to take part in our following two mini surveys?

- Yes, I would like to take part in the following mini survey
- No, I do not want to take part in the following mini survey

* 34. Please leave us <u>your name</u> (the only reason that we ask for this is to make sure that we can link your responses to the following one to avoid duplicating some of the questions. All responses will be stored anonymously and securely)

35. If you have any other comments on your experience of the EV and the charging infrastructure, we would like to know. Please write them down in the space below.

Appendix C. RCN project Final Questionnaire

Use of rapid charge points

1. Have you used the rapid charge points more often than previously during the last 3 months ?

- ◯ Yes
- ◯ Same
- ◯ No

2. On average, on how many days a month do you use a rapid charger?

[ ]

3. What is your main motivation for using the rapid chargers?

- ◯ primary means of charging my EV
- ◯ to extend the range for a long journey
- ◯ because I was in the region already
- ◯ curiosity / to try out a fast charger for myself
- ◯ to have access to free parking
- ◯ to have access to free energy
- ◯ other

Please specify other

[ ]

4. Are you making journeys now that you were not able to make one year ago because of the availability of rapid charge points?

- ◯ Yes
- ◯ Same
- ◯ No

5. Has the availability of Rapid Charge Points helped you travel further with an EV within the last 12 months?

- ◯ Yes I have travelled further with an EV
- ◯ Yes I will travel further with an EV
- ◯ No I have not made longer trips with an EV
- ◯ No it will not affect how far I travel with an EV as I use a different vehicle for longer journeys.
- ◯ I do not need to travel any further

6. Has the availability of Rapid Charge Points helped you travel more often with an EV within the last 12 months?

- ◯ Yes it has made me use an EV more often
- ◯ Yes I will use an EV more often if needed
- ◯ No I have not used tan EV more often
- ◯ No it has not affected how often I use an EV

7. Approximately what percentage of your regular trips require you to use a rapid charge point?

[ ]

8. Are you regularly making longer (above 50 miles) journeys that require a rapid charge point?

- ◯ Yes
- ◯ Same
- ◯ No

9. How many times in a month are you making these longer journeys?

[ ]

10. What is the longest trip in your EV that you've undertaken that involved using a rapid charger?

[ ]

11. For which purpose are you making these longer journeys?

- ☐ Commuting
- ☐ Business
- ☐ Education (including driving someone else)
- ☐ Shopping
- ☐ Driving someone else
- ☐ Visiting friends
- ☐ Leisure
- ☐ Other, please specify:

[ ]

12. Have you done / are you planning to do a trip with your EV in the following locations?

- [ ] Between the UK and Ireland
- [ ] To mainland Europe
- [ ] None of the above

Please specify:

13. In the previous survey 64% of the responded stated that they sit in/by their car waiting or go for a walk when they plug their car into the rapid charge point. If this was you, why do you do these rather than other activities?

- [ ] It gives me time to do some work
- [ ] There are no facilities available
- [ ] I am not interested in the facilities available
- [ ] I prefer not to spend money
- [ ] Other (please specify)

14. If you have arrived at a rapid charge point that has been out of service, what did you do? (Please, tick all applicable options)

- [ ] I called the hotline to report the fault
- [ ] I tried to repair the problem myself
- [ ] I reported the problem to the charging post host
- [ ] I used the nearest available regular charging post
- [ ] I try once or twice and then I go to the nearest available rapid charger
- [ ] Other please specify
- [ ] Not applicable

Other, please specify

15. What would you do if you found the rapid charger you wanted to use was occupied by another vehicle?

- I would not wait
- I'd wait up to 15 minutes
- I'd wait up to 30 minutes
- I'd wait longer than 30 minutes
- Other, please specify

16. How many miles (kilometres) did you approximately drive in a typical year with your previous vehicle which was replaced by the EV? (Please specify the unit)

17. How many miles (kilometres) have you approximately driven in the last year with your EV? (Please specify the unit)

18. Approximately what percentage of your overall driving (including EV and non EV) is:

Urban

Rural

Intercity

Other, please specify:

19. What is on average your total daily driving distance? (please specify the unit)

With your EV

With another conventional vehicle in the household

20. Do you have access to a charger in the following locations?

	Yes	No	I don't know
Home			
Other private locations			
Workplace			
Public car parks			
Rapid charge points			

21. How often do you charge your EV at the following locations?

	Daily	Several times a week	Once a week	Few times a month	Once a month	Few times a year	Never
Home	○	○	○	○	○	○	○
Other private locations	○	○	○	○	○	○	○
Workplace	○	○	○	○	○	○	○
Public	○	○	○	○	○	○	○
Rapid charge points	○	○	○	○	○	○	○

22. What percentage of energy do you charge in the following locations?

Home	
Other private locations	
Workplace	
Public car parks	
Rapid charge points	

23. Which state of charge has the battery of your EV usually when you start charging it?

	under 20%	between 20 and 50%	above than 50%	Varying state of charge	Don't know
Home	○	○	○	○	○
Other private locations	○	○	○	○	○
Workplace	○	○	○	○	○
Public car parks	○	○	○	○	○
Rapid charge points	○	○	○	○	○

24. Are you the only driver of the EV?

○ Yes

○ No

25. If you are not the only driver, please specify the percentage of usage of the EV for each household member (0= no user)

Me	
My partner	
My children	
Other people in the household	
People I work with	

26. In the previous survey, the majority of the drivers stated that they are more pleased with the EV than their previous vehicle. If it was you, what is the reason?

- Fuel saving
- Because I enjoying driving an electric vehicle
- Free parking
- I would like to contribute to environmental and climate protection
- I am not more pleased with the EV than the previous vehicle
- Other (please specify)

27. How important are the following factors for the mass uptake of EV?

	Not at all important	Important	Very important	No opinion
Availability of rapid charge points				
Availability of 3-7 kW charge points				
EV price				
Range of the vehicle				
Other, Please specify				

Other (please specify)

28. Would you use the following services?

	Yes, definitely	Yes, probably	Probably not	Definitely not	No idea
Real time charge point availability data	○	○	○	○	○
Reservation of charge point	○	○	○	○	○
Contactless payment	○	○	○	○	○
Other	○	○	○	○	○

Please specify:

Your views on energy

29. Do you have any renewable energy source installed at home? (e.g. photovoltaic panels)

- ○ Yes
- ○ No

Please specify:

30. How important is it for you that your charge comes from green energy?

- ○ Not at all important
- ○ Important
- ○ Very Important
- ○ No opinion

31. Would you be willing to pay extra to charge with green energy?

- ○ Yes
- ○ No
- ○ Not sure

32. Information on your current EV

Make

Model

Year

* 33. Have you taken part in the previous Rapid Charge Network surveys?

- ◯ Yes and I have given my name.
- ◯ Yes but I did not give my name.
- ◯ No, I have not taken part in the previous surveys.
- ◯ I am not sure.

Personal Information

34. Gender

- ◯ Male
- ◯ Female

35. Age group

◯ 17-20	◯ 41-45	◯ 66-70
◯ 21-25	◯ 46-50	◯ 71-75
◯ 26-30	◯ 51-55	◯ 76-80
◯ 31-35	◯ 56-60	◯ 81-90
◯ 36-40	◯ 61-65	◯ 90+

36. Postcode

Home address	
Work address	

37. Household numbers (include yourself)

Over 17 years old	
Under 17 years old	
Holding a full driving licence	

38. Please indicate which of the following statements describe your situation. Please tick one only.

- ◯ I have bought my EV.
- ◯ I am leasing my EV.
- ◯ It is a company owned EV but I am the only user.
- ◯ It is a company owned EV and I share it with my colleagues.
- ◯ Other, please specify your reason:

39. Did the EV replace another vehicle in the household?

- ◯ It replaces a petrol car (under 5 years old)
- ◯ It replaces a petrol car (over 5 years old)
- ◯ It replaces a diesel car (under 5 years old)
- ◯ It replaces a diesel car (over 5 years old)
- ◯ It is an additional vehicle
- ◯ The EV was my first car

40. If the EV replaced another vehicle, please specify its characteristics.

Make	
Model	
Engine Size	
Fuel	
Year	

41. Your Name

Thank you for participating in the study. We really appreciate your time and effort.

Appendix D. NE PIV Drivers' Questionnaire 2016

Newcastle University

EV and Plug-in Hybrid Drivers Attitudes to recharging

Welcome to my Drivers survey 2016

Following on from my involvement in the UK's Plugged in Places (PIP) and Rapid Charge Network (RCN) recharging projects, I am conducting part-time PhD research at Newcastle University **looking into business models to justify the ongoing provision of charge points in Public places for EV and Plug-in hybrid vehicles.**

Please answer these questions **even if you no longer own or have use of an EV / Plug-in hybrid vehicle,** since all experience and opinions are valuable to this research. Your responses will help me to:

- **identify the impact** that public charge point provision has had on you as a Driver, and
- **understand your preferences for recharging** in the future.

All the information you give will be held anonymously and securely. Access to your data is limited to the people involved in this research and any data published will not be identifiable as yours. You can chose to omit any questions you do not wish to answer, and you may chose to withdraw from the study at any time and for any reason.

Thank you very much for participating in this survey. Your feedback is very important and I do greatly appreciate your time and effort in answering these questions.

* Please tick this box to indicate that you have agreed to take part in this survey

◯ I agree

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Newcastle University

EV and Plug-in Hybrid Drivers Attitudes to recharging

SECTION A: About Your recharging behaviour

I would like to start by asking a few questions about how you usually do (or did) recharge your EV / Plug-in hybrid vehicle. Please answer questions A1 - A10 considering this recharging behaviour.

A1. Where do / did you recharge your vehicle ? Please select the appropriate frequency for each type of location shown

	Often	Sometimes	Seldom	Never
At Home	◯	◯	◯	◯
At Work	◯	◯	◯	◯
In Public places (eg. on streets, in car parks, at facilities where you don't work, motorway services, fuel stations etc)	◯	◯	◯	◯

For the purposes of this research, **any charge point OTHER THAN those at a home or workplace is called a PUBLIC charge point.** With that in mind, please answer questions A2 to A10.

A2. How important are / were the following factors to your use of Public charge points ?

	Very Important	Moderately Important	Not important
The Location of the charge point	◯	◯	◯
Speed of recharging	◯	◯	◯
Ease of use eg. access methods, instructions, controls on the charge point	◯	◯	◯
Reliability - the charge point is working when you want to use it	◯	◯	◯
Availability - no queue when you want to use it	◯	◯	◯
Cost	◯	◯	◯

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A3. How long do / did you usually park whilst charging your EV in Public places ?

	Often	Sometimes	Seldom	Never
Less than 30 minutes	◯	◯	◯	◯
Up to 1 hour	◯	◯	◯	◯
Up to 4 hours	◯	◯	◯	◯
Over 4 hours	◯	◯	◯	◯

A4. How frequently do / did you use Public charge points in the following types of location? (Please tick ALL that apply)

	Often	Sometimes	Seldom	Never
On City centre streets	◯	◯	◯	◯
On Residential streets	◯	◯	◯	◯
In short stay carparks	◯	◯	◯	◯
In long stay carparks	◯	◯	◯	◯
At Service Areas INSIDE towns/cities (eg. petrol/diesel l filling stations, supermarkets etc)	◯	◯	◯	◯
At Service Areas BETWEEN towns/cities (eg. motorway service stations)	◯	◯	◯	◯
At Transport Interchanges eg.park & ride sites, metro/underground, railway stations, airports, ports	◯	◯	◯	◯

Other (please describe)

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A5. How often have you had to queue to use a Public charge point ?

- ◯ Often
- ◯ Sometimes
- ◯ Seldom
- ◯ Never

A6. How often have you found that a Public charge point you wanted to use was not working ?

- ◯ Often
- ◯ Sometimes
- ◯ Seldom
- ◯ Never

A7. Have the following requirements ever prevented you from using a Public charge point ? (Please tick ALL that apply)

- ☐ A physical barrier to the site
- ☐ Need for an RFID card/tag
- ☐ Need for a Smart Phone App
- ☐ Need for a parking permit
- ☐ Need to pay to park

Other (please describe)

A8. Have you ever paid to use a Public charge point ?

- ◯ Yes
- ◯ No

A9. Have you ever received a fine whilst using a Public charge point ?

- [ ] No never
- [ ] Yes,because I overstayed my maximum time
- [ ] Yes, because my vehicle wasn't plugged in
- [ ] Yes, because the charge point wasn't working
- [ ] Yes, because I didn't know I needed to pay for parking

Other (please specify)

A10. How often do / did you use the following additional services whilst charging your vehicle at Public charge points ?

	Often	Sometimes	Seldom	Never
Wifi	○	○	○	○
Toilets	○	○	○	○
Shelter	○	○	○	○
Vending machines	○	○	○	○
Shops	○	○	○	○
Cafes/restaurants	○	○	○	○

Other (please specify)

Newcastle University

EV and Plug-in Hybrid Drivers Attitudes to recharging

SECTION B: About your recharging preferences

Questions B1 to B11 ask how you would LIKE to be able to recharge your EV/Plug-in hybrid IN AN IDEAL WORLD.
Please answer these questions to indicate your preferences, which may not necessarily be the same as your current recharging behaviour.
Please do not feel constrained by the current charging equipment you have access to.

B1. Where would you PREFER to charge your vehicle ? Please rank the following where 1 = Most preferred, 3 = least preferred.

- Near home
- Near destination
- In between home and destination

B2. How long do you PREFER to recharge your vehicle for ? Please rank the following where 1 = Most preferred, 4 = least preferred.

- < 30 minutes
- Up to 1 hour
- Up to 4 hours
- More than 4 hours

B3. Please rank your PREFERENCE for public charge point LOCATIONS, where 1 = most preferred, 8 = least preferred.

- On City centre streets
- On Residential streets
- In Public car parks
- At Petrol/diesel filling stations
- At Supermarkets, shopping centres
- At Leisure facilities
- At Motorway service areas
- At Transport interchanges (eg. Park & ride sites, metro/underground, railway stations, airports, ports)

B4. On what DAYS of the week would you LIKE to use Public charge points ?

	Often	Sometimes	Seldom	Never
Monday	○	○	○	○
Tuesday	○	○	○	○
Wednesday	○	○	○	○
Thursday	○	○	○	○
Friday	○	○	○	○
Saturday	○	○	○	○
Sunday	○	○	○	○

B5. At what times of day would you LIKE to use Public charge points on WEEKDAYS (Monday to Friday) ?

	Often	Sometimes	Seldom	Never
Overnight (Midnight 12am to 6am)	○	○	○	○
Morning (6am to 12pm Noon)	○	○	○	○
Afternoon (Noon 12pm to 6pm)	○	○	○	○
Evening (6pm to Midnight)	○	○	○	○

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B6. At what times of day would you LIKE to use Public charge points at the WEEKEND (Saturday and Sunday) ?

	Often	Sometimes	Seldom	Never
Overnight (Midnight 12am to 6am)	◯	◯	◯	◯
Morning (6am to 12pm Noon)	◯	◯	◯	◯
Afternoon (Noon 12pm to 6pm)	◯	◯	◯	◯
Evening (6pm to Midnight)	◯	◯	◯	◯

B7. Would you LIKE to be able to reserve a Public charge point?

◯ Yes

◯ No

◯ Maybe

B8. Please RANK the following methods for accessing/using PUBLIC charge points in your order of PREFERENCE, where 1 = most preferred method, 5 = least preferred.

- [ ] RFID card/tag
- [ ] Smart phone App
- [ ] By phone/text
- [ ] By bank card
- [ ] Another method (please describe below)

If you have Another method to suggest for accessing Public charge points please describe it here.

B9. How would you class your PREFERRED amount of use of Public charge points ?

◯ Low use (Up to 50 kWh per month)

◯ Medium use (Between 51 kWh to 150 kWh per month)

◯ High Use (Above 151 kWh per month)

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B10. How important would the following incentives be to your use of Public charge points ?

	Very Important	Moderately Important	Not Important
Free to park AND to charge my vehicle	◯	◯	◯
Free to charge my vehicle (but I WILL pay for parking)	◯	◯	◯
Free parking in public parking bays (irrespective of whether you are charging or not)	◯	◯	◯
Use of bus/no car lanes (speeds up travel to PUBLIC charge points)	◯	◯	◯
Exemption from congestion/toll charges (reduces cost of travel to PUBLIC charge points)	◯	◯	◯

B11. Are there any other incentives which would make you use Public charge points more often?

◯ No

◯ Yes (please describe below)

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Newcastle University

EV and Plug-in Hybrid Drivers Attitudes to recharging

SECTION C: About your willingness to pay to use Public charge points

Questions C1 to C14 ask you some more specific questionsabout whether you would pay to use Public charge points.
Payments would help to cover the costs of charge point provision (installation, operation and maintenance), which may encourage further investment and lead to more Public charge points being provided in the future.

C1. What types of Public charge point would you be willing to pay to use (please tick ALL that apply) ?

- ☐ Standard chargers (delivering 3 kW per hour)
- ☐ Fast chargers (delivering 7 kW per hour)
- ☐ Rapid chargers (delivering 50 kW per hour)
- ☐ None
- ☐ Other (please specify)

C2. In which locations would you be willing to pay to use a Public charge point (please tick ALL that apply)?

- ☐ On City Centre streets
- ☐ On Residential streets
- ☐ In Public car parks
- ☐ At Petrol/diesel filling stations
- ☐ At Supermarkets, shopping centres
- ☐ At Leisure facilities
- ☐ At Motorway Service Areas
- ☐ At Transport Interchanges (eg. Park&Ride, metro/underground stations, railway stations, airports, ports etc)
- ☐ None
- ☐ Other (please specify)

C3. If you had to PAY to use Public charge points, how important would the following factors be to your use of them ?

	Very Important	Moderately Important	Not important
The Location of the charge point	◯	◯	◯
Speed of recharging	◯	◯	◯
Ease of use eg. access methods, instructions, controls on the charge point	◯	◯	◯
Reliability - the charge point is working when you want to use it	◯	◯	◯
Availability - no queue when you want to use it	◯	◯	◯
Cost	◯	◯	◯
Additional services available	◯	◯	◯

C4. Would you be willing to pay MORE for a QUICKER recharging experience ?

◯ No

◯ Yes

C5. If you had to pay to charge your vehicle at Public charge points, please rank your PREFERENCE for how this amount should be calculated. Where 1 = most preferred method, 5 = least preferred.

- By energy received (ie. per kWh)
- By duration of recharge
- By fixed fee per use
- By time parked
- By a Monthly / Annual subscription

FOR INFORMATION: Figures published by DECC for 2015 UK Home energy bills indicate that the average Annual Household Electricity bill = £584 for 3,800 kWh, equating to £0.15 / 15p per kWh.
Please consider this as a reference point in answering the following questions.

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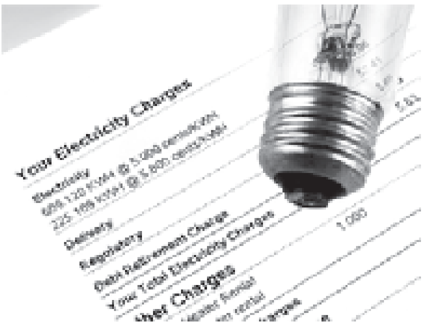

C6. How much would you be willing to pay **per kWh** of energy received from a Public charge point (please tick ALL that apply) ?

- ☐ 10p (= £1 for 10 kWh)
- ☐ 15p (= £1.50 for 10 kWh)
- ☐ 20p (= £2 for 10 kWh)
- ☐ 30p (= £3 for 10 kWh)
- ☐ 45p (= £4.50 for 10 kWh)
- ☐ 50p (= £5.00 for 10 kWh)
- ☐ £0

C7. How much would you be willing to pay **PER MINUTE to use a Public charge point which delivers 3 or 7 kW per hour**, EXCLUDING any parking fees (please tick all that apply) ?

- ☐ 1p per minute = £0.60 per hour
- ☐ 2p per minute = £1.20 per hour
- ☐ 3p per minute = £1.80 per hour
- ☐ 4p per minute = £2.40 per hour
- ☐ 5p per minute = £3.00 per hour
- ☐ £0

C8. How much would you be willing to pay **PER MINUTE to use a Public charge point which can charge your vehicle to 80% full in 30 minutes (called a Rapid charge point),** EXCLUDING any parking fees (please tick all that apply) ?

- ☐ 10p per minute = £3.00 for 30 mins
- ☐ 15p per minute = £4.50 for 30 mins
- ☐ 20p per minute = £6.00 for 30 mins
- ☐ 25p per minute = £7.50 for 30 mins
- ☐ 30p per minute = £9.00 for 30 mins
- ☐ £0

C9. How much would you be willing to pay at a Public charge point **AS A FIXED FEE per charge event,** regardless of the electricity received or duration of charge (please tick ALL that apply) ?

- ☐ £2.00
- ☐ £4.00
- ☐ £6.00
- ☐ £8.00
- ☐ £10.00
- ☐ £0

C10. How much would you be willing to pay **for a Monthly subscription** to use Public charge points (please tick ALL that apply) ?

	Low use (<50 kWh/month)	Medium use (51 - 150 kWh/month)	High use (>151 kWh/month)
£5	☐	☐	☐
£10	☐	☐	☐
£15	☐	☐	☐
£22.50	☐	☐	☐
£30	☐	☐	☐
£45	☐	☐	☐
£60	☐	☐	☐
£75	☐	☐	☐
£90 or more	☐	☐	☐

C11. If fees were introduced, how would this affect your use of Public charge points ?

- Not at all
- Charge less on Public charge points
- Charge more on Public charge points
- Stop using Public charge points
- I don't know

C12. If Time of Use tariffs were introduced on Public charge points (higher fee at times of peak energy demand) how would this affect your use ?

- Not at all
- Charge outside of peak times
- Charge less on public charge points
- Stop using public charge points
- I don't know

C13. Would you be willing to pay a fee to reserve a Public charge point ?

- Yes
- No

C14. How much are you willing to spend on average on additional services (eg. cafe, shops) whilst charging your vehicle on a public charge point ?

- Less than £5
- Up to £10
- Up to £20
- More than £20
- £0

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EV and Plug-in Hybrid Drivers Attitudes to recharging

SECTION D: About you

And finally, just a few questions about you to finish off with.

D1. Please indicate which of the following statements BEST describes**your current situation regarding an EV or plug-in hybrid vehicle.**

- I own one
- I lease one
- I use one provided by work for my use only
- I use a pool car provided by work
- I use one through a car-club
- I no longer use one

If you no longer use an EV or plug-in hybrid please state briefly why.

D2. Which type of ultra-low emission vehicle do / did you drive ?

- Electric Vehicle (EV)
- Plug-in Hybrid vehicle

D3. How many miles do / did you drive per year in your EV / Plug-in hybrid vehicle?

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D4. Did the EV / Plug-in hybrid REPLACE another vehicle in your household ?

- ◯ No it is an additional vehicle
- ◯ No it is the first vehicle I've owned/leased
- ◯ Yes, a petrol vehicle OVER 5 years old
- ◯ Yes, a petrol vehicle UNDER 5 years old
- ◯ Yes, a diesel vehicle OVER 5 years old
- ◯ Yes, a diesel vehicle UNDER 5 years old

D5. Please rank your MOTIVATIONS for driving a low emission vehicle, where 1 = Most important.

- Cost savings
- Appealing technology
- Appealing design
- Environmental concerns
- Social well-being & quality of life
- Financial incentives (towards vehicle and travel/parking)

D6. Please select which area you live in

D7. Do you have access to off-street parking at your home ?

D8. Do you have access to parking at your workplace ?

D9. Please indicate your Gender.

- ◯ Male
- ◯ Female

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D10. Please select your age group.

- ◯ Less than 18
- ◯ 18 - 24
- ◯ 25 - 34
- ◯ 35 - 44
- ◯ 45 - 54
- ◯ 55 - 64
- ◯ 65 or above

That's it - you have finished this survey.
Thanks very much for taking the time to answer these questions.

If you would be happy for me to contact you againto discuss your responses or to see how your opinions have changed in the future, please enter your email address here:

Email Address ________________

Appendix E. Charge Point Owners' Questionnaire 2015

Charge Point Owners Attitudes to EV recharging

1. Welcome to my charge point owners survey 2015

Thank you for agreeing to participate in this research questionnaire.

Following on from my involvement in the UK's Plugged in Places project I am now conducting part time PhD research at Newcastle University looking for an appropriate style of business model to justify the on-going provision of public EV charge points. Your responses will help me to identify the economic, social and environmental impacts that charge point provision has had on you as a charge point owner.

All the information you give will be held anonymously and securely. Access to your data is limited to the people involved in this research and any data published will not be identifiable as yours. You may choose to withdraw from the study at any time and for any reason and you can chose to omit any questions you do not wish to answer.

Thank you for participating in our survey.Your feedback is very important and we do greatly appreciate your time and effort in answering these questions.

* 1. Please tick this box to indicate that you have agreed to take part in this survey

- [ ] I agree

* 2. Please confirm your name and brief contact details:

Your Name	
Organisation Name	
Postal Code	
Email Address	

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Charge Point Owners Attitudes to EV recharging

2. About Your EV charge points

I would like to start by asking a few questions about the EV charge points on your site(s).

3. What type(s) of EV charge point(s) does your organisation have ? (please tick ALL that apply)

- ☐ 3 kW AC
- ☐ 7 kW AC
- ☐ 22 kW AC
- ☐ 43 kW AC
- ☐ 44/50 kW DC Chademo
- ☐ 44/50 kW DC CCS
- ☐ Other (please specify)

4. Who owns the charge points on your site(s)?

- ◯ Your organisation
- ◯ Your landlord
- ◯ Other (please specify)

5. Who can use the charge points on your site(s) ? (please tick ALL that apply).

- ☐ The general public
- ☐ Your own staff/employees
- ☐ Visitors
- ☐ Your own fleet users

6. How do you give EV drivers ACCESS to the charge points on your site(s)?

- ◯ We pay a supplier to do this eg.CYC
- ◯ We give EV drivers my organisation's master card/key upon request
- ◯ Other

If Other please specify OR if you use a supplier please name them here

7. On what DAYS of the week are the charge points available for use ? (Please tick ALL that apply)

- [ ] Monday
- [ ] Tuesday
- [ ] Wednesday
- [ ] Thursday
- [ ] Friday
- [ ] Saturday
- [ ] Sunday

8. At what times of day are they available for use ?

- ○ 24 hours per day
- ○ Business opening hours only
- ○ Car park opening hours only
- ○ Other (please specify)

9. At what types of LOCATIONS are the charge points ? (Please tick ALL that apply)

- [ ] Inner city road side
- [ ] Residential road side
- [ ] In short stay public carparks
- [ ] In long stay public carparks
- [ ] In private car parks (including Workplace car parks)
- [ ] In Service areas between towns/cities
- [ ] At transport interchanges eg.park & ride sites, metro/underground, railway stations, airports, ports
- [ ] In underground carpark locations
- [ ] Other (please specify)

10. Are there any barriers to entry to these locations ? (Please tick ALL that apply)

- [ ] entry barrier at all times
- [ ] permit controlled
- [ ] parking ticket required
- [ ] entry barrier out of hours only
- [ ] None
- [ ] Other (please specify)

11. Do you monitor the use of your charge points ?

- ◯ Yes
- ◯ No, we don't monitor it currently

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Charge Point Owners Attitudes to EV recharging

3. About the use of your charge points

I'm now going to ask you a few questions about how you measure the performance of these charge points, and about how you judge the success of your investment in this infrastructure.

12. How do you monitor or measure the Use of the charge points ? (Please tick ALL that apply)

- ☐ Number of charging events delivered
- ☐ Amount of energy delivered
- ☐ Number of individual Users
- ☐ Number of repeat Users
- ☐ % of time in use
- ☐ Customer feedback
- ☐ Other

Other (please specify)

13. Where do you get this Use data from ?

- ◯ I pay a supplier to provide this eg.CYC (using their website or reports)
- ◯ Customer feedback
- ◯ Other (please specify)

14. How frequently are your charge points used, by LOCATION type ?

	Frequently (more than once per day)	Occasionally (about once per week)	Rarely (less than once per month)	Never	N/A
Inner city road side	◯	◯	◯	◯	◯
Residential road side	◯	◯	◯	◯	◯
In short stay public carparks	◯	◯	◯	◯	◯
In long stay public carparks	◯	◯	◯	◯	◯
In private car parks (incl. Workplace carparks)	◯	◯	◯	◯	◯
In Service Areas between towns/cities	◯	◯	◯	◯	◯
At transport interchanges eg.park & ride sites, metro, railway stations, airports, ports	◯	◯	◯	◯	◯
In underground carpark locations	◯	◯	◯	◯	◯
Other	◯	◯	◯	◯	◯

15. How often do you review this Use data ?

◯ Weekly

◯ Monthly

◯ Quarterly

◯ Annually

◯ Never

◯ Other (please specify)

16. Do you set any Key Performance Indicators (KPIs) for charge point Use ? (please tick ALL that apply)

☐ Number of charging events delivered

☐ Amount of energy delivered

☐ Number of individual Users

☐ Number of repeat Users

☐ % of time in use

☐ Customer feedback

☐ Other (please specify)

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Charge Point Owners Attitudes to EV recharging

4. About the performance of your charge points

17. How much charger "down-time" have you experienced on average (where the charge point is unavailable for any reason) ?

- ◯ None
- ◯ a few short instances (less than 1 week each)
- ◯ lots of short instances (less than 1 week each)
- ◯ a few long instances (more than 1 month each)
- ◯ lots of long instances (more than 1 month each)
- ◯ I don't know

18. Have you received any complaints from EV drivers unable to access the charge points in any of these LOCATIONS ? (Please tick ALL that apply)

- ☐ Inner city road side
- ☐ Residential road side
- ☐ In public carparks
- ☐ In private car parks (including Workplace carparks)
- ☐ In service areas between towns/cities
- ☐ At transport interchanges eg.park & ride sites, metro/underground, railway stations, airports, ports
- ☐ In underground carpark locations
- ☐ I don't know
- ☐ No

19. Do you know why your charge points have been unavailable ? (Please tick ALL that apply)

- ☐ Hardware problems
- ☐ Software problems
- ☐ Damage or vandalism
- ☐ Poor communications connection
- ☐ Non-Evs parking in EV bays
- ☐ EVs parking in charging bays but not charging
- ☐ I don't know
- ☐ Other (please specify)

20. Do you have a maintenance supplier for your charge points ?

- No
- Yes
- I don't know

If you have a supplier, please name them here

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Charge Point Owners Attitudes to EV recharging

5. About the demand for and enforcement of your charge points

21. Have you experienced any queues of EV drivers waiting to use your charge points ? (Please tick ALL that apply)

- Inner city road side
- Residential road side
- In public carparks
- In private car parks (including Workplace carparks)
- In service areas between towns/cities
- At transport interchanges eg.park & ride sites, metro/underground, railway stations, airports, ports
- In underground carparks
- I don't know
- No

22. Have you ever ENFORCED the use of EV charging bays ? For example by administering warnings, fines, penalties, clamping, or towing away ? (Please tick ALL that apply)

- Non EV parking in EV bays
- EV parking beyond the time allowed
- EV parking but not charging
- EV not displaying required permit
- EV not displaying required parking ticket
- No
- Other (please specify)

23. Do you LIMIT the use of your charge points in any way ? (Please tick ALL that apply)

- [ ] By parking time
- [ ] By charging time
- [ ] By amount of electricity delivered
- [ ] At the end of a charging event
- [ ] No

24. Do you charge any fees to EV drivers ?

- ( ) Yes
- ( ) No

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Charge Point Owners Attitudes to EV recharging

6. Your thoughts about the business case for charge point provision

Have you chosen to adopt any revenue generating opportunities for your charge points ?

25. What kind of fees do you charge to EV drivers ? (Please tick ALL that apply)

	by duration	by electricity supplied	a fixed fee
For each recharging event	[ ]	[ ]	[ ]
Through a subscription	[ ]	[ ]	[ ]
Parking fees	[ ]	[ ]	[ ]

When did you start charging fees (approx. month and year) ?

26. Do these fees vary ? (Please tick ALL that apply)

- [ ] By day of the week
- [ ] By time of the day
- [ ] By user eg. employees, visitors, the public
- [ ] No

27. Approximately how much revenue have you generated from fees for Recharging Services (not Parking), and over how long ?

Approx. revenue generated (£)

Approx. duration (number of months)

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Charge Point Owners Attitudes to EV recharging

7. About the cost of operating your charge points.

How much is it costing you to operate your charge points ?

28. Roughly how much has it cost you to operate your charge point(s) over the last year ?

	Less than £100 per year	Between £101 and £500 per year	Between £501 and £10000 per year	More than £1000 per year	Not Applicable
Annual electricity costs	◯	◯	◯	◯	◯
Network Operator costs	◯	◯	◯	◯	◯
Maintenance costs	◯	◯	◯	◯	◯
Enforcement costs	◯	◯	◯	◯	◯
Promotion costs	◯	◯	◯	◯	◯
Lost Parking Revenue	◯	◯	◯	◯	◯
Other costs	◯	◯	◯	◯	◯

Other Costs (please specify)

29. How much do you pay for your electricity ? (in pence per kWh)

30. How often do you review this cost and revenue data ?

◯ Monthly

◯ Quarterly

◯ Annually

◯ Never

◯ Other (please specify)

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Charge Point Owners Attitudes to EV recharging

8. About your reasons for Charge Point provision

Next I'd like to explore WHY you decided to provide Charge Points and your opinion about the future of EV recharging facilities.

31. How important were the following external factors in your decision to provide charge points ?

	very important	important	moderately important	of little importance	unimportant
Business Need (to operate your own EVs)	○	○	○	○	○
Public demand	○	○	○	○	○
Employee demand	○	○	○	○	○
Political strategy	○	○	○	○	○
Regional strategy	○	○	○	○	○
Environmental concerns	○	○	○	○	○
Health concerns	○	○	○	○	○
The availability of grants towards cost	○	○	○	○	○
Other factors	○	○	○	○	○

Please list any Other factors here

32. How important is the provision of charge points to your Organisation's internal policies and goals ?

	Very important	Important	Moderately important	Of little importance	Unimportant
Economic goals	○	○	○	○	○
Environmental goals	○	○	○	○	○
Sustainable Transport	○	○	○	○	○
Health and wellbeing	○	○	○	○	○
Carbon reduction	○	○	○	○	○
Corporate Social Responsibility	○	○	○	○	○
Others	○	○	○	○	○

Others (please specify)

33. Did you set any TARGETS for charge points to deliver against these policies or goals (please tick ALL that apply) ?

- ☐ Economic goals
- ☐ Environmental goals
- ☐ Sustainable transport
- ☐ Health and wellbeing
- ☐ Carbon reduction
- ☐ Corporate Social Responsibility
- ☐ Others

Others (please specify)

34. How important is the success of your charge point provision to the following stakeholders ?

	Very important	Important	Moderately important	Of little importance	Unimportant
Your Organisation's directors /leaders	○	○	○	○	○
Your financial managers	○	○	○	○	○
Your employees	○	○	○	○	○
Your customers and/or suppliers	○	○	○	○	○
EV drivers	○	○	○	○	○
The general public	○	○	○	○	○
Local Government	○	○	○	○	○
National Government	○	○	○	○	○
The press	○	○	○	○	○
Others	○	○	○	○	○

Others (please specify)

35. Have you seen an increase in the use of your charge points ?

- ○ Yes within the last 6 months
- ○ within the last year
- ○ within the last 3 years
- ○ No increase in use
- ○ I don't know

36. Do you anticipate that charge point use will increase in the future ?

- Yes within the next year
- within the next 5 years
- within the next 10 years
- No I don't believe it will increase
- I don't know

37. Would you consider installing MORE charge points in the future (please tick ALL that apply) ?

- If EV driver demand requires it
- If our organisations uses EVs in its fleet
- If costs can be recovered through fees
- If we can make a profit from it
- If political pressure requires it
- If grants are available towards the costs
- No we won't
- Other (please specify)

38. In the future do you intend to charge EV Drivers a fee for using your charge points ?

- We already do
- Yes within 1 year
- within 1 to 2 years
- within 2 to 5 years
- Maybe in 5+ years
- I don't know
- No

39. What effect you think charging EV drivers a fee to use your charge points will have on use ?

- Reduce use
- No effect
- Increase use

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Charge Point Owners Attitudes to EV recharging

9. About your organisation

And finally, just a few questions about your Organisation to finish off with.

40. What type of Organisation are you ?

- ◯ Local Authority
- ◯ Educational esablishment
- ◯ Government owned
- ◯ Privately owned
- ◯ Third sector
- ◯ Other (please specify)

41. How many employees does your Organisation have ?

- ◯ Less than 10
- ◯ Between 11 and 50
- ◯ Between 51 and 250
- ◯ Over 251

42. Do any of your employees have their own EV ?

- ◯ Yes
- ◯ No
- ◯ I don't know

43. Does your Organisation have a vehicle fleet ?

- ◯ Less than 5 vehicles
- ◯ Between 6 and 50 vehicles
- ◯ More than 50 vehicles
- ◯ No

44. What proportion of this fleet is made up of Electric or plug-in hybrid vehicles ?

- None
- Under 10%
- Between 11% and 50%
- Between 51% and 99%
- 100%

45. Does your Organisation produce any of the following reports ?

- Environmental performance
- Sustainable Transport
- Health and wellbeing
- Social Accounts
- Corporate Social Responsibility
- Others (please specify)

46. Would you be willing to explore the use of an alternative business model including social & environmental aspects of charge point provision ?

- Yes
- Maybe
- No

47. Would you be willing to take part in a follow-up interview if appropriate ?

- Yes
- Maybe
- No

That's it you have finished this survey. Thanks very much for taking the time to answer these questions.

Appendix F. NE PIV Drivers' Questionnaire 2019

This survey is aimed at electric vehicle drivers who use the public charging network in North East England (Tyne and Wear, Durham and Northumberland). The answers that you give will help to shape the charging network in the future.

This survey is conducted by Zero Carbon Futures on behalf of the North East Regional Transport Team.

All the information you give will be held anonymously and securely. Access to your data is limited to the people involved in this research.

Thank you for your time, your input is important to us.

Part 1: Perceptions of the network today

* 1. On average how many miles a day do you drive in your EV?

On week days

At weekends

* 2. How often do you charge your car?

- Every day
- Most days
- A few times a week
- Other (please specify)
- Once a week
- A few times a month

3. What percentage of your charging is done on the following:

at home (%)

at work (%)

on public charging (standard) (%)

on public charging (rapid) (%)

4. We'd love to know which public charge points you use. Can you tell us the locations (name or postcode) of the public charge points that you use most frequently?

1 ______

2 ______

3 ______

5. What are the factors that make you choose these locations? (tick all that apply)

- ☐ The charge point is on my regular route
- ☐ The charge point is near to my home
- ☐ The charge point is at work
- ☐ The charge point is near to work
- ☐ There are facilities nearby
- ☐ The type of charge point at this location
- ☐ I'm guaranteed a charge at that location

Other (please specify)

______

* 6. How often have you found that a public charge point that you wanted to use was not working?

- ◯ Always
- ◯ Usually
- ◯ Sometimes
- ◯ Rarely
- ◯ Never
- ◯ Not applicable / I don't use public infrastructure

* 7. How often have you found that a public charge point that you wanted to use was already occupied?

- ◯ Always
- ◯ Usually
- ◯ Sometimes
- ◯ Rarely
- ◯ Never
- ◯ Not applicable / I don't use public infrastructure

8. On a scale of 1 – 10 how satisfied are you with the current regional charging network? (1 being not at all satisfied and 10 being very satisfied).

1 10

9. What would improve the local public charging network for you?

______

10. Now that parking fees have been introduced to some areas, how has this affected your use of public charge points?

- No change
- I charge less on public charge points
- I charge more on public charge points
- I have stopped using the public network
- Don't know

11. What is your preferred method of accessing the charge points?

- RFID / swipe card
- Contactless payment card
- Through an app
- Other (please specify)

The North East network will be growing over the next year and we want to hear a little more about what you think.

Part 2: the future of the network

* 12. How often do you currently use rapid charge points? By rapid charge points we mean any charge point providing 43Kw or above.

- Every day
- A few times a week
- About once a week
- A few times a month
- Once a month
- Less than once a month
- Never

* 13. If you don't use rapid charge points often, can you tell us why (please tick all that apply)?

- [ ] I have other options available to me
- [ ] They aren't where I need them to be
- [ ] I don't like waiting
- [ ] It's too cost prohibitive
- [ ] Not applicable
- [ ] Other (please comment)

14. Thinking about your charging habits over the last 12 months, has your use of rapid charging:

- Increased
- Stayed the same
- Decreased

Over the next 12 months, we will see the addition of 2 EV filling stations and 11 rapid charging clusters into the local area. The map below shows the locations of this additional charging infrastructure.

* 15. Do you think that the introduction of this new infrastructure will have an impact on your charging?

- Yes
- Maybe
- No
- Don't know
- Other (please specify)

16. What is your preference for the future of charging locations? (Please rank in order of preference with 1 being highest):

- In residential locations — N/A
- In transit locations (motorways and main roads) — N/A
- City Centre — N/A
- Workplaces — N/A
- Out of town leisure hubs (such as retail parks / supermarkets) — N/A

17. When planning your EV journeys, what tools do you use?

- Zap map
- A network operator's website
- A network operator's app
- Google maps
- Other (please specify)

Part 3: You and your vehicle

18. What make / model of EV do you drive?

19. What is the battery capacity (kWh) of your current vehicle?

20. Is the EV your primary car?

- Yes
- No

21. What is the primary use of your vehicle?

- For personal use
- For business use (as a company car)
- For business use (as part of a shared fleet)
- As a taxi
- I use a car share vehicle
- Other (please specify)

22. Please rank your motivations for driving an electric vehicle? (Please rank in order of preference with 1 being highest).

- Cost savings ☐ N/A
- Appealing technology ☐ N/A
- Appealing design ☐ N/A
- Environmental concerns ☐ N/A
- Social well-being and quality of life ☐ N/A
- Financial incentives (towards vehicle and travel / parking) ☐ N/A

23. Did the EV replace another vehicle in the household or work?

- It replaces a petrol car
- It replaces a diesel car
- It replaces another electric car
- It is an additional vehicle
- It is our first car

Part 4: About you

24. What is your gender?

- Female
- Male

25. Age group

- Under 24
- 25 - 34
- 35 - 44
- 45 - 54
- 55 - 64
- 65 or above

26. Which area do you live in?

27. Which area do you work in?

28. Would you be willing to take part in a more detailed telephone interview?

- Yes
- No

29. If yes, please share your email address

30. Do you have any further comments that you would like to share with us?

Appendix G. Workshop 1 Agenda

iBUILD Workshop 12th November 2014

Hilton Treetops Hotel, Leeds

Making the business case for public charging infrastructure

Speakers:

Chair: Yvonne Hübner (Senior Research Associate, Transport Operations Research Group, Newcastle University)

- Josey Wardle (Infrastructure Manager, ZCF)
- Alexandra Prescott (Director, Charge Your Car)
- Adrian Vinsome (CENEX)
- Jeff Hardy (Senior Manager, Sustainable Development, Ofgem)
- Brian Orr (Managing Director, EV Matters)
- Derek McCreadie (Low Emission Officer, City of York Council)
- Neil Ellison (previously Sustainability Manager, Stockton-on-Tees Borough Council)

Agenda:

- 13:00 Welcome and introductions (Yvonne Hübner)
- 13:10 Introduction to the research (Josey Wardle)
- 13:20 3-minute pitches by each speaker to answer the questions:

  How can we make a business case for public charging infrastructure stack up?

  What costs and benefits should we take into account when making a business case for public EV charging infrastructure?
- 13:45 Plenary session with question and answers
- 14:45 End

Aim of the debate:

The aim of this debate is to discuss options for a sustainable business model for public electric vehicle recharging infrastructure. The early provision of EV recharging infrastructure has been heavily subsidised by UK government, local authorities and private companies as part of sustainable transport and emission reduction plans. However, as public subsidies decline, the recharging infrastructure will begin a move to operation on a more commercial basis. The introduction of fees for EV recharging is likely to affect the behaviour of EV drivers in terms of their recharging habits (time, location, duration, etc.), willingness to pay, journey characteristics and potentially their overall EV use. These behavioural changes will, in turn, affect the owners of recharging equipment and the businesses operating this equipment in recharging networks. Coupling these events with uncertainties about changes in vehicle and recharging technology and likely EV uptake generate many uncertainties and unknowns around the creation of a sustainable business model for the provision of a public EV recharging infrastructure in the UK. At this workshop we will discuss the feasibility of options for a sustainable business model for public recharging.

About the iBUILD Project:

iBUILD stands for 'Infrastructure BUsiness models, valuation and Innovation for Local Delivery'. It is a project funded by the Engineering and Physical Sciences Research Council and the Economic and Social Research Council. The aim of the project is to develop new business models to improve the delivery of infrastructure systems and the services they provide. These new business models will better exploit the technical and market opportunities that emerge from the increased interdependence of modern infrastructure systems. One of the case studies is on public electric vehicle charging infrastructure and their back-office operation. For more information, please visit the project website: https://research.ncl.ac.uk/ibuild/

Appendix H. Workshop 2 Agenda

Are EV Filling Stations a logical answer for mass adoption of EV and the lack of parking & charging at homes?

Location: The Key Building, Science Central, Firebrick Avenue, Newcastle Upon Tyne, NE4 5TQ

Date and time: Monday 6th March 2017, 12.00 to 17.00 with lunch and refreshments provided.

Aim of the session:

Bringing together selected participants from national and local government, the EV charging industry, utility and service providers, EV dealers and EV users to discuss the concept of EV Filling Stations as a solution to EV charging needs. We propose to use the integration framework developed by the iBUILD project to discuss the question:

"Are EV Filling Stations a logical answer for mass adoption of EV and the lack of parking & charging at homes?"

This round-table session will be led by a facilitator to guide us through the methodology. We invite you to contribute your views on the varied needs and values associated with this innovative approach to EV charging, including:

- Desired Outcomes, plus Enablers and Constraints.
- Alternative EV charging interventions.
- Developing a Value Map for EV Filling Stations – what are the elements of "Value" in this context, who can benefit from them, where, when & how?
- What Funding and Finance routes are available?
- What might a business model look like for EV Filling Stations?

About the iBUILD project:

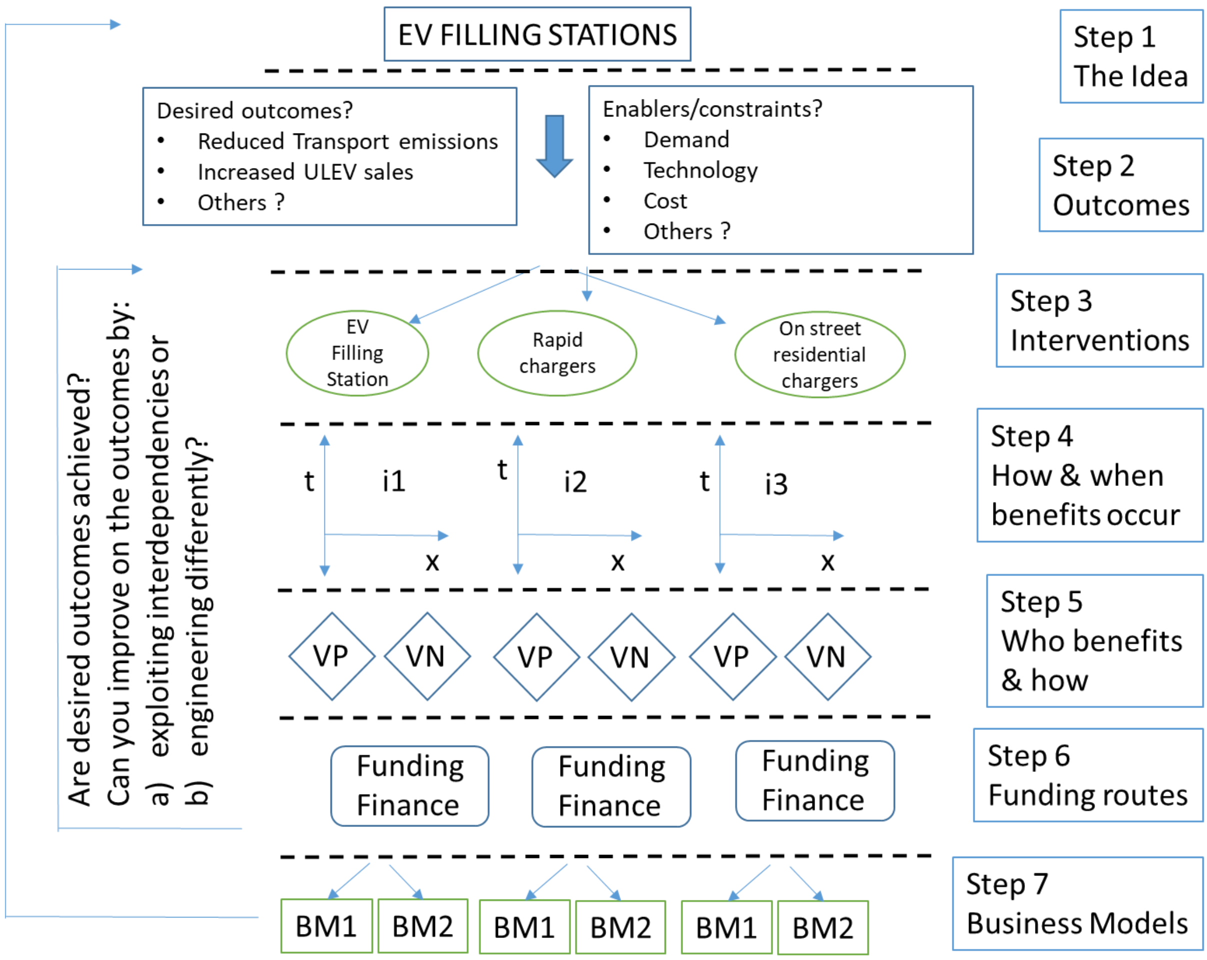
iBUILD is an interdisciplinary EPSRC/ESRC-funded project, led by Newcastle University, that is looking at deriving alternative business models for local infrastructure delivery. Here the focus is not only on funding and financing but a more holistic approach to valuing infrastructure beyond solely economics. From the various elements of the programme (interdependencies, funding and finance, value) we have derived a framework/process that when worked through may improve the initial infrastructure challenge, need or desire.

At this event we propose to test this framework by addressing the question: Are EV Filling Stations a logical answer to mass adoption of EV, and the problems of lack of parking/charging at homes?

Agenda

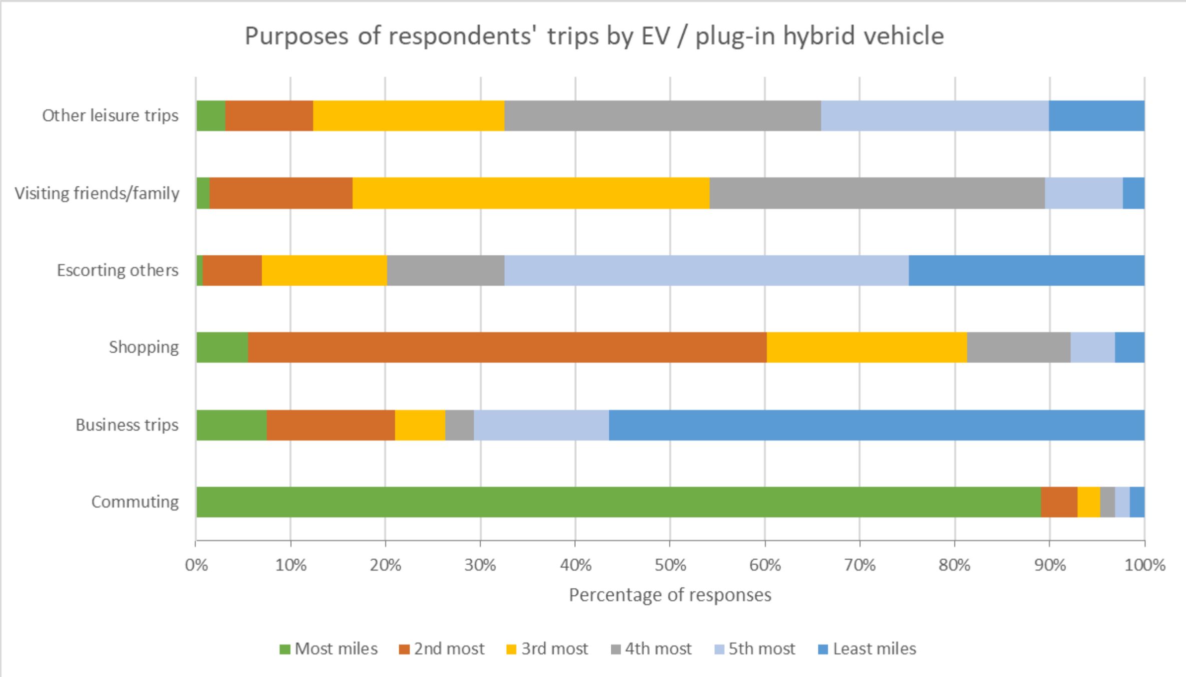
12:00	Welcome and introductions accompanied by a working lunch.
12:15	Introduction to the iBUILD research, integration framework and Decision Theatre methodology to be used.
12.30	Introduction to the EV Filling Station concept and EV charging landscape.
12.45	Discussion of alternative EV charging interventions.
13.15	Example of Green Infrastructure Value Map.
13.30	Creating a Value Map for EV Filling Stations.
15.00	BREAK
15.15	Identifying individual Value Propositions and those who will benefit.
15.45	Introduction to funding and financing mechanisms.
15.50	Identifying the sources of funding and finance.
16.15	Discussion about Business Models for set-up and ongoing operation.
17.00	CLOSE

Appendix I. Workshop 2 Infrastructure Value Framework

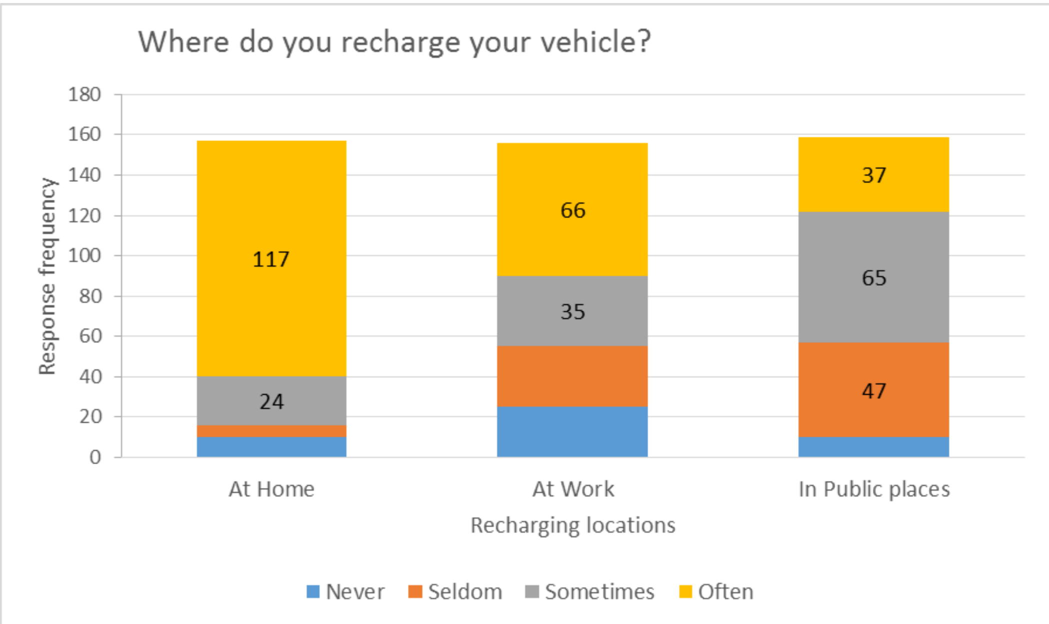


Appendix J. PIV Drivers' Survey Results

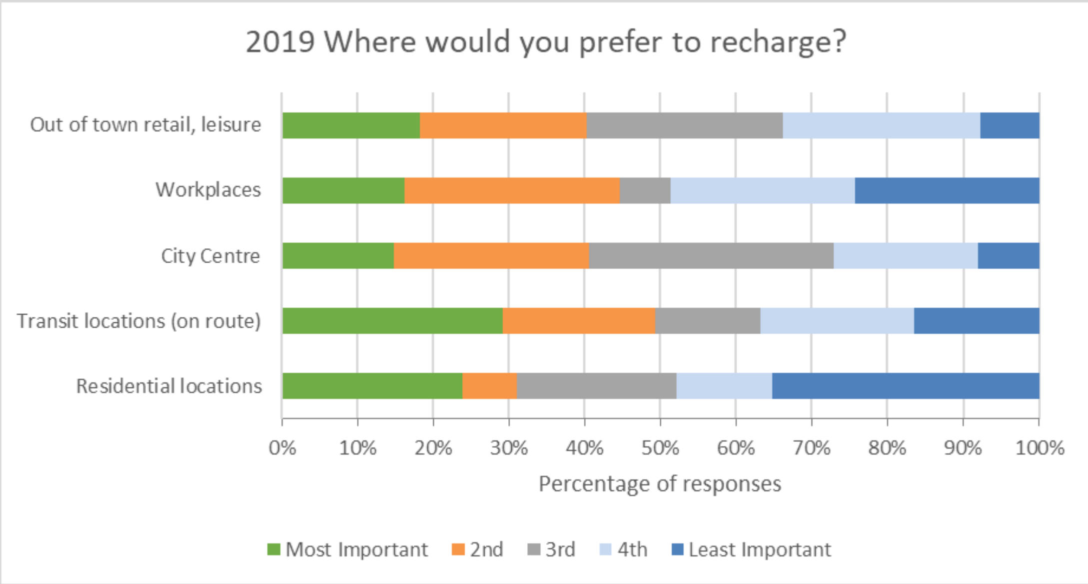
NE drivers' PIV trips (2016).



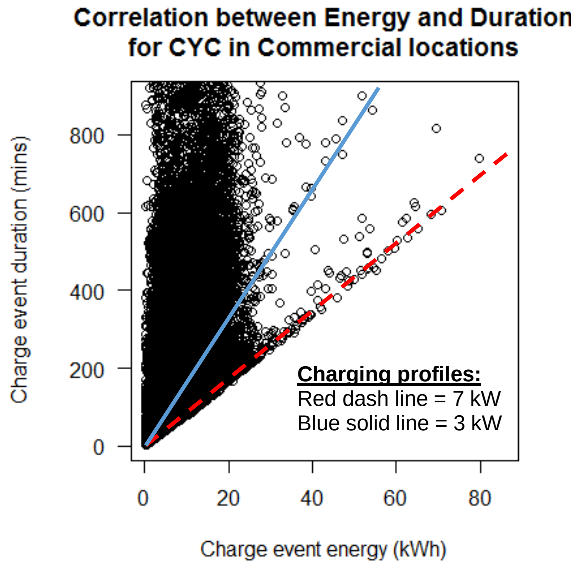
NE PIV drivers' main recharging locations (2016).

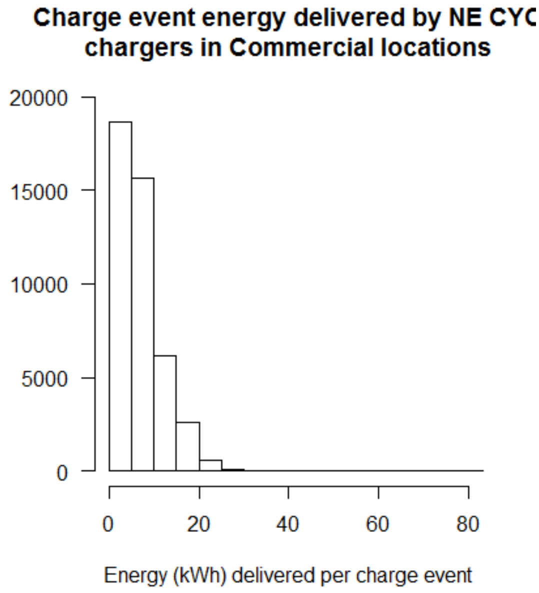


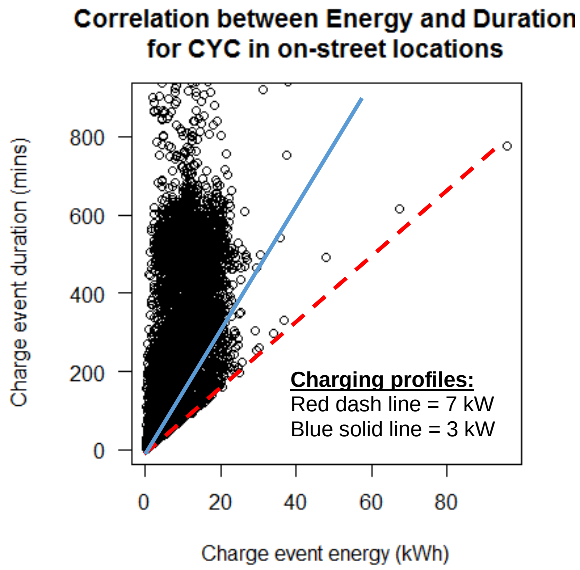
NE PIV drivers' preferred public recharging locations (2019).

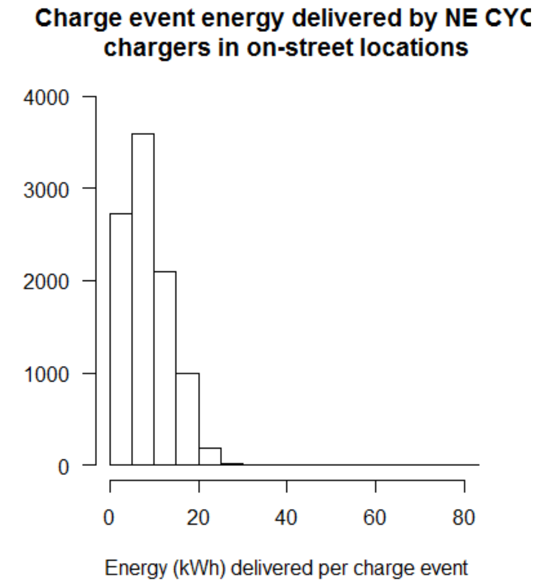


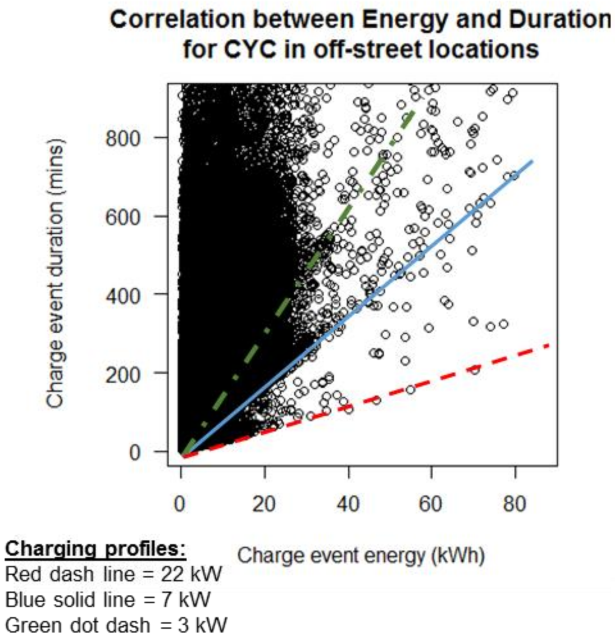
Appendix K. NECYC Energy Duration Correlation

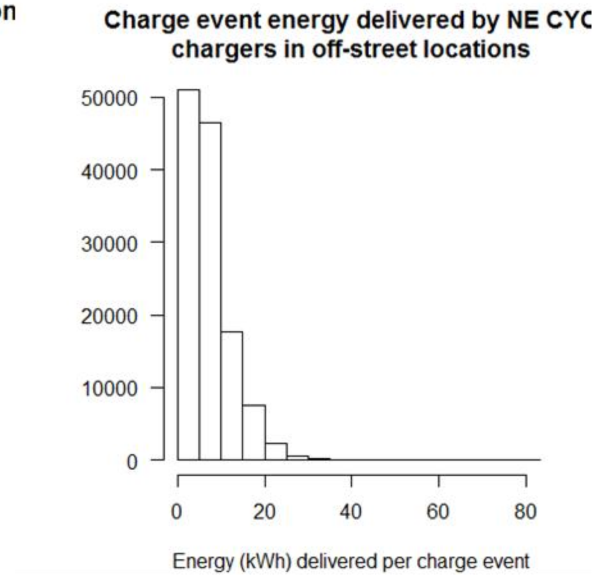


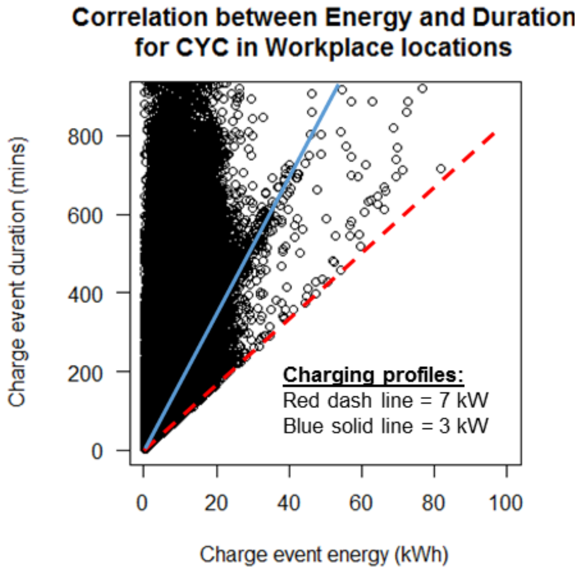


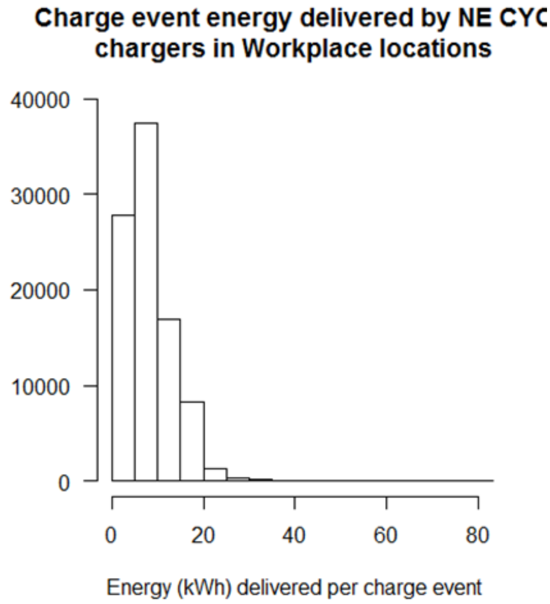





Correlation between Energy and Duration
for CYC in off-street locations
Charge event duration (mins)
800
600
400
200
0
0
20
40
60
80
Charge event energy (kWh)
Charging profiles:
Red dash line = 22 kW
Blue solid line = 7 kW
Green dot dash = 3 kW


Charge event energy delivered by NE CYC
chargers in off-street locations
50000
40000
30000
20000
10000
0
0
20
40
60
80
Energy (kWh) delivered per charge event


Correlation between Energy and Duration
for CYC in Workplace locations
Charge event duration (mins)
800
600
400
200
0
Charging profiles:
Red dash line = 7 kW
Blue solid line = 3 kW
0
20
40
60
80
100
Charge event energy (kWh)


Charge event energy delivered by NE CYC
chargers in Workplace locations
40000
30000
20000
10000
0
0
20
40
60
80
Energy (kWh) delivered per charge event