



Programme Area: Energy Storage and Distribution

Project: Consumers, Vehicles and Energy Integration (CVEI)

Title: D2.1. Consumer attitudes and behaviours report

Abstract:

This report represents Deliverable 2.1, Consumer Attitudes and Behaviours. The purpose of this report is to provide understanding of consumer attitudes towards ULEV adoption including detail of existing and new barriers to adoption; to capture and discuss lessons learnt from previous consumer trials to identify risks and develop recommendations to mitigate the risks; and to qualitatively explore consumer attitudes to managed charging scenarios (with consumers who have experience of a BEV or PHEV).

Each chapter of this Report provides a summary of the overall results from the individual research activities. These are collated into an overall key findings section within the report (Section 6). In the Executive Summary, only the key findings for input into other areas of the project are summarised.

Context:

The objective of the Consumers, Vehicles and Energy Integration project is to inform UK Government and European policy and to help shape energy and automotive industry products, propositions and investment strategies. Additionally, it aims to develop an integrated set of analytical tools that models future market scenarios in order to test the impact of future policy, industry and societal choices. The project is made up of two stages:

- Stage 1 aims to characterize market and policy frameworks, business propositions, and the integrated vehicle and energy infrastructure system and technologies best suited to enabling a cost-effective UK energy system for low-carbon vehicles, using the amalgamated analytical toolset.
- Stage 2 aims to fill knowledge gaps and validate assumptions from Stage 1 through scientifically robust research, including real world trials with private vehicle consumers and case studies with business fleets. A mainstream consumer uptake trial will be carried out to measure attitudes to PiVs after direct experience of them, and consumer charging trials will measure mainstream consumer PiV charging behaviours and responses to managed harging options.

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D2.1 Consumer attitudes and behaviours report

A report describing research undertaken into mainstream consumers' attitudes to plug-in vehicle adoption and use of managed charging schemes

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This report is delivered under the "Consumers, Vehicles and Energy Integration" project, commissioned and funded by the Energy Technologies Institute



Contents amendment record

This report has been amended and issued as follows:

Version	Date	Description	Editor	Technical Referee
1	14/04/2016	First draft for ETI	NK/ED	SS
2	09/11/2016	Second Version for ETI	NK	SS
3	09/12/2016	Third Version for ETI	HAK	SS
4	06/01/2017	Final Report for ETI	HAK	SS

Prepared for: ETI

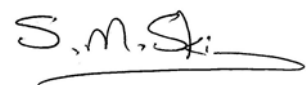
Project Ref: TR1006 Consumers, Vehicle and Energy Integration (CVEI) project
- Stage 1

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Acronyms

AER	All Electric Range
AFD	Alternative Fuel Discount
AFV	Alternatively Fuelled Vehicle
BEV	Battery Electric Vehicle
CNG	Compressed Natural Gas
DfT	Department for Transport
DSR	Demand Side Response
ECCo	Electric Car Consumer choice model
ECOS	Employee Car Ownership Schemes
EV	Electric Vehicle (including all plug-in vehicles)
FCV	Fuel Cell Vehicle
GHG	Greenhouse Gas
HEV	Hybrid Electric Vehicle (not including plug-in hybrid vehicles)
HOV	High Occupancy Vehicle Lane
ICE	Internal Combustion Engine
LCC	London Congestion Charge
LEZ	Low Emission Zone
MC	Managed Charging
NGV	Natural Gas Vehicles
NTS	National Travel Survey
OLEV	Office for Low Emission Vehicles
PCP	Personal Contract Purchase
PiP	Plugged-in Places
PiV	Plug-in Vehicle
PHEV	Plug-in Hybrid Electric Vehicle
PiCG	Plug-in Car Grant
RCT	Randomised Controlled Trial
RE-EV	Range-extended Electric Vehicle
TCO	Total cost of ownership
TDI	Turbocharged Direct Injection
ToU	Time of Use
UCC	Utility Controlled Charging
ULEV	Ultra Low Emission Vehicle
VRI	Vehicle-to-refuelling-station Index
WP	Work Package
WTP	Willingness to Pay

Glossary

Item	Description
Affective attitudes	The emotions and feelings evoked by owning and using a vehicle.
Analytical tools	The quantitative part of the Analytical Framework, used to calculate values for the quantitative Success Metrics.
Analytical framework	Overarching Multi-Criteria Assessment (MCA) framework applied to each narrative to help understand what 'good looks like' for mass market deployment and use of ULEVs and the potential trade-offs, via the assessment of the Success Metrics. This framework comprises the analytical tools which are used to help inform the quantitative assessment as well as a set of supporting qualitative assessment metrics.
Battery Electric Vehicle	A vehicle powered solely by a battery, such battery being charged only by a source of electricity external to and not part of the vehicle itself.
Consumer	A private, domestic, individual driver who owns or leases his/her own vehicle.
Demand management	The modification of one or more energy consumers' demand for energy through various methods including financial incentives, time of use tariffs and/or education.
Descriptive (or behavioural) norms	Perceptions of what other group members you associate with actually do.
Early adopter	Those who adopt after Innovators, and only after awareness, knowledge, and positive attitudes have diffused to them from Innovator. Times to adoption are between one and two standard deviations before the mean time to adopt.
Injunctive norms	Perceptions of what other group members (e.g. family group, friendship group) approve or disapprove of.
Innovators	People high in innovativeness who are first to adopt new technology. They are sources of awareness, knowledge, and positive attitudes towards the innovation whose times to adoption are greater than two standard deviations before the mean time to adopt
Instrumental attitudes	Attitudes towards factors relating to general practical or functional attributes of driving a vehicle.
Mainstream consumer/adopter	All those whose adoption of technology has been influenced by diffusion of awareness, knowledge, and positive attitudes from people who have already adopted the innovation (i.e. everyone except innovators)
Managed charging	Means the management of vehicle charging in such a way as to control the timing and/or extent of energy transfer to provide Demand Management benefits to the energy system and the vehicle user.
Personal norms	Perceived obligations to act in a way consistent with personal views.
Plug-in Hybrid Electric Vehicle	A vehicle that is equipped so that it may be powered both by an external electricity source and by liquid fuel.
Provincial norms	The same as injunctive norms but more specifically referring to other people who live under similar conditions such as in the same locality.
Range-extended Electric Vehicle	A vehicle that is equipped so that it may be powered both by an external electricity source and by liquid fuel; similar to a PHEV, except that a RE-EV generally uses the engine solely to charge the battery whereas a PHEV generally uses the engine for direct propulsion).
Self-identity	The perception of oneself including how one sees one's self and how one perceives that others see oneself.

Social norms

Similar to injunctive norms but more specifically referring to the approval or disapproval by close friends/family/colleagues. Informal understandings that influence the behaviour of members of a group, or wider society.

**Symbolic meaning/
attitudes**

What the vehicle says about its owner/driver in terms of social status, social conscience and personal values

Executive Summary

Background

The ETI's previous research on light duty electric mobility focussed on the potential for Plug-in Vehicles (PiVs) to replace internal combustion engine (ICE) vehicles, and the potential carbon benefits that could accrue. It included pioneering research with mainstream consumers on their attitudes to potential uptake of PiVs.

The Consumers, Vehicles and Energy Integration (CVEI) project builds on that work. It is designed to investigate how the integration of vehicles with the energy supply system can benefit vehicle users, vehicle manufacturers and those involved in the supply of energy. The project aims to inform UK Government and European policy and to help shape energy and automotive industry products, propositions and investment strategies. The opportunity will be taken to update understanding of the potential uptake of PiVs, as it has now become possible to give mainstream consumers direct experience of using both Battery Electric Vehicles (BEVs) and Plug-in Hybrid Electric Vehicles (PHEVs).

The project is made up of two stages:

- **Stage 1** aims to characterise market and policy frameworks, business propositions, the integrated vehicle and energy infrastructure system and relevant technologies.
- **Stage 2** aims to fill knowledge gaps and validate assumptions from Stage 1 through scientifically robust research, including real world trials with private vehicle consumers and case studies with business fleets. A mainstream consumer uptake trial will be carried out to measure attitudes to PiVs after direct experience of them, and consumer charging trials will measure mainstream consumer PiV charging behaviours and responses to managed charging options.

Stage 1 is made up of four interrelated Work Packages (WPs) covering:

- WP1 - the development of analytical tools and future scenarios;
- WP2 - pre-trial research on consumer and fleet behaviours and attitudes;
- WP3 - vehicle energy supply management and technologies; and
- WP4 - energy infrastructure systems and technologies (WP4).

This report is the output for Task 2.1 in Work Package 2, consumers' attitudes and behaviours to PiV adoption and energy demand management.

Research activities

The following research activities were completed:

- A review of literature to update and expand on that carried out in the ETI's previous PiV work (as referred above), to establish:
 - a. current knowledge of consumers' attitudes to electric vehicle (EV) adoption; and
 - b. current knowledge of consumer attitudes towards energy demand management.
- A review of practical 'lessons learned' from relevant previous PiV trials to inform Stage 2 trial development.

- In-depth interviews with PiV owners and mainstream consumers to provide early insight into charging behaviours and attitudes to managed charging, to support WP1 framework development and analysis, and inform Stage 2 trial development.

Literature reviews

A short form of systematic review was employed for both reviews. This approach sought to maintain the rigour of a systematic review whilst accounting for time and resource constraints. The reviews explored the areas summarised in Table X1.

Table X1: Summary of topics reviewed

Review of EV adoption	Review of energy demand management
Incentives and barriers to EV adoption	Acceptability of demand management and tariffs
Perceptions of EVs	Impact of demand management and tariffs on charging and EV use behaviour
Charging	Energy tariffs and EV adoption
Finance models	Evidence and knowledge gaps
Consumer and social psychology	
EV usage patterns	
Evidence and knowledge gaps	

In addition to these reviews, the key findings of a recently published TRL-Shell randomised controlled trial with mainstream consumers are also summarised.

Lessons learned

The aim of the lessons learned review was to establish practical lessons that can be learned from relevant PiV and/or energy management trials that have been undertaken to date. The purpose of this task was to ensure that the design of the trial mitigates or minimises known risks, reduces the number of assumptions and improves the accuracy of time, data and cost predictions.

Literature from the earlier reviews was filtered for reporting of trials of interest and supplemented by seven discursive interviews with those known to have been previously involved in running PiV or managed charging trials with consumers or fleet drivers.

Reported and observed limitations and lessons learned were coded under the following headings: study design; participants and recruitment; vehicles; technology and communications; infrastructure; managing risks and practicalities; data and analysis; and reporting.

Consumer interviews

Little is known as yet about how consumer drivers will experience engagement with charging options that provide for some degree of energy system integration, such as time of use tariffs or managed charging, or to what extent they will be willing to engage with such options.

For widespread energy system integration in the next few decades, it would be necessary for there to be wide engagement among mass-market consumer segments that use PiVs. Interviews were carried out with consumer drivers who have direct experience of charging their own PiV to gain early insight into the factors that might

influence such engagement. At the present state of UK market development these were necessarily all PiV Innovators or potential Innovators. These are likely to show higher levels of engagement than mainstream consumers, but their responses nevertheless form a useful basis for developing hypotheses about factors that might influence the levels of engagement of mainstream consumers.

Qualitative interviews were conducted to:

- inform understanding of consumers' attitudes towards PiV uptake and managed charging; and
- contribute to the effective design of the Stage 2 managed charging field trial by providing consumer perspectives on managed charging.

Sixty interviews were conducted with four groups of participants:

- 15 consumers who have owned or leased a BEV for 18 months or longer ('BEV18').
- 15 consumers who have owned or leased a BEV for six months or less ('BEV6').
- 15 consumers who have owned or leased a PHEV for any length of time ('PHEV').
- 15 non-PiV owners who have had previous experience of driving and charging a PiV ('ICE'), e.g. as a participant in a previous PiV trial.

Key findings for input into Work Package 1 (analytical tools, initial analysis, and Stage 2 design)

Each chapter of this Report provides a summary of the overall results from the individual research activities. These are collated into an overall key findings section within the report (Section 6). In this Executive Summary, only the key findings for input into other areas of the project are summarised.

Literature reviews

The literature reviews established some key findings that have implications for modelling the integration of PiV energy demand with the wider energy system:

- **Purchase price remains a key disincentive to PiV adoption.** So long as there are substantial price premiums over ICE vehicles, adoption of (and so electricity demand from) PiVs will be low. This can be offset through policy interventions that reduce the effective purchase price seen by consumers.
- **Short range and resultant restricted utility of BEVs will continue to greatly reduce their appeal to most consumers.** Growth in PiV electricity demand will be limited until BEV range has been substantially improved.
- **Running cost savings versus ICE vehicles are a substantial incentive to PiV adoption.** However both falling petrol/diesel prices and increased ICE fuel efficiency would reduce the PiV advantage over ICE. This should be taken into account in modelling PiV adoption.
- There is very little research evidence on adoption of PHEVs; the evidence there is supports the view that **PHEVs are preferred over BEVs by the majority of consumers** because they do not have the same restricted utility.
- **Vehicle choice is known to be influenced by symbolic motives** (whose influences are difficult to measure in choice experiments). The influence of the symbolism of PiVs on adoption has been very little researched, so this adds

substantially to uncertainty over adoption rates. This suggests the importance of sensitivity analyses around overall PiV adoption rates in the CVEI analysis.

- **The role of public charging infrastructure in driving PiV adoption is not well understood.**
- **Existing consumer users primarily charge their PiVs at home, in the evening.** Thus consumer PiV use is largely restricted to households with the ability to charge at home. It is not known how far an extensive network of public chargers would facilitate adoption of PiVs by households that cannot charge them at home.

In addition, the review confirmed that there are significant gaps in knowledge in the field. Some topics (such as adoption of and charging behaviour with PHEVs, managed or charging of PiVs) have been under-researched, while substantial methodological weaknesses (such as generalisation of conclusions from PiV Innovator responses to the wider population) have undermined the value of the evidence base for others. These have significance for the scope and design of the Stage 2 trials.

- Previous field trials measuring attitudes towards adoption of PiVs have used samples with substantial biases towards PiV Innovators (particularly those studies where participants' own PiVs were used). None of these studies can be used to make valid predictions regarding mainstream consumers' attitudes towards adoption of PiVs. Research with mainstream consumers is therefore essential if we are to accurately model PiV adoption rates and electricity demand.
- The literature regarding attitudes towards adoption of PHEVs, and charging behaviour with a PHEV, is very sparse. Research on both PHEV adoption and charging behaviour is essential if we are to accurately model PiV adoption rates and electricity demand.
- Research evidence of any kind relating to managed charging of PiVs is also sparse. At the moment in modelling PiV energy demand we can only make plausible assumptions about consumer response to PiV managed charging value propositions. Measurement of actual responses by users is essential if we are to accurately model ways in which PiV energy demand can be integrated into the wider UK energy system.
- Methodological quality of much of the research in the field, including most field trials with PiVs, is weak, using uncontrolled designs that are vulnerable to the effects of confounding variables and from which it is difficult to draw valid conclusions. Robust modelling of the integration of PiVs into the energy system needs to be grounded in controlled field studies from which valid conclusions about causal relationships can be drawn.

Lessons learned

While many previous trials have methodological weaknesses that limit their value in informing modelling of the integration of PiVs into the wider energy system, they nevertheless have encountered and addressed many of the practical problems associated with running field studies involving participants in using and charging PiVs. Such practical, operational details are not typically included in research publications but form part of the researchers' stock of "know-how". The review of lessons learned aimed to tap into such know-how, to identify where possible key practical problems that have already been encountered, and solutions that have already been identified, so as to mitigate

practical risks to the Stage 2 trials. The review suggests the following actions would contribute to the minimisation of operational risks in Trial execution:

- **Focus trial design on the primary aims and research questions of the project**, avoiding as far as possible secondary aims and additional independent and dependent variables that complicate analyses and reduce statistical power.
- **Ensure the collection only of the data necessary to answer and explore the pre-defined research questions.** Trials can all too easily generate large volumes of data, the processing of that inhibits rather than enhancing, analysis. Post-hoc “fishing” for associations in data can lead to statistical errors.
- **To maximise generalisability, vehicles selected for trial should represent popular vehicle categories and mid-range models.** The generalisability of results obtained with less popular vehicle categories (e.g. 2-seater vehicles) is low.
- **Ensure all materials are well designed** and have been tested in advance through piloting.
- **Ensure processes for participant follow-up and support are in place.**
- **Work with experienced suppliers to provide charge point installation and communication network.** Inexperienced suppliers can be a cause of delay and loss of data.
- **Adhere to established electrical equipment installation guidelines.**
- **Ensure careful planning and piloting of the process of vehicle handover to/from participants.**
- **Avoid vehicle downtime during trials** by planning for vehicle maintenance checks and cleaning between handovers.
- **Some trials have struggled as a result of inadequate or inappropriate allocation of staff resources.** Ensure accurate and adequate resourcing of the trials.

Consumer interviews

The consumer interviews were necessarily restricted to PiV Innovators since they concerned long term experience of having and using PiVs. Thus caution is needed in generalising from the findings on attitudes to PiVs. However, the interviews established some key findings in relation to charging behaviour and the responses of those with experience of charging their own PiVs to managed charging propositions¹. These findings have implications for modelling the integration of PiV energy demand with the wider energy system.

¹ At the time the field research for D2.1 was conducted, the terms “Time of Use (ToU)” and “Managed Charging (MC)” were used to distinguish between the two major classes of Managed Charging propositions as seen from the user perspective. During the course of Stage 1 the Project Team and ETI agreed that both of these are examples of “Managed Charging” as defined in the contract, and have adopted the use of the clearer terms “User-Managed Charging” and “Supplier-Managed Charging” respectively for the two classes of propositions. In this report the former terminology is used for consistency with the research materials.

- In general, users' perceptions of the advantages and disadvantages of BEVs aligned with those identified in the literature review, though with an emphasis on the positives that we interpret as reflecting participants' Innovator motivations.
- PHEV were seen by their users as conferring many of the benefits of PiVs without the dis-utilities of restricted range and the burden of planning required to make long journeys. However BEV users were often critical of PHEVs and their users who they characterised as not willing to commit to PiVs. PHEVs were also seen by BEV users as a nuisance, "blocking" public charge points even though not as dependent on them as BEV users.
- Most users charged their vehicles (BEVs and PHEVs) at home, overnight, following a well-established routine. There was a general preference among both BEV and PHEV users for fully recharging their vehicles whenever possible.
- Participants were not generally enthusiastic about either time of use or managed charging tariffs, seeing little benefit unless reductions in charging costs of between 25% and 60% could be achieved. Even such savings were not generally seen as important, as the cost of PiV charging is perceived as already low.
- Two-thirds of participants expressed a preference for time of use tariffs over managed charging tariffs, based on simplicity, retention of personal control, and reduction of perceived risk that vehicle would not be fully charged at the end of the planned charging period. Those that favoured managed charging tended to be BEV Innovators, who saw advantages to society as a whole that perhaps aligned with their symbolic motivations for having a BEV in the early market.

Some specific findings provide information that will help the design of the Stage 2 Trials, including the specific design of User-Managed and supplier-managed charging experimental conditions:

- Managed charging propositions are unfamiliar to potential participants, and will require clear explanation at recruitment (to ensure informed consent) and in briefing prior to participation. This should include information on whether/how users could over-ride the managed charging system when they felt this was required.
- The supplier-managed charging tariff condition will need to offer participants a clear advantage to 'handing over' control of charging to the energy supplier, to maximise engagement with it during their participation.
- Mandatory use of smartphone apps may deter many from using ToU or MC. If use of a smartphone app is required, this should be made clear during recruitment. Participants should be fully briefed in its use to ensure that they are comfortable with using it as part of the trial.
- Households with solar panels could confound the trial due to a desire to charge when most suited to energy supply from the panels. The presence of solar panels should be determined during recruitment and participants with solar panels excluded from participation in any trials of charging behaviour.

1 Introduction

1.1 Project aims

The Consumers, Vehicles and Energy Integration project was designed to investigate challenges and opportunities involved in transitioning to a secure and sustainable low carbon vehicle fleet. The project seeks to explore how the integration of vehicles with the energy supply system can benefit vehicle users, vehicle manufacturers and those involved in the supply of energy.

The project aims to inform UK Government and European policy and to help shape energy and automotive industry products, propositions and investment strategies. The project will achieve this in two stages. Stage 1 aims to characterise market and policy frameworks, business propositions, the integrated vehicle and energy infrastructure system and technologies best suited to enabling a cost-effective UK energy system for low-carbon vehicles. Stage 2 aims to fill knowledge gaps and validate assumptions from Stage 1 through scientifically robust research, including real world trials, with private vehicle consumers and business fleets. The results of Stage 2 will be used to update and improve the analytical tools developed in Stage 1.

1.2 Overview of the project

Stage 1 of the CVEI project is made up of four interrelated Work Packages (WPs). Work Packages 1 and 4 involve the development of the analytical framework needed to characterise market and policy frameworks, business propositions, the integrated vehicle and energy infrastructure system and technologies best suited to enabling a cost-effective UK energy system for low-carbon vehicles; and initial analyses using the framework. Recognising that there are substantial gaps in knowledge about both the potential for uptake of PiVs by mainstream consumers and fleets, and their potential engagement with demand management options, WP1 also involves the design of consumer trials and fleet case studies aimed at addressing the key gaps. WP2 informs the analytical framework via a detailed literature review and qualitative exploration of consumer and fleet vehicle usage behaviours (including charging behaviours), and attitudes to the adoption of low emission vehicles. WP3 informs the analytical framework by focussing on vehicle energy supply management systems and technologies.

The Stages, Work Packages, project tasks and the relationships between them are shown graphically in Figure 1.

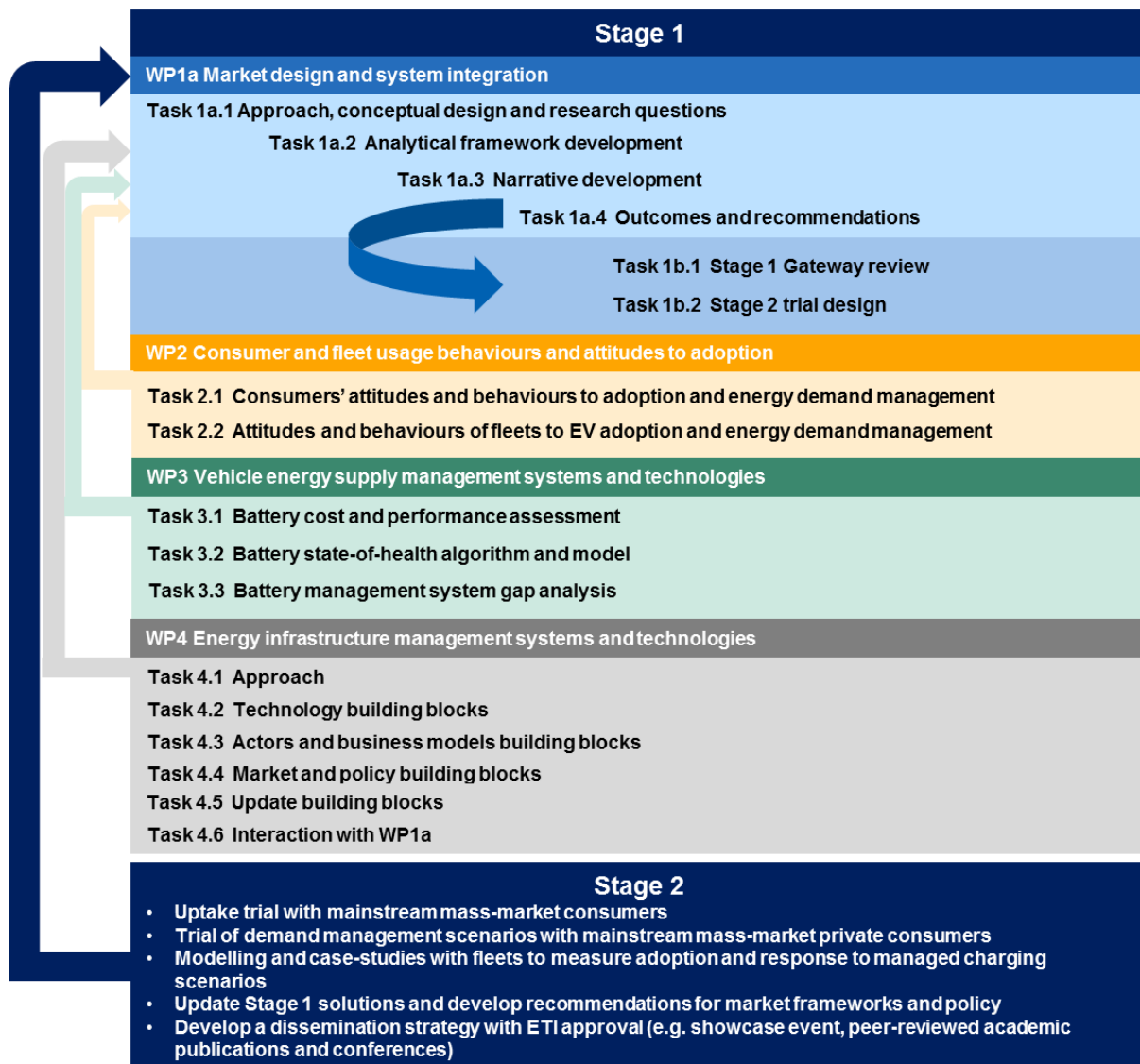


Figure 1: Overview of CVEI project

1.3 This report

This report is the output for Task 2.1 in Work Package 2: Consumers' attitudes and behaviours to PiV adoption and energy demand management.

The following objectives were defined for this task:

- *To update our understanding of consumer attitudes towards ULEV adoption including detail of existing and new barriers to adoption.*

To support future integration of plug-in light duty vehicle use with the UK energy system requires an accurate understanding of the scale and pace of plug-in vehicle adoption. The EV market and consumers knowledge of ULEVs is constantly developing. Research seeking to predict future adoption is required to review current knowledge of consumers' attitudes and behaviours. The ETI's earlier Plug-in Vehicles project showed that attitudes of EV "Pioneers²" are very poor

² A label for the segment in that project's segmentation analysis having the most similarity with the Innovators of diffusion theory.

predictors of uptake among private mainstream consumer drivers (Anable, Kinnear, Hutchins, Delmonte & Skippon, 2016), hence it is necessary to critically appraise current findings that may be based on the attitudes of PiV Innovators.

- *To explore what lessons can be learned from previous consumer trials to identify risks and develop recommendations to mitigate the risks.*

The ETI Plug-in Vehicles project engaged with mainstream consumers, however, few of the participants had direct experience of using a PiV, making their responses “psychologically distant”. Real-world trials in Stage 2 of this CVEI project propose to address this limitation. In order to ensure the trials maximise validity by minimising risks associated with real world fieldwork, it is prudent to establish where lessons can be learned from previous trials.

- *To qualitatively explore consumer attitudes to managed charging scenarios (with consumers who have experience of a BEV or PHEV).*

The potential for the implementation of future tariffs to manage consumer charging demand depends on a willingness to adopt a new system of pricing and control. Cost-based managed charging of any product is a very unfamiliar experience for consumers today. Exploration of novel concepts such as this lends itself to qualitative research methods, such as interviews. Qualitative research does not seek to build a statistically representative picture, but rather to identify as far as possible all the key themes in the ways the population being studied (in this case, private consumers) construes and responds to the topic. To do this, qualitative researchers seek not representativeness but rather sufficient diversity in participants to achieve “saturation” – a point where adding further participants does not elicit further themes.

To meet these objectives, Task 2.1 comprised of the following research activities:

- A state-of-the-art review of literature to establish what is currently known about consumers’ attitudes to:
 - a. EV adoption
 - b. Managed charging, particularly expectations and acceptance of energy demand management.
- A review of ‘lessons learned’ from relevant previous EV trials.
- In-depth interviews with consumers who have experienced charging an EV, either as owners or as participants in previous trials.

Each of the three activities is presented separately in sections 3, 4 and 5. Section 2 briefly considers the definition of consumers based upon their position in the commonly cited diffusion model of adoption.

2 Defining consumers

2.1 Adoption of an innovation: Rogers' Diffusion Model

Most research on adoption of innovations, including research on adoption of EVs, is explicitly or implicitly framed within Rogers' (2003) Diffusion model. This suggests that, once an innovation has become available, individual differences in times to adopt are driven at least in part by differences in a trait, Innovativeness, which reflects a general behavioural tendency to engage with new experiences, try new things, and be seen as ahead of the majority. It further suggests that adoption will proceed through a process of diffusion, in which awareness of, knowledge about, and positive attitudes towards the innovation diffuse through a population in a process of uni-directional influence, starting with adoption by a few "Innovators" (people high in Innovativeness) progressing next to "Early Adopters" and then more widely into the population, with the attitudes of low-Innovativeness "Laggards" being the last to shift. This process gives rise to a normal distribution of times to adoption, and an ogive (cumulative normal) S-curve distribution of adoption with time (Figure 2 and Figure 3).

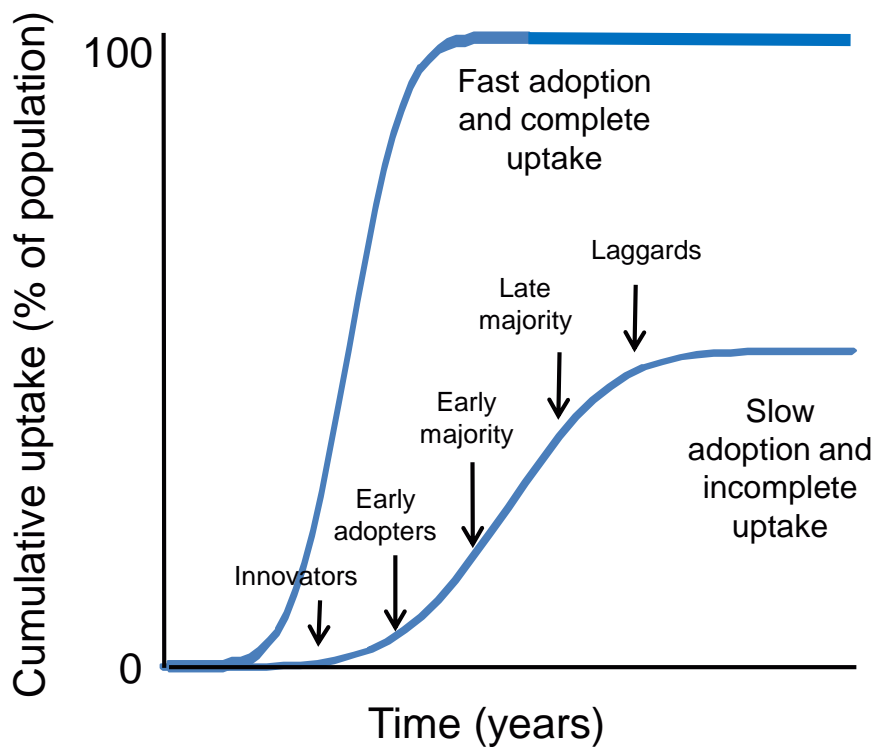


Figure 2: Adoption of an innovation: Rogers' Diffusion Model

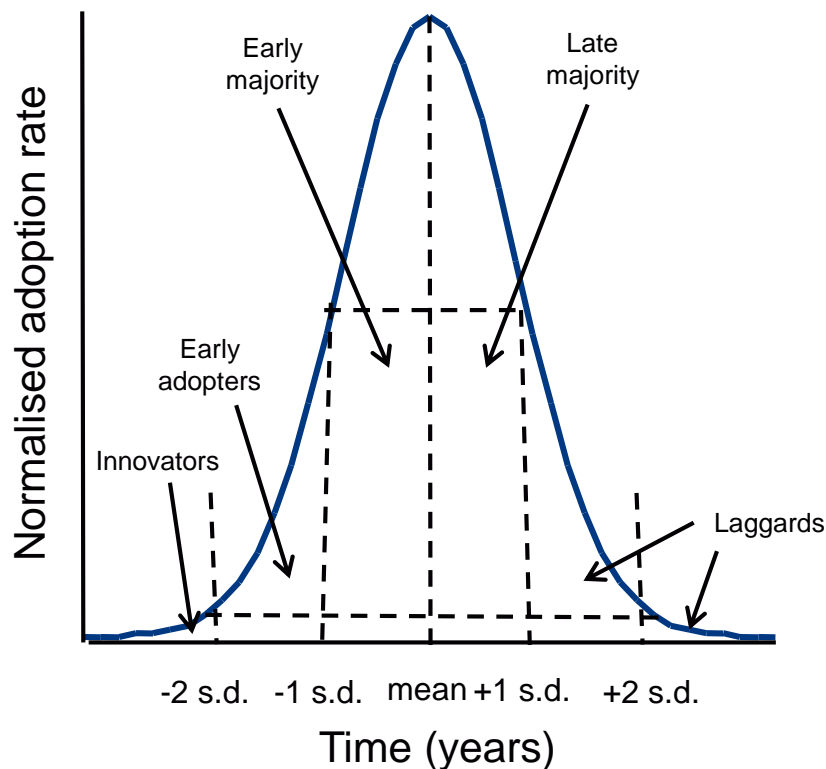


Figure 3: Diffusion model: The distribution of times to adopt, and the statistical definition of adoption segments in terms of position relative to the distribution

Innovators are distinctive in this model in that they are the sources of awareness, knowledge, and positive attitudes towards the innovation. All others in the population act as receivers of awareness, knowledge, and positive attitudes, and then are sources for further diffusion. The last few to adopt are receivers only. It is useful, therefore, to define a category of non-Innovators, all those whose adoption has been influenced by diffusion of awareness, knowledge, and positive attitudes from people who have already adopted the innovation. We shall refer to them as mainstream adopters³. They include all those in the Early Adopter, Early Majority, Late Majority, and Laggard segments in the diffusion model.

Operationally, the various segments – “Innovators”, “Laggards”, etc. – are defined statistically, in terms of position in relation to the normal distribution curve. Thus Innovators are all those whose times to adoption are earlier than two standard deviations before the population mean time to adoption (around 2.5% of the population); Early Adopters are all those whose times to adoption lie between two and one standard deviation sooner than the mean time to adoption (a further 13.5% of the population) and so on.

2.2 PiV Innovators, Early Adopters, and “mainstream” adopters

In the EV uptake literature, the term “Early Adopter” tends to be used imprecisely to refer to anyone who adopts early, and is often not distinguished from “Innovator”. In Rogers’ model, Early Adopters are those who adopt after Innovators, and only after awareness, knowledge, and positive attitudes have diffused to them from Innovators.

³ We shall sometimes also refer to Mainstream consumers or Mainstream car users where this is contextually appropriate. In all cases we shall be referring to those who are Mainstream adopters in relation to EV adoption.

In the 2016 UK light duty vehicle market, 2.5% of the total vehicle parc would be over 800,000 vehicles. So far tens, but not hundreds, of thousands of EVs have been adopted in the UK. It follows that all present users of EVs are therefore Innovators in diffusion model terms.

The ETI PIV project segmentation study (Anable, Kinnear, Hutchins, Delmonte, & Skippon, 2011) defined a segment called "Pioneers" who were high in Innovativeness. None of the sample in that study were Innovators at the time (i.e. non had already adopted an EV), but the segment was defined in relation to responses to questionnaire items measuring innovativeness, so they can best be regarded, approximately, as potential Innovators.

3 Literature review

3.1 Aim

The aim of the literature review was to update our understanding of consumer attitudes towards ULEV⁴ adoption and to explore research relating to consumer acceptance of potential future energy tariffs and EV charging conditions.

Section 3.2 describes the method used for collating the literature to review. Section 3.3 reviews the literature relevant to consumer attitudes to EV adoption (Review 1) and section 3.4 reviews consumer acceptance of managed charging (Review 2).

3.2 Method

The review was subject to a rapid evidence assessment methodology. This aims to maintain the rigour of a systematic review, whilst accounting for time and resource constraints. The following stages were undertaken for Review 1 and 2:

1. *Defining research questions and scope:* The first stage requires the definition of research questions to structure the subsequent search and review stages. The research questions for each review are outlined in section 3.2.1.
2. *Search term development:* A grid of search terms was developed based on the research questions. This can be seen in section 3.2.1. Evidence on PHEVs and BEVs was included but evidence on other alternatively fuelled vehicles (AFVs) was excluded. Evidence on electric vans, lorries and other heavy goods vehicles was deemed to be out of scope. Evidence on both private and business/fleet purchasers was in scope for the evidence search, but the literature on fleet consumers is not reviewed in this report (see deliverable D2.2).
3. *Quick scoping review:* A non-systematic overview of existing research was undertaken. This was particularly necessary for Review 1 (Consumer attitudes to adoption) as two previous comprehensive reviews have been undertaken relatively recently (i) Anable, Schiutema and Stannard (2014) – undertaken in 2011 as part of the previous ETI-funded PiV study (ii) DfT (2015) – a rapid evidence assessment undertaken to review research on ‘Ultra Low Emission Vehicle’ (ULEV) adoption for the UK Department for Transport. The latter study itself drew upon the former. The intention here is not to repeat these reviews, although some material from them is used to set the basis for more recent evidence where appropriate. The evidence review here cites the original sources of literature except where the above reviews have created a novel synthesis or concluded on the specific state of the evidence, in which case the review (Anable et al., 2014 or Brook Lyndhurst, 2015) are themselves cited.

⁴ While the current project is focused on PiVs specifically, it was necessary to adopt more generic terminology for appraising the wider literature to include learnings from ULEV and EV studies. In this chapter only, the most common term in the literature ‘EV’ is used rather than ‘PiV’. While in most cases this refers to plug-in vehicles only, it is not always clear from publications in the research literature which specific vehicle types are addressed: for instance, some questionnaire studies refer only to “electric vehicles”, without distinguishing between BEVs, PHEVs, RE-EVs, or HEVs. Where the specific vehicle type studied is known this is reported (e.g. PiV, BEV, PHEV, RE-EV, HEV).

4. *Literature searching and collating:* The evidence base on ULEVs is extensive (at least in terms of quantity) and rapid evidence assessments, by definition, are not intended to systematically review all available evidence on a given subject. In order to focus the rapid evidence assessment on evidence most able to provide new insights following on from the above two reviews, only sources published from 2012 were considered. Commercial and academic search engines were used (TRL library and information centre; Web of Science; Scopus; Google Scholar) and additional potential sources were identified by members of the research team. In addition, some references were sourced from 'snowballing' using the citations listed in other pieces of literature.
5. *Assess relevance and quality of studies:* The search terms and use of search engines produced 631 unique references (589 for Review 1 and 42 for Review 2). These were logged and assessed (i) against the research questions for relevance, and (ii) for quality (see criteria below). This screening reduced the core list of documents to 95 (82 for Review 1 and 13 for Review 2). A further 27 references (22 for Review 1 and 5 for Review 2) were added during the course of the reviewing phase through snowballing. This is summarised in Table 1.
6. *Reviewing:* the methods used and key findings from each of the studies were documented in an excel spreadsheet against each research question. In the text to follow the evidence synthesis highlights a number of key studies to illustrate each topic where appropriate. Commentary on the quality of this evidence is provided throughout the text 'in situ'.

Table 1: Search results and final number of references consulted

	Review 1: EV adoption	Review 2: Managed charging
# references after initial searching (Web of Science; Scopus; Google Scholar)	589	42
# references remaining after screening	82	13
References added through snowballing	22	5
Total number of references consulted in depth	104	18

3.2.1 Research questions and search terms

Relevant search terms (

Table 2) and the subsequent search term criteria (Table 3) were generated from the defined research questions (RQs) (

Table 2).

Table 2: Research questions and associated search terms

Research question	Search terms used	Section
1.1 What is the relative importance of the following monetary barriers and incentives related to the cost of 'purchase' and non-fuel running costs in the uptake of EVs?	purchase cost/price; maintenance/ servicing; depreciation/residual/re sale value; insurance/breakdown cover; tax incentives/grants/ subsidies; other perks (access to bus/HOV lanes; exemption from congestion charge; preferential parking)]	3.3.1 Monetary barriers and incentives
1.2 What is the relative importance of the following elements related to the non-monetised benefits in the uptake of EVs?	access to bus lanes; access to HOV lanes; parking incentives; road user charging incentives; other	3.3.2 Other monetised and non-monetised barriers and incentives
1.3 What is the relative importance of the following non-cost barriers in the uptake of EVs?	vehicle range; choice of makes and models; perceptions about performance and user experience	3.3.3 Technological perceptions and acceptance
1.4 What is the relative importance of the availability of different refuelling/charging propositions in the uptake of EVs?	at home; at work; public; on street; rapid; slow; trickle; wireless; grants for charge points	3.3.4 Refuelling availability and charging time
1.5 What is the role of the following methods of ownership or finance on the uptake of EVs?	outright purchase; contract purchase; lease; battery lease; contact hire; car club; car sharing; pool car; loans; packages	3.3.5 Financing and ownership models
1.6 What is the role of consumer psychology and wider societal processes?	Pro environmental attitudes; interest in new technology; emotions; symbolic meanings; social norms and diffusion through networks; the role of information	3.3.6 Consumer psychology and wider societal processes
1.7 What do we understand about variations across different population groups and space?		3.3.7 Variation across social groups and space
1.8 How are/will EVs be used after adoption?		3.3.8 EV usage patterns
1.9 What is the state of the evidence, where are the remaining research gaps with respect to consumer attitudes to EV adoption? What recommendations for further research emerge from these findings?		3.3.9 Evidence gaps and research recommendations

<p>2.1 What is the relative importance of fuel pricing/payment/demand management options in the uptake of EVs?</p> <ul style="list-style-type: none"> • How do people rank the attractiveness or acceptability of various types of pricing structure/tariffs and methods of billing? • How do people take these payment systems and tariffs into consideration when adopting EVs? • How acceptable are various types of demand management/controllability and to whom/where/when? • What is the impact of different tariffs/ demand management on charging (and driving/usage) behaviour? • How are these elements taken into account in conjunction with other elements of the consumer proposition? • What are the impacts of these pricing and controllability propositions on uptake of EVs? (Materiality) 	<p>static/time of use tariff/pricing; dynamic/real-time tariff/pricing; critical peak tariff/pricing; peak-time rebates; controllability; direct control/connection; remote control/connection; load/demand management; automated charging; advanced metering; smart grid; smart meter; billing (traditional; own account; PAYG)</p>	<p>3.4 Review 2: Consumer attitudes to managed charging</p>
<p>2.2 What is the state of the evidence and where are the remaining research gaps with respect to managed charging and EVs? What recommendations for further research emerge from these findings?</p>		<p>3.4.4 Evidence gaps and research recommendations</p>

Table 3: Search term criteria

Always use one of these search terms:	
low emission	<i>and</i> car <i>or</i> vehicle <i>or</i> automobile <i>or</i> taxi <i>or</i> fleet
[ultra] low carbon	
electric	
plug-in	
battery	
hybrid	
PLUS terms in review 1 or 2:	
Review 1 (adoption) (post-2012 only)	Review 2 (demand management)
cost	charg* + home
price	charg* + work
insurance	charg* + public
maintenance	charg* + rapid
servicing	charg* + slow
depreciation/residual/resale value	charg* + on-street
breakdown cover	charg* + wireless
tax	charg* + grant
BIK	charg* + payment
incentive	charg* + cost
grant	charg* + pricing
subsidy	charg* + tariff
availability	charg* + billing
information	charg* + rebates
marketing	charg* + control*
access	charg* + demand management
parking	charg* + smart grid
charg*	charg* + meter*
priority	charg* + account
purchas*	charg* + subscription
contract	charg* + membership
leas*	V2G
hire	V2Home
loan	
financ*	
pool car	
mobility as a service	
car sharing	
car club	
attitudes	
psychology	
diffusion	
policy	

3.2.2 Inclusion criteria

Literature resulting from the search process was only put forward for an assessment against the quality criteria if it met the criteria for relevance to the review. This was undertaken by quickly noting the relevance of the paper to inform each research question, based on the abstract and a very quick skim read of the article/report.

It should be noted that the search terms resulted in the inclusion of both conceptual (including review) and empirical papers. Both of these were included even though the emphasis in this review is to assess the state of the art in research that informs us about actual consumer intentions and behaviours. Review papers can offer some useful perspectives and 'food for thought' and were included for this reason. The review also produced literature from around the world but where results were clearly influenced by country-specific factors which could not be easily transferred to the UK context, a lower relevance score was applied. Specific features to note about each review are as follows:

- Review 1: many studies have created models to estimate the demand for EVs based on stated preference or choice experiment data to test different technology and pricing scenarios. The results of these studies are difficult to synthesise without a systematic evaluation of the vehicle attributes included and the trade-offs examined. There are also context/country specific confounding factors that need to be considered as responses in these types of surveys are particularly biased by a consumers current 'baseline' experience (Hess & Stathopoulos, 2013). As a result, these studies were used sparingly in the review and used only where a novel set of vehicle characteristics or choices were examined.
- Review 2: there was a much larger rejection rate among references discovered for this review because many studies of demand response have not investigated consumer attitudes or acceptability. Many studies may simply quantify behaviour through metrics of electricity consumption with some commentary on demand shifting and these were also used sparingly as they tend to provide little insight into consumer motivations. In addition, as will be explained, the literature on EV and demand management is particularly limited. As a result, the review was widened to include a few studies providing behavioural insight into domestic energy demand management more generally.

Based on the above considerations, each paper was scored for each research question as shown in Table 4.

Table 4: Inclusion criteria scoring

Criteria	Score
very helpful/answers the research question	3
quite helpful/partially addresses the research question	2
slightly helpful/may point to other useful sources of evidence	1
no help	0

3.2.3 Quality

An assessment of the quality of the evidence on consumer EV adoption and demand management was made. Each piece of evidence was subject to an assessment of their quality based largely on the methodology adopted. The criteria shown in Table 5 were used to undertake this assessment.

Table 5: Quality criteria

Method used	Score	Sampling	Controls	Analysis
1 - Quant (survey) 2 - Qual 3 - Quant + Qual 4 - Secondary data analysis 5 - Review/ thinkpiece 6 - Other	4	Very good sample size and representativeness	Good use of control groups	-
	3	Adequate sample with some limitations	Incomplete/some use of control groups and/or statistical modelling to control confounding variables	Appropriate statistical methods (e.g. stating confidence limits) or coding methods
	2	Just about acceptable if heavily caveated	No consideration - but acknowledged/ discussed	Some attempt to assess likely confidence limits or significance of effects or explain coding
	1	Sampling approach too inadequate to use (small and/or too selective)	No consideration - results too limited to use	Too limited to use
	0	Other or N/A	Other or N/A	Other or N/A
	Notes	For review papers use scale to judge coverage and approach to literature collection	Not relevant for review or qual papers	Not relevant for review or qual papers

A note of caution is required regarding the application of these quality criteria. The literature on EV adoption has some clear methodological limitations which are to some degree very challenging to overcome – EVs are a new technology and it is difficult to reduce participant ‘psychological distance’ to improve the validity of inferences about acceptance or adoption drawn from their responses. There are studies which recognise this explicitly and adopt various approaches to mitigate against it and these are prioritised where possible. However, the approaches to doing this can themselves be flawed to some degree. For instance, psychological distance can be reduced by giving people direct experience of using EVs in a trial. However, many trials have sample biases such as using samples of early adopters or people especially motivated to considering EVs. In additions, these studies have often failed to measure ‘baseline’ behaviour before participants trial the EV or test what would happen if the participant was given any new car. Overall, therefore, it can be very dangerous to generalise to the majority based on these findings.

Psychological distance can also be overcome to some degree by providing information to ensure participants have some familiarity with the technology, but this is not a substitute for experience and would ideally involve the inclusion of control groups to understand the impact of this information – but this type of study design is rarely adopted. In addition, many studies involve simpler attitude measurements which themselves are trying to understand the ‘real’ state of understanding and (mis)perceptions of consumers as they currently stand, but here the quality and representativeness of the sample is paramount. Quality control of modelling studies can be less harsh than quantitative

surveys as it is assumed that controls are essentially built into the model and yet assumptions that are also built in can be inadequate. Finally, conceptual and review papers are not based on empirical research and need to be assessed based on a much looser set of criteria relating to how systematic the review was and coverage of the issues.

Taking all of this into account, the quality criteria could not be rigidly applied otherwise this would result in very few studies being included in the review. In other words, it was not possible to only include studies that had used a randomised sample, or a control-group design or had very large and representative samples in their trial design. These issues are commented on in situ in the text where relevant and revisited in the sections noting evidence gaps and priorities for future research.

3.3 Review 1: Consumer attitudes to EV adoption

The literature on private consumer EV acceptance and adoption is large and growing rapidly. With respect to the examination of the adoption of this technology, there is a clear focus in this literature on personal cost-benefit related factors, particularly with respect to (i) monetary incentives, (ii) technological perceptions and acceptance (including range and availability of charging stations), and (iii) consumer characteristics. Less dominant but equally as important are the following areas also covered in this review: (iv) methods of financing and ownership (v) consumer experience, psychology and wider social processes and (vi) variations across social groups, space and time. Although this review is focused on consumer adoption, it also covers a section on the use of EVs, to the extent that it is covered in the literature. Finally evidence gaps and areas for future research are summarised.

3.3.1 Monetary barriers and incentives

Section summary

- Purchase price is a barrier to acceptance of EVs, while running cost savings are a motivator. This is an important distinction because barriers can carry more weight than motivators in the process of decision making.
- Recent large scale 'polling' of the UK population shows fewer people identify cost as a barrier to adoption, and three-quarters do not rule out owning an EV entirely.
- The disutility associated with the purchase price of conventional vehicles is smaller than for EVs, as ICE vehicles are considered a safer investment. Even where optimistic cost parity and range scenarios are tested, ICE vehicles are preferred. This puts into focus other factors taken into account such as uncertainty and psychological factors.
- Both EV 'experts' and EV 'non-experts' considered cost-related factors like purchasing price and limited range to be much more important than social identity processes. However, studies have shown that 'hidden' motives about symbolism and self-identity come through strongly in questionnaire studies and may have equal or even stronger effects on acceptance than cost-related factors (see section 3.3.6).
- PHEVs emerge consistently (where differentiated) as more popular than BEVs, even where information on running cost savings is given. These findings calibrate

to some extent the trade-off made between range and running cost. However, it might also be partially due to lower perceived risk of battery replacement costs.

- Current BEV owners are less financially motivated than PHEV owners. For both powertrains, current owners tend to be very aware of how much their car saves them in running costs. However, later adopters may be less willing to perform these calculations.
- Providing information on running costs may be less effective than total cost of ownership (TCO), although this may be more the case in the US where fuel costs are lower. However, where fuel prices are increasing or volatile, consumers may consider an EV as an insurance policy against future rises.
- The absolute and relative price of petrol, diesel and electricity is a confounding factor. The implied payback period of willingness to pay (WTP) may have increased recently as the fuel price has reduced with recent evidence among UK car buyers indicating a higher payback period for EVs (~seven years) compared with earlier studies (Element Energy, 2016).
- This means that increased fuel efficiency standards combined with declining petrol prices could be in conflict with incentives to encourage EV uptake.
-
- Very few studies separate out residual value to test its specific impact. The lack of experience makes this a difficult issue. It is possible that consumers are becoming less concerned or that resale value may actually be starting to become an encouraging factor. However, it is also possible that during the consideration of a new vehicle technology, resale value 'gets lost' among a whole set of more pressing concerns.
- International comparisons suggest a positive relationship between financial incentives and EV uptake, but there are confounding examples and causal relationships have not been proven.
- In one study, the current market share of EVs in the UK is found to be low relative to the level of financial incentive. However, it is clear from the evidence that for comparisons to be meaningful, the combined level of incentives on offer needs to be put in the context of the TCO of the EV relative to an ICE vehicle counterpart in each country.
- How long incentives have been on offer is another factor, as well as different incentive and responses for BEVs versus PHEVs. All countries with a market share over 1% have had incentives in place for at least three years previously.
- There is insufficient evidence as to the impact of withdrawing subsidies.
- Consumers do not tend to cite the price incentive as the reason for adopting an EV, but the majority say they would not have done so without it.
- Purchase incentives are more influential for higher value vehicles.
- Later adopters may be more motivated by material and tangible benefits and so incentives may become more important in the market place.

3.3.1.1 Purchase price

A review of the literature on the uptake of alternatively fuelled vehicles can leave no doubt as to the importance of purchase price in the car adoption decision. The literature is vast and based on a plethora of conceptual frameworks and research methodologies (e.g. choice modelling, attitudinal, experimental, preference valuation studies and others), but nevertheless findings consistently suggest that purchase price is a high ranking, if not the highest ranking motivator or barrier to adoption. Questions still remain, however, about the relative role of this factor against other monetary and non-monetary vehicle and contextual characteristics, as well as how purchase price is taken into account in the car buying process.

The review undertaken for the Department for Transport in 2015 (Brook Lyndhurst, 2015) concluded that the most important factors taken into account by private car buyers when choosing a new car are costs – both purchase price and running costs – as well as reliability, safety and comfort. This finding was heavily based on data collected by the Department for Transport (DfT) in 2014 with ~700 adults (16+ car owners and non-car owners) about attitudes towards car buying and EVs, and subsequently repeated in 2015 (Figure 4). Caution must be exercised with these results due to their inclusion of car buyers and non-car buyers in the sample and the fact that for most questions, participants were able to choose more than one option.

Findings from these two consecutive annual surveys place purchase price as the top factor in *buying cars in general* (Figure 4), the top factor in *encouraging* EV adoption (Figure 5), but as the third ranking factor (after charging and range) as a *deterrent* to adoption (Figure 6).

In this DfT survey data, environmental characteristics rank above size and performance factors in *general car purchase* which is not totally consistent with the broader evidence base as we will discuss in the relevant sections below. To encourage EV purchase specifically, cost (which here is a mixture of purchase and running cost) is also ranked top and environmental 'friendliness' again ranks highly (fourth), but other high ranking response options for this list of discouraging factors also included battery range and charging convenience (Figure 6).

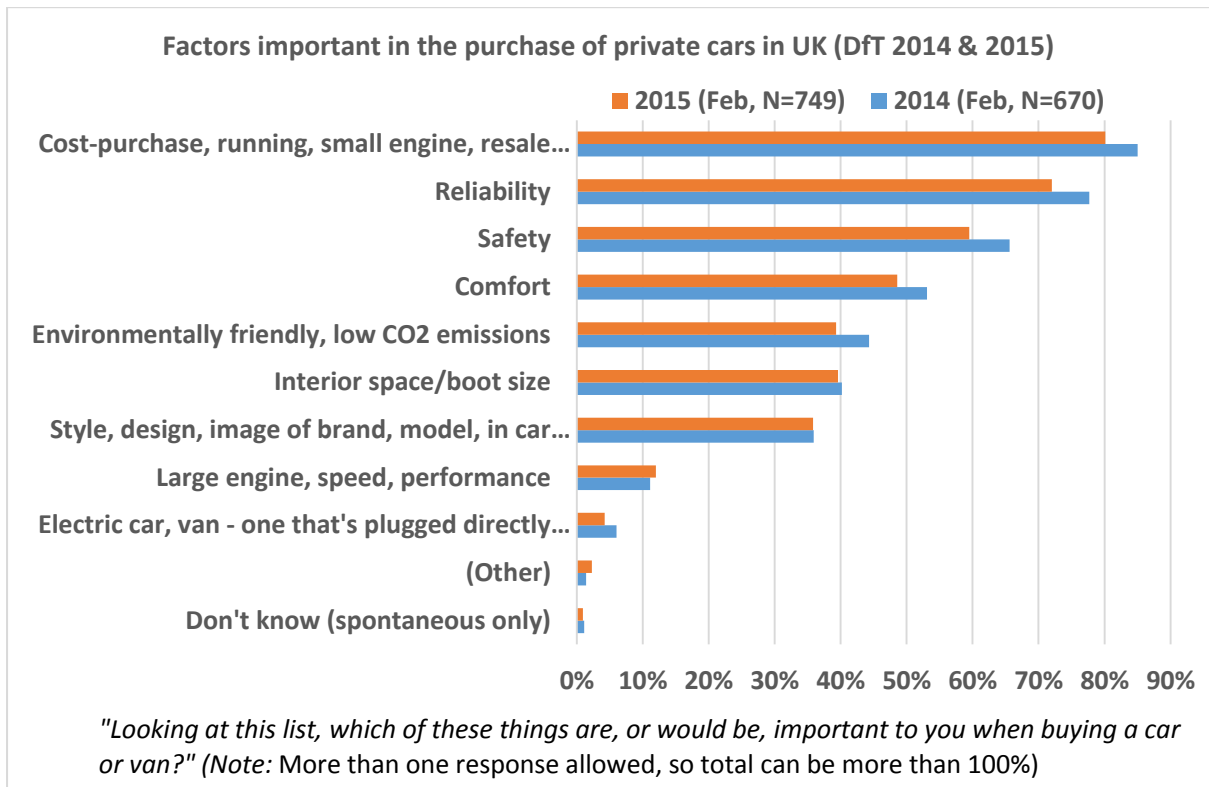


Figure 4: Factors important in the purchase of private cars in the UK (DfT 2014 and 2015)

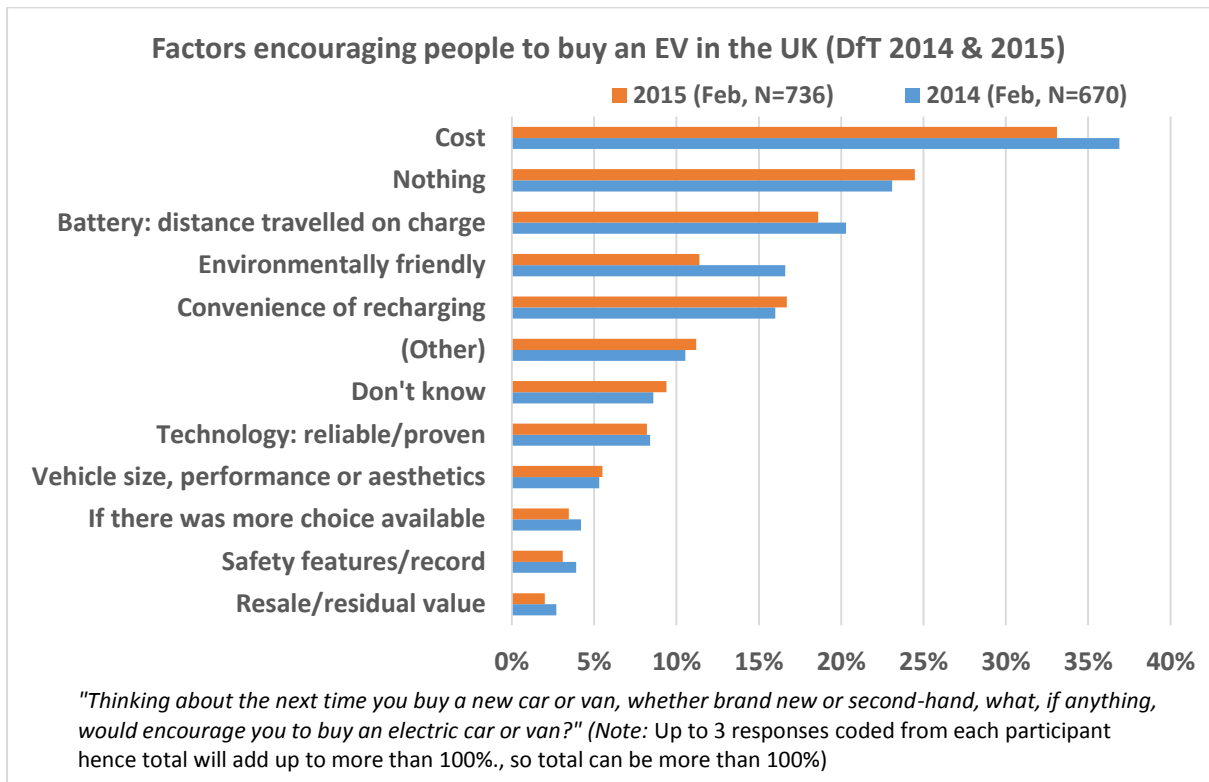


Figure 5: Factors encouraging people to buy an EV in the UK (DfT 2014 and 2015)

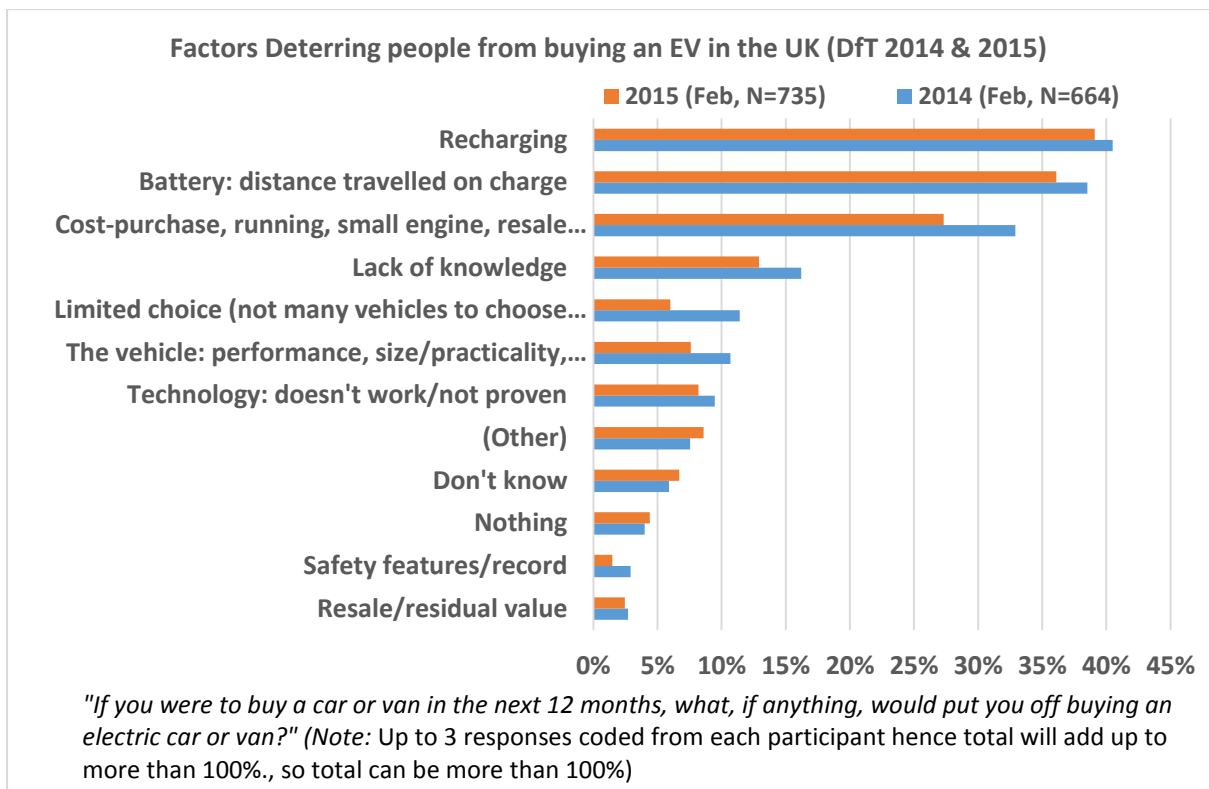


Figure 6: Factors deterring people from buying an EV in the UK (DfT 2014 and 2015)

There are several noteworthy observations to make about these results. Firstly, as the highest ranked factor, EV cost was only chosen as important by 33-37% of participants even though more than one response was permitted to be chosen. If we remove the 23-24% of people who said that 'nothing' would encourage them (these could be people who do not intend to own any sort of car), this still leaves more people who say that cost is *not* a factor than say that it is. Secondly, although the second highest ranked factor to encourage EV uptake was 'nothing', this implies that three-quarters of participants do not entirely rule out EVs.

The above figures ask what factors would encourage or motivate adoption. Surveys will elicit different answers if they frame the question in terms of what would *deter* adoption versus what would *encourage* adoption. In the case of 'deterring', the DfT figures show cost factors to rank below charging and concerns about range (Figure 6). Lack of knowledge, although only cited by 13-16% of participants and reducing over time, may also be an important underlying factor given its potential to mediate or exaggerate several of the other perceived barriers (see section 2.2.6.6). It is also interesting to note the reduction in the number of people citing 'lack of choice' as a barrier between 2014 and 2015 which may be a reflection of the increased number of makes and models appearing on the market during this period.

Attitudinal surveys which rank the factors in similar ways to that carried out by the DfT are generally found in published reports from government agencies, research consultants and third sector organisations each finding broadly the same ranking of factors across a variety of different country contexts (see Anable et al., 2014 and Brook Lyndhurst, 2015). An important distinction can and should be made between explorations of *would-be* EV owners and car buyers who have *already* chosen an EV to understand what motivated them to do so. Given the early market for EVs, clearly studies of the latter produce results on early adopters of EVs and this is not necessarily a good indication of

the factors that may become most important in the minds of mainstream adopters (see Anable et al., 2016 for a discussion of this). Nevertheless, some indications from early adopters indicate EV owners and trial participants report saving money on fuel costs and cite this as an advantage of owning an EV over an ICE vehicle – even if it does not necessarily translate into lower total costs of ownership.

Hutchins et al., (2013) is a key source of information on this in the UK context. The study was carried out by TRL for DfT/OLEV based on a survey of 192 private EV owners who had taken advantage of the PiCG. This study was reviewed in Brook Lyndhurst (2015), but some results are repeated here due to their significance to this review. Hutchins et al. found that 58% of the EV owners cited 'save fuel money' as a reason for choosing an EV rather than an ICE vehicle. The results highlight that financial and environmental factors, plus an interest in new technology, were the most frequently cited reasons for buying an EV. Participants were not prompted with any response options and could provide more than one answer.

Hutchins et al. (2013) reported that EV owners "*tended to be very aware of the amount that using an EV had saved them, and described the cost savings they had made*" (p.66). This is an example of where mainstream adopters could be quite different by not being minded to carry out these types of calculations, as has been empirically tested and discussed in detail in Anable et al. (2014). However, Anable et al. (2014) also make the point that this may not matter, as it is the general sense of saving money which makes EVs seem advantageous over ICE vehicles. This is discussed more in section 2.2.1.2.

These findings on the importance of cost as a barrier to EV uptake are replicated in academic literature, mainly based outside of the UK, including in other reviews of the literature (Turcksin, Mairesse & Macharis, 2013; Rezvani, Jansson & Bodin, 2015). One of the main weaknesses of this literature on EV adoption (including in-depth studies covered below looking at psychological and sociological processes) is the lack of distinction often made between types of plug-in vehicle. However, there are exceptions and these examinations consistently find PHEVs to have a greater acceptance/attraction than BEVs. For instance:

- Baptista, Rolim, and Silva (2012) did an online survey in Portugal that included information to participants about HEVs, BEVs and PHEVs (e.g. vehicle range, battery charge time). The majority (90%) were aware of HEVs and BEVs, but only 56% of PHEVs. HEVs were most popular in terms of alleged 'willingness to buy', then PHEVs and then BEVs (40%, 25%, 13%). Although willingness to buy BEVs increased as participants were given information about fuel being 2–3 times cheaper, PHEVs were still more popular than BEVs (67% vs 57%).
- Axsen and Kurani (2013b) studied 508 new car buyers in California in 2011 to compare stated interests across a number of powertrains. PHEV designs were selected most frequently, particularly those that "blend" electricity and gasoline in charge-depleting operation and thus require less expensive, less powerful batteries. They observed this same pattern in the higher and lower price scenarios, and also in the "points" games where prices were not presented at all.

These results suggest that perceptions of functional (or other – see below) limitations 'trump' price concerns. Barth, Jugert, and Fritsche (2016) offer an important word of caution, however, that the role of different factors change during a single car purchasing journey. This reflects earlier work by Lane (2005) that tracked the relative importance of various vehicle characteristics and showed that price became less important as the purchase came closer.

Much of the remaining literature on the role of purchase price takes the form of academic modelling studies. Indeed, there is a vast literature devoted to models with various discrete and discrete-continuous choice modelling approaches⁵ (see Nie, Ghamami, Zockaie & Xiao, 2016 and Anable et al., 2014 for reviews). This body of literature is too vast to be summarised here and is largely undertaken outside of the UK context. However, in this literature, PHEV and BEV are more often looked at separately and we summarise some of the most recent studies that take this approach.

- Element Energy (2016) have conducted a recent choice experiment with 2,020 new car buyers in the UK and found the net willingness to pay across all attributes reflect a customer preference for PHEVs. In the case of BEVs, only Innovators were prepared to pay a premium.
- Hoen and Koetse (2014) undertook a mixed logit model from an online stated choice experiment of Dutch private car owners. They distinguish between HEV, PHEV, BEV, Fuel cell and Flexifuel vehicles. Results showed that negative preferences for all alternative fuel vehicles were large, especially for the electric and fuel cell car, mostly as a result of their limited driving range and considerable refuelling times. An interaction model revealed that annual mileage was by far the most important factor that determined heterogeneity in preferences for the electric and fuel cell car. When annual mileage increased, the preference for electric and fuel cell cars decreased substantially, whilst the willingness to pay for driving range increased substantially. Other variables such as using the car for holidays abroad and the daily commute also appeared to be relevant for car choice.
- Axsen, Goldberg, and Bailey (2015b) revealed that PHEV oriented consumers place highest value on fuel cost savings (more than five times that of the HEV-oriented class). Interestingly, the fuel cost coefficient was not significant for the BEV-enthusiast class, suggesting that their enthusiasm is not financially motivated.
- Krause, Lane, Carley, and Graham (2016) used a discrete choice survey with 961 potential new vehicle purchasers in large U.S. cities to look at BEV, PHEV, a conventional hybrid, or a conventional gasoline vehicle. When vehicles were presented with their current attributes, the conventional hybrid was the favoured option. Under the breakthrough technology scenario that brings all vehicle powertrains into parity with gasoline vehicles along dimensions of cost, driving range, and charge times, 44% of participants stated an intention to purchase a

⁵ It is worth noting that the range of modelling studies in the literature is broader than discrete choice modelling approaches. Adepetu, Keshav, and Arya (2016) suggest there are three major types of adoption models: Agent-Based Models (ABMs), consumer choice models, and diffusion rate models. Al-Alawi and Bradley (2013) provide a detailed review of different EV adoption models in each of these three categories. Nie et al. (2016) alerts us to a number of recent studies attempt to predict the evolution of market penetration of EVs also by simulation. Many of these studies simulate the vehicle choice behaviour of agents using classical multinomial logit (Shafiei, Thorkelsson, Ásgeirsson, Davidsdottir, Raberto, & Stefansson, 2012) or nested logit model (Lin & Greene, 2010b; NRC, 2013). A different decision process is proposed in Eppstein, Grover, Marshall, and Rizzo (2011) to account for spatial and social effects, as well as media influences. Simulation studies are often employed to evaluate the impact of energy policy (Lin & Greene, 2010a), fuel prices (Eppstein et al., 2011; Shafiei et al., 2012), and availability of infrastructure (Lin & Greene, 2011; Dong, Liu, & Lin, 2014) on the future market share.

BEV, which made it the most frequently selected option with consumer intent to purchase some form of PiV growing to almost two-thirds (65%) of participants.

Only in one study above did BEVs come out more favourably than PHEVs in terms of consumer willingness to pay. Yet, as Krause et al. (2016) note, by definition, choice experiments force consumers to essentially estimate the relative influence of each vehicle attribute separately. However, in practice, changes in EV price, range, and charge time may be interdependent in which an improvement in one dimension is accompanied by either an improvement or worsening in another and it would be impossible for consumers to weigh up the relative merit of each of the attributes so clearly.

Krause et al. (2016) also made another interesting observation when considering why 100% of participants would not prefer an EV under optimistic 'parity' scenarios. They suggested that participants may be aware of other issues that have received significant media attention such as safety issues from overheated batteries, poor battery performance, and diminished resale values (citing for example Woodyard, 2015). Alternatively, reluctance may be due to something personal, such as the possibility that they do not have access to a parking space in their apartment building or condominium where they can plug in. Opportunistically, if batteries are improving, some consumers may perceive that it is better to wait on purchasing a plug-in design until after the technology is perfected. Alternatively, consumers may have developed a high level of comfort with gasoline vehicles that cannot be overcome without extensive hands-on experience with an alternative powertrain and word-of-mouth praise from trusted friends and family members (NRC, 2015). However, these latter 'ponderings' all point to PHEVs being more popular in the short term than BEVs as has been found in the more straightforward attitudinal surveys and some modelling exercises.

Similarly, Bahamonde-Birke and Hannapi (2016) noted from their choice experiment and survey data in Austria that the disutility of the purchase price associated with conventional vehicles is smaller than the disutility ascribed to the EVs. They offered a possible explanation for this phenomenon, suggesting conventional vehicles may be considered as a safer investment as the market information for EVs, such as resale price and depreciation, is unknown.

Recognising limitations with the more 'sanitised' modelling studies, Barth et al. (2016) measured whether the laypersons' perceptions of important predictors of EV adoption are comparable to those of 'EV experts' (e.g. developers and decision makers) in Germany. Qualitative interviews were followed by a survey study. The analysis tested whether cost-related advantages and disadvantages were predictive of EV acceptance and whether norms and collective efficacy have independent effects even when controlling for cost-related factors and demographic variables. The qualitative results suggest that both EV experts and EV non-experts considered cost-related factors like purchasing price and limited range to be much more important than social identity processes. However, hierarchical regression analyses of the survey data showed that norms and collective efficacy have equal or even stronger effects on acceptance than cost-related factors. Kim, Rasouli, and Timmermans (2014) on the other hand found social influence to be less important than cost considerations but their inclusion improved their modelling considerably. We return to these 'hidden' motivators related to factors such as symbolism, subjective norms and social identity in Section 3.3.6

Only one reference was found that examined the different willingness to pay (WTP) for alternative technologies in the first versus second hand markets. Hoen and Koetse

(2014) compared values for new and second-hand cars in their mixed logit model. The only differences in estimation results between new and second-hand cars were those on price and monthly costs. In other words, second-hand car buyers were more price sensitive than new car buyers, but preferences for other attribute levels were similar. The WTP for improvements in AFV characteristics was almost twice as low for people who indicated their next car would be a second-hand car than for people who indicated their next car would be a new car. The authors suggested that these results were somewhat unexpected considering that older cars are typically driven less than new cars, and they therefore suggested that driving range limitations might be less of a problem for second-hand car buyers resulting *ceteris paribus* in higher WTP for electric and fuel cell cars.

To summarise the literature on purchase price, studies on consumers' acquisition of cars with emergent technologies show that it is determined by multiple variables, often in interaction. In particular, when allowed to provide 'own word' responses, cost is clearly seen to be very important but only one of among a number of important factors. However, free responses in qualitative interview studies do not necessarily elicit other, more hidden motivations which are revealed as equally or more important than price when attitudinally rich survey methods are used. As a result, most studies conclude that policy approaches based solely on financial benefits and other policy-related advantages are unlikely to produce much change in longer term. On the other hand, as we shall see below, neither moral approaches (i.e. appealing to values to change broad world views and beliefs) nor educational approaches (i.e. providing information to change specific attitudes and beliefs) alone will be sufficient to change behaviour. There is, however, strong evidence that significant governmental incentives and regulations combined with information or moral appeals will be much more effective. These aspects are explored below.

3.3.1.2 *Running costs*

The evidence presented above shows that the relative importance of running costs and purchase price in the adoption decision can vary according to whether or not *motivators* or *barriers* are being measured – i.e. purchase price is a key *barrier* whereas reduced running costs are a key *motivator*. The key is therefore to understand the trade-offs made between these two financial considerations. However, there remains a considerable gap in understanding around the implicit discount rates consumers' use and the payback periods consumers consider acceptable for alternatively fuelled vehicles (Liu & Santos, 2015). This is at least in part due to the difficulty once again of eliciting this information in surveys.

Although EVs can compare favourably with conventional vehicles in terms of their TCO, most people either do not or cannot make such calculations (Hagman, Ritzén, Stier, & Susilo, in press; Morton, 2013). Hagman et al. (in press) note that the testing of a TCO model with consumers which includes a variety of running costs including depreciation, interest rate payments and maintenance costs would be a challenging computational task for consumers due to bounded access of relevant data and the prediction of future conditions. This is reflected in the following studies which found the disutility of the purchase price associated with conventional vehicles is smaller than that for EVs but when exposed to EVs, willingness to pay increases:

- Bahamonde-Birke and Hanappi (2016) estimated discrete choice models on 1,449 participants in Austria. The purchase price negatively affected the utility associated with a given alternative. It is noteworthy that the disutility of the

purchase price associated with the conventional vehicles was smaller than the disutility ascribed to the EVs. The authors offered a possible explanation for this phenomenon that conventional vehicles may be considered as a safer investment, as the market information for EVs, such as resale price and depreciation, is likely unknown for large segments of the population. Finally, the disutility of the purchase price was smaller for wealthier individuals, which is in line with our expectations.

- Larson, Viáfara, Parsons, and Elias (2014) conducted a small survey (n=240) of people with and without exposure to EVs in Canada, which revealed that consumers are unwilling to pay large premiums for EVs, even when given information on future fuel savings. A consumer group with experience or exposure to EVs is somewhat different.

People tend to use simple rules and heuristics to draw conclusions about the fuel efficiency of vehicles and their likely TCO, for example comparing the fuel efficiency of a new vehicle to their old vehicle (Anable et al., 2014) or using the cost of their most recent refuel as an indicator of running cost (Morton, Anable, & Nelson, in press). In addition, the role of these attributes is also subject to change as costs change, as the decision making evolves for an individual during his/her car purchase 'journey' and over time as the market transitions to mainstream consumers.

Evidence that consumers may lack an intuitive understanding for the relative prices of gasoline and electricity as well as the different amounts of these two energy sources that are used by vehicles over their lifetimes:

- Krause et al. (2013) in a survey of 2,302 adults in 21 large cities in the US, found that almost two-thirds of the participants provided incorrect answers to basic factual questions about PiVs and, of those, approximately 75% underestimated the fuel savings for a PiV.
- Axsen and Kurani (2012) held focus groups with car buyers demonstrating that few engage in any calculations comparing the elevated cost of purchasing the fuel-saving technology with savings in overall fuel expenses over the ownership lifetime.

Although consumers might not engage in the calculations, surveys indicate that the vast majority of participants believe that fuel economy is an important vehicle attribute but they do not necessarily find that this leads to EV adoption intention. For instance, Carley, Krause, Lane, and Graham (2013) found that fuel costs emerge as a primary tangible advantage but this fails to exert a strong influence on purchase intentions. Instead, interest in EVs is shaped primarily by consumers' perceptions of EV disadvantages.

However, it is still difficult to understand from the evidence how consumers take running costs into account and therefore how much importance they have. One study attempted to look in more depth at the role of running costs by providing detailed information on running costs for a number of vehicles. Dumortier et al. (2015) assessed the effect of presenting the consumer with monthly cost of ownership in addition to five-year fuel expenditure savings using a rank ordered logit model on an HEV, BEV and PHEV. A total of 3,199 participants were collected from 32 US metropolitan areas. The rank-ordered logit model reveals that the provisioning of the five-year fuel expenditure savings information is not statistically significant for any vehicle. The authors speculate that this may be different in Europe where fuel prices are much higher. However, when total cost of ownership information is disclosed to participants interested in small/midsized cars,

the likelihood of ranking a HEV, PHEV, and BEV more favourably increases and is statistically significant (especially PHEV and BEV).

The majority of studies focus on fuel costs despite the fact that running costs comprise of a number of different types of expenditure including annual taxes, servicing, insurance etc. In this review only a couple of studies attempted to look at these separately and it has to be concluded that the state of knowledge on how these different costs are considered is poor:

- The above mentioned DfT (2014 & 2015) survey included a question to identify the role of these cost factors individually (although it only asked those recipients who had previously suggested that cost was a deterrent to buying an EV) (Figure 7). The proportion of participants citing purchase and running costs as a factor to encourage purchase has reduced over this time period. By contrast, resale value, whilst low ranking, saw the greatest increase between 2014 and 2015 – a tripling from 5% to 17% of these participants (See section 3.3.1.3 below for a discussion of the role of residual value). Maintenance cost is the third ranking factor.
- Bahamonde-Birke and Hanappi (2016) found higher fuel and maintenance costs to negatively impact the utility ascribed to a certain alternative. It was not possible to identify a statistically different valuation of these two features, meaning that fuel and maintenance costs are perceived equally by their Austrian population.

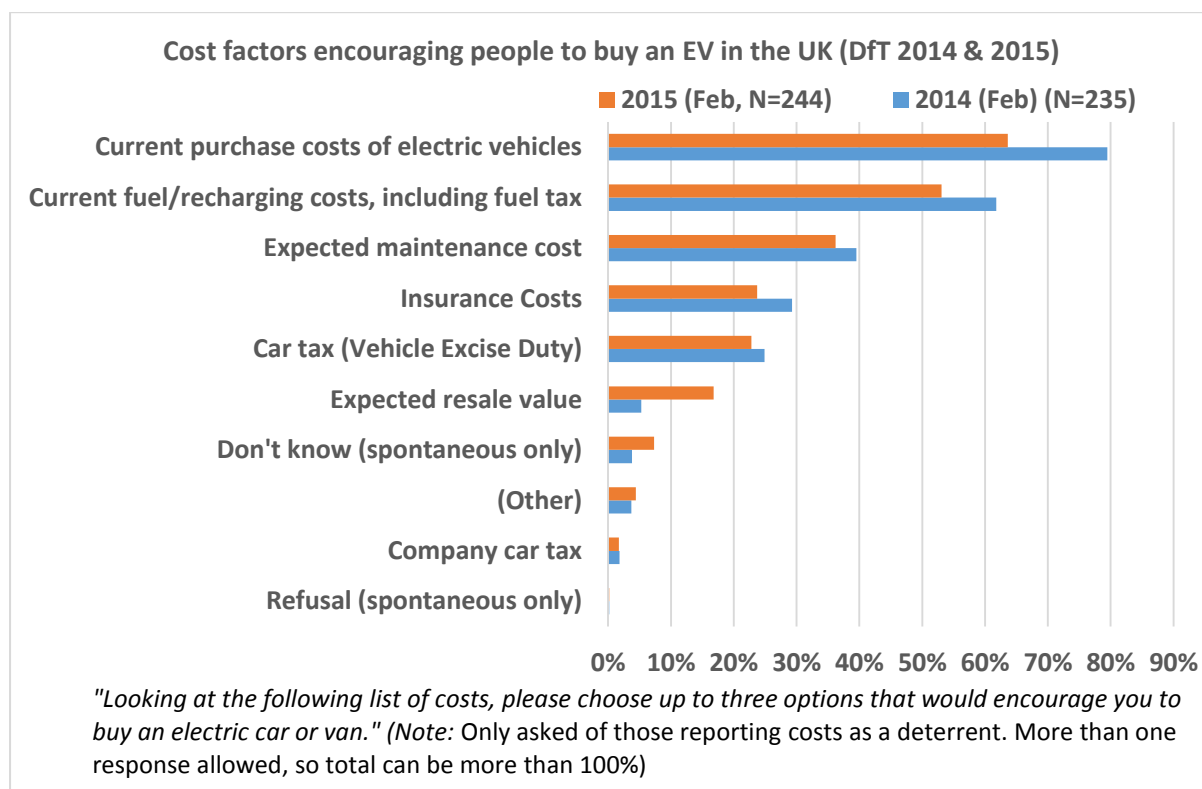


Figure 7: Cost factors encouraging people to buy an EV in the UK (DfT 2014 and 2015)

The absolute and relative price of petrol/diesel and electricity is another confounding factor in the consumer decision making process. Increases and perhaps even more specifically *volatility* in fuel prices appear to make the running cost savings of EVs more salient to buyers.

Element Energy (2016) have conducted a recent choice experiment with 2,020 new car buyers in the UK and found the overall willingness to pay for fuel cost savings implied a seven year payback period. They observe that this value is significantly lower than the average vehicle lifetime of 12-13 years and it is also slightly higher than other studies observing 3-6 years but they explain this by the fact that the survey was carried out in March 2015 after the rapid falls in petrol prices at the end of 2014 so participants may have factored-in increasing future fuel prices in their answers.

Reid and Spence (2016) cited a US study showing that an increase in gasoline fuel efficiency has a significant effect on the percentage of potential EV adopters (Deloitte, 2011). Specifically, Deloitte found that achieving an average fuel efficiency of 50mpg would reduce the consumers interested in purchasing PiVs by 68 percent. Additionally, the vast majority of participants indicated that gas prices were a significant determinant in their purchase choice. If gas prices rose to \$5.00 per gallon, then the share of participants interested in EVs would rise to 78 percent (Deloitte, 2011).

As a result, it is a logical conclusion that increased fuel efficiency standards coupled with declining gasoline prices conflict with implemented incentives to encourage EV uptake.

Reid and Spence (2016) noted that the US Environmental Protection Agency may be in conflict with itself as it oversees both the EV incentive schemes and the car fuel economy standards there. Because fuel prices and fuel efficiency play important roles in consumer purchasing choices, and combustion engine vehicles are notably less expensive than their PiV counterparts, increased fuel economy standards may impede, rather than encourage, PiV sales.

Da Silva and Moura (2016) advocate a rethink on the tax applied to conventional vehicles in order to counter greater ICE vehicle efficiency. They concluded that the increase in the tax applied to fossil-fuel sales as well as applied to conventional vehicles' sales are the most efficient policies to increase the diffusion of EVs.

Rezvani et al. (2015) postulated that because during the last few years the fuel efficiency of ICE vehicles has increased rather dramatically, the EV may lose out in terms of its perception as an innovation by consumers as ICE vehicles are viewed instead as having new types of innovative engines and other technologies. This poses challenges to EV manufacturers to continuously re-innovate EVs if the aim is to make consumers perceive it as an innovation over time. They also called for continuous research on the perceived differences of ICE vehicles and EVs among consumers.

In addition, the size of the difference between electricity and oil prices may explain some of the variations in the relationship between incentives and in EV uptake in different countries but this is an under researched area.

Norway, for example, has relatively high gas prices but relatively low electricity tariffs, whereas the difference is notably smaller in Denmark (Mock & Yang, 2014). It is worth noting that there may be geographical sensitivities to fuel price changes.

Hanappi et al. (2012, cited in Hjorthol, 2013) did an online survey in the area of Vienna to examine determinants in the decision to purchase alternative fuelled vehicles. The total sample was 714 participants aged between 17 and 85 years. They found that high fuel prices have the greatest effect on the market share of EVs in rural areas, whereas in regions with medium density it is the increase in the range of EVs that had the greatest effect. This might be relevant in the UK where there is already a generally higher sensitivity to fuel prices in rural areas (Dunkerley, Rohr & Daly, 2014).

Overall, this review found little evidence to update the research already reviewed in Anable et al. (2014) which suggested that that the speed of price increases and the relative costs of different fuels are more important than absolute prices. People react to sharp rises in fuel prices, making purchase decisions on the basis of perceived costs and savings rather than detailed payback calculations – which in any case would be difficult to make, as future fuel prices are unknown (Anable et al., 2014). People may consider EVs to offer ‘an insurance policy’ against rising fuel prices. Although the purchase cost of an EV is higher than that of a conventional vehicle, the buyers may feel protected from the impact of potential or likely future increases in fuel prices (Hutchins et al., 2013). People tend to assume that electricity prices will rise more slowly than petrol prices (Anable et al., 2014). However, there remains a considerable gap in understanding in relation to how absolute and changing running costs are considered and around the implicit discount rates consumers use and the payback periods consumers consider acceptable for AFVs.

3.3.1.3 Residual value

Majid and Russell (2015) used a hedonic price model with US sales price data from the used car market of 11 models of car data between 2004 and 2011 and showed that hybrid vehicles lose value faster than their non-hybrid counterparts. As they explain: *“In theory, green products should retain greater value than non-green equivalent products because they offer cost savings over time through decreased expenditure on energy or waste. However, the argument for greater value retention ignores the fact that green technology’s rapid evolution makes it more susceptible to cannibalization due to technological improvements.”* (Majid & Russell, 2015, p.994). This is a vicious circle, though, as reluctance to adopt green products (partly because of the resale value issue in this case) may itself harm the value.

Very few studies separate out residual value as to test its specific impact, even if an assumption for depreciation is included in TCO calculations to be tested (e.g. Dumortier et al., 2015). As noted in Brook Lyndhurst (2015): *“The lack of experiential evidence to date may reflect the fact these are issues likely to only emerge over an extended period of ownership, and that most research to date has been with trial participants and owners relatively early on in their ownership of an EV”* (p.26). What evidence there is suggests that resale value is currently being perceived as a disadvantage by some EV owners, but this could change rapidly. The few additional findings of this review are as follows:

- DfT (2014 and 2015, see Figure 7 above) data collected one year apart place ‘expected resale value’ below purchase cost and most other cost factors as a motivator of EV adoption. It is notable that the proportion of people who suggested this is an ‘encouraging’ factor increased approximately threefold between 2014 and 2015. It is possible that this signals increased confidence in EVs’ durability by consumers. After all, as Lim, Mak, and Rong (2014) note, *“EV manufacturers show much higher degrees of confidence in the durability and resale values of EVs, as evident from their recently announced guarantee programs on resale values and battery depreciation”* (p.2).
- Figenbaum, Kolbenstvedt & Elvebakk (2014) found that 56% of EV owners in Norway cited uncertainty over the resale value of their EV as a disadvantage. Only range-related issues and uncertainty over the continuation of incentives were cited as disadvantages by a higher proportion of participants.

- Although undertaken with the UK light commercial vehicles sector, Kirk, Bristow, and Zanni (2014) identified the lack of a reliable residual value projection for gas powered vehicles as a secondary level inhibitor after infrastructure constraints and vehicle cost. They ponder why other research has not found residual value to be a strong factor, including with fleets, and suggest that this is perhaps because the process of entertaining a new option encourages consideration of the whole picture rather than the business as usual decision making pattern. This is an interesting observation which further research could explore with private adopters.

3.3.1.4 Government financial incentives

In the UK, two main financial incentives targeted at alleviating the cost of ownership (as opposed to use) have been available now for several years:

- The Plug-in Car Grant (PiCG): This was introduced in 2011 to reduce the up-front cost of ULEVs by providing a 25% grant towards the cost of new plug-in cars, up to a maximum of £5,000. From 1st April 2015, the grant was raised to cover up to 35% of the vehicle's recommended retail price, meaning buyers of cheaper EVs can still qualify for the maximum of £5,000. From March 2016 cars with a range of greater than 70 miles, including hydrogen fuel cell vehicles, will receive £4,500 but hybrids with a shorter electric range and costing less than £60,000 will receive £2,500. The grant is due to continue until at least March 2018⁶.
- The Electric Vehicle Homecharge scheme: This was introduced in 2013 (initially as the Domestic Chargepoint Grant) to enable ULEV owners to receive a grant towards the installation of a domestic charge point. From 1st March 2016 the grant offers £500 per installation (previously 75% capped at £700) which on average covers around half the cost of installing a dedicated charge point.

Separating out and accurately quantifying the impact of public incentives is challenging if not virtually impossible. Nevertheless, the experience to date of financial incentives in a variety of different country contexts over different time periods and at different 'states' of EV market development provides some evidence upon which to assess whether or not they have a role to play, even if the magnitude of their impact is less clear. However, the evidence is still weak on both the impact incentives might have as the market matures and what might happen when existing incentives are removed.

The evidence on the role of financial incentives comes in two main forms: (i) comparative analysis of incentives and EV uptake in different countries at an aggregate scale; (ii) findings from research with consumers on the impact of incentives. Other factors, notably measures which accrue ongoing benefits to EV owners during ownership, have been found to mediate the relationship between financial incentives and EV uptake.

3.3.1.5 Comparative analysis of uptake of incentives in different countries

Attempts have been made to quantify the impact of incentives by analysing and comparing levels of EV uptake in different countries (or in different states, in the case of some US studies) with different levels of incentives. International comparisons suggest a positive relationship between financial incentives and EV uptake but the findings from this have been quite mixed with confounding examples (of countries with high incentives

⁶ http://www.lowcvp.org.uk/news.government-announces-extension-to-plugin-car-grant_3373.htm

but low EV uptake). As noted by Brook Lyndhurst in their 2015 review for DfT, "in studies where a relationship has been found between incentives and EV uptake this has generally come with a number of caveats about the strength of this relationship and the confidence that can be placed in the findings" (p.33).

The following studies each took data from a number of countries on EV sales, levels of incentive and, variously, other factors such as charging infrastructure.

Sierzchula, Bakker, Maat, and van Wee (2014) regressed EV market share on financial incentives, urban density, education level, an environmentalism indicator, fuel price, EV price, the presence of production facilities, per capita vehicles, model availability, introduction date, charging infrastructure and electricity price for 30 countries. Their model explained two-thirds of the variance, with financial incentives and charging infrastructure the greatest explanatory factors. Charging infrastructure was a stronger predictor than financial incentives. Adding a charging station (per 100,000 residents) had a greater impact on predicting EV market share than did increasing market incentives by \$1000. The presence of a local manufacturing facility was also a significant variable. Holding all other factors constant, a \$1000 increase in financial incentives would increase a country's market share of EVs by 0.06%. For charging infrastructure, holding all other factors constant, each additional station per 100,000 residents that a country added would increase its EV market share by 0.12%. Figure 8 shows the EV market share and corresponding market incentives by country in 2012. On the basis of the analysis, the authors reached the following conclusions: "...while this study does show that financial incentives are positively correlated to national EV market shares, it is definitely not evidence of a causal relationship and should be treated with prudence" (p.192).

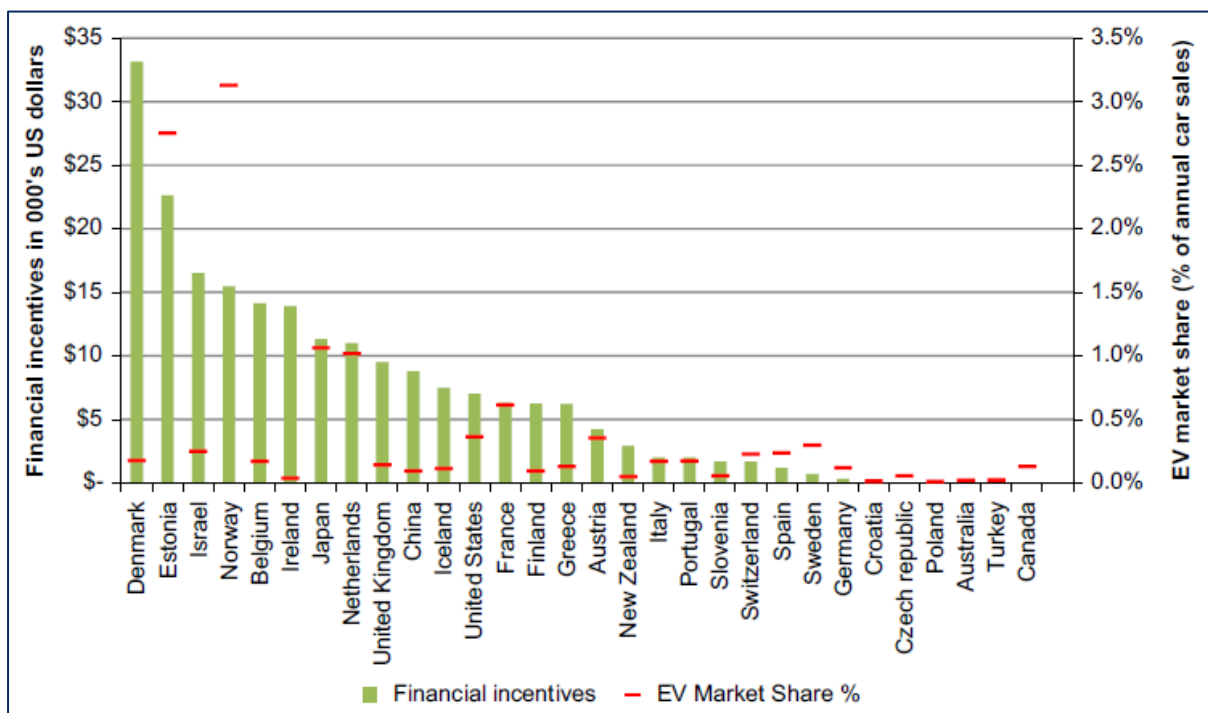


Figure 8: Financial incentives by country and corresponding EV market share for 2012 (from Sierzchula et al., 2014)

Mock and Yang (2014) looked at bundles of price incentives and created an equivalent 'per vehicle' metric (in terms of the percentage of a vehicle's base price. It does so by focusing on two representative vehicles (the Renault Zoe BEV and the Volvo V60 PHEV) to examine the relationship between financial incentives and EV market share in various

global regions in 2012-13. The study looks at three types of financial incentive: (i) direct subsidies (e.g. a one-time bonus upon purchasing an EV); (ii) fiscal incentives such as reduced purchase and/or annual taxes for EVs); (iii) fuel cost savings due to electricity prices being lower than fuel prices. Figure 9 summarises these relationships. The research findings indicate that fiscal incentives matter, but are clearly not the only factor that influences today's EV market growth. For example, despite a relatively high level of fiscal incentives, the current market share of EVs in the United Kingdom (UK) was found to be low in comparison with other markets. The authors suggest that "many confounding factors mean that a clear direct relationship remains elusive between national fiscal incentives and electric vehicles' early market growth across each of the major vehicle markets—as seen in the spread of the data and the lack of an obvious trend line in Figure 9. This indicates both the limitation of fiscal policy and also the limited understanding of all the underlying factors and other policies that could help drive and sustain the electric vehicle marketplace" (p.iii).

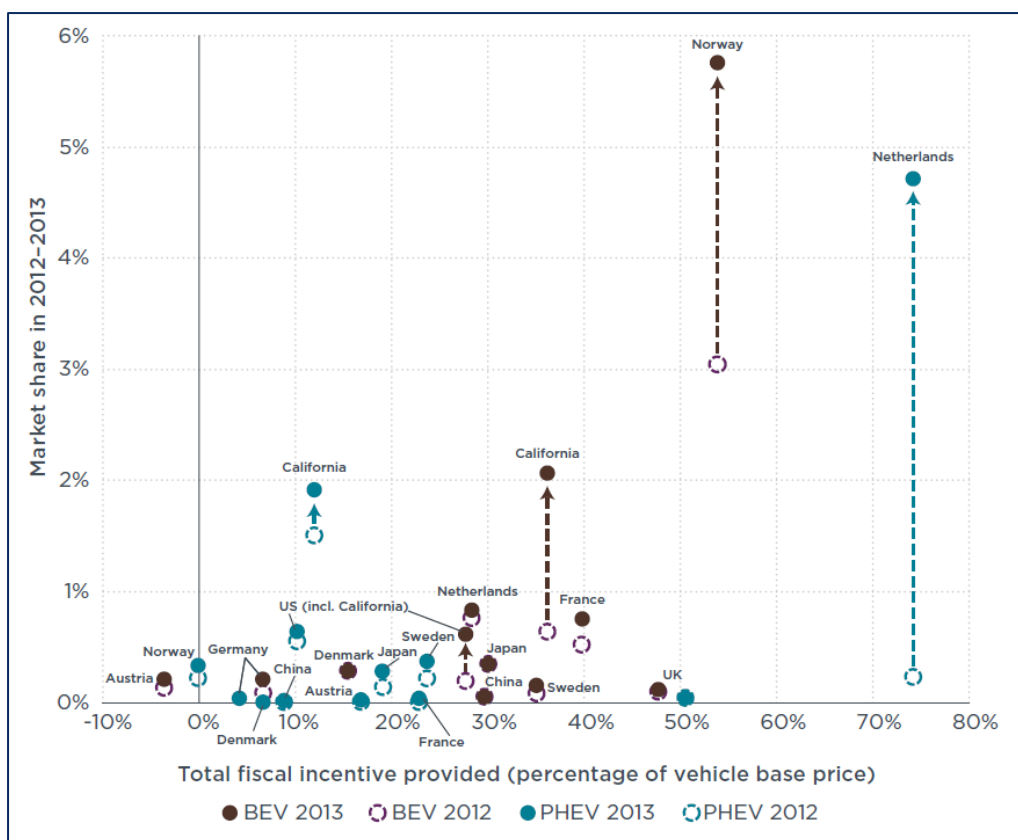


Figure 9: 2012 and 2013 market share vs. per-vehicle incentive for battery-electric (BEV) and plug-in hybrid electric (PHEV) (from Mock & Yang, 2014)

The above two studies demonstrate the difficulty in settling on a meaningful metric for the incentives provided in order to evaluate their impact. Many studies, such as Sierzchula et al. (2014), use the 'face value' level of the incentive to perform the analysis and in this case the results appear to show that Norway in particular has both high incentives and high EV market share, but Denmark and, to a certain extent the UK, defy this relationship given their relatively high incentives but lower market uptake. However, if combinations of fiscal incentives are examined together and then further put in context of total cost of ownership (TCO) in each country for the plug-in vehicles relative to equivalent ICE vehicle counterparts (Mock & Yang, 2014), the role of incentives will differ in each context. Mock and Yang explain the disproportionate success

of the EV market in Norway not just by the absolute level of the subsidies but by the fact that the TCO of the equivalent ICE vehicle is significantly higher than the base price due to the taxation regime and the cost of fuel. By contrast in Norway, the tax incentive for PHEVs is not so generous because the incentive structure is based on power plus a high VAT based on vehicle price, and so the TCO of a PHEV is higher than that of the equivalent diesel. This therefore also demonstrates that the basis of the tax incentive (e.g. CO₂, vehicle price or power) also makes a difference. In the Netherlands, the CO₂-based registration and ownership taxes mean that the advantage between a plug-in and electric equivalent may be quite small and getting smaller as ICE vehicles become more efficient. In California, the authors find higher growth rate and market share than other markets with the same level of fiscal incentives and suggest this is due at least in part to other non-monetary incentives (such as HOV lanes – discussed below).

Mock and Yang (2014) also found that the level of incentives provided tends to be higher for company cars than for private cars but could not look specifically at the relationship between these incentive levels and uptake as the data are not well broken down between private and company EV shares other than in Germany where the share of EVs is about three times higher for company cars than for private cars.

The role of incentives is further complicated by the fact that there may be country-specific (cultural) responses to incentives, as well as differential responses by consumers at different places on the market adoption trajectory.

Helveston et al. (2015) found that US participants have a significantly lower willingness to pay for BEV technology than those in China, though American consumers are more responsive to subsidies for PHEVs than BEVs. This is presumably largely due to the different policy and social environments and the fact that the supply of BEVs is more restricted potentially generating a prestige or status effect for which higher premiums might be paid. Nevertheless, this demonstrates how the role of incentives needs to be set in country-specific contexts.

There are also features of financial incentives themselves (other than how big they are) that mediate their impact. These include:

- *How long incentives are in place:* Norway introduced its exemption from registration tax for EVs in 1996 and its VAT exemption in 2001, whereas other countries, including the UK, have introduced financial incentives in the last five years. Figenbaum and Kolbenstvedt (2013) and Element Energy et al. (2013) suggest this is one reason why Norway's EV market share is so high. Financial incentives in the Netherlands were also introduced relatively early, in 2006, (Vergis, Turrentine, Fulton & Fulton, 2014) which may help to partly explain their large EV market share.
- *BEV vs PHEV:* As reported in Brook Lyndhurst (2015), Mock and Yang (2014) and Element Energy et al. (2013), differences in the value of incentives for BEVs and PHEVs may influence the relative market share of each – although no findings are ventured on the implications for overall uptake of EVs. In Norway, BEVs have been eligible for all financial (and non-financial) incentives since their introduction, whereas PHEVs have only recently been deemed eligible for some of these. Almost all EVs sold in Norway have been BEVs (Figenbaum et al., 2014). In contrast, in the Netherlands incentives have been similar for PHEVs and BEVs and it is suggested that this has resulted in most EV sales having been PHEVs. In California, BEVs qualify for higher financial incentives than PHEVs, which may explain why, in contrast to the Netherlands, BEVs represent around half of EV

sales (Center for Sustainable Energy, 2015). Vergis and Chen (2015) examined the correlation between social, economic, geographic and policy factors on plug-in EV adoption of US states. They found different sets of variables to be significantly correlated with PHEV and BEV market shares, respectively, which suggests that these markets are distinct and that policies aimed at promoting EVs in general may not be equally effective at supporting both BEV and PHEV markets. They found incentives (the presence of a direct purchase incentive and the cumulative number of other supportive incentives and policies in the state directed towards EVs) to have a greater impact on PHEV uptake than BEV uptake. By contrast, environmentalism and vehicle miles travelled were less impactful on PHEVs compared to BEVs. The differences between the factors that are correlated with PHEV and BEV respectively highlight the possibility that different strategies may be required for promoting the adoption of the two vehicle types.

As noted by Brook Lyndhurst (2015) and confirmed by this present review, there is insufficient evidence to date to draw any firm conclusions about the impacts of reducing or withdrawing incentives on EV uptake. Two examples were found in the literature:

- In British Columbia, funding for a \$5,000 purchase rebate for EVs expired in February 2014, but its reinstatement was then announced a year later. Although some data on EV sales before and after February 2014 has been published in an online article, it does not provide a robust basis for assessing the impact of the expiration of the rebate (Brook Lyndhurst, 2015).
- The case of the Netherlands, where the main financial incentive for PHEVs expired on the 1st January 2014, was reported in Vergis et al. (2014). The authors comment that *"it appears that in the months leading into the dissolution of PHEV incentives purchases were high, fell shortly after the expiration of the PHEV incentives, and have since regained ground"* (p.6) (Figure 10). Indeed, most recent data for December 2015 shows that an historic 16,000 vehicles were sold and *"represent the monthly highest volume of a given market outside China"*⁷. Thus, whilst the very sharp rise and fall immediately prior to and after the withdrawal of the incentive suggests that incentives elicit a powerful consumer response, as mentioned above, basing analysis on the face value of an incentive (or its withdrawal) cannot provide sufficient explanation or offer a reliable basis on which to predict consumer behaviour. Nevertheless, the impact of withdrawal at different TCO differentials between ICE vehicles and EVs requires much more research.

⁷ <http://ev-sales.blogspot.co.uk/2016/01/netherlands-december-2015.html>

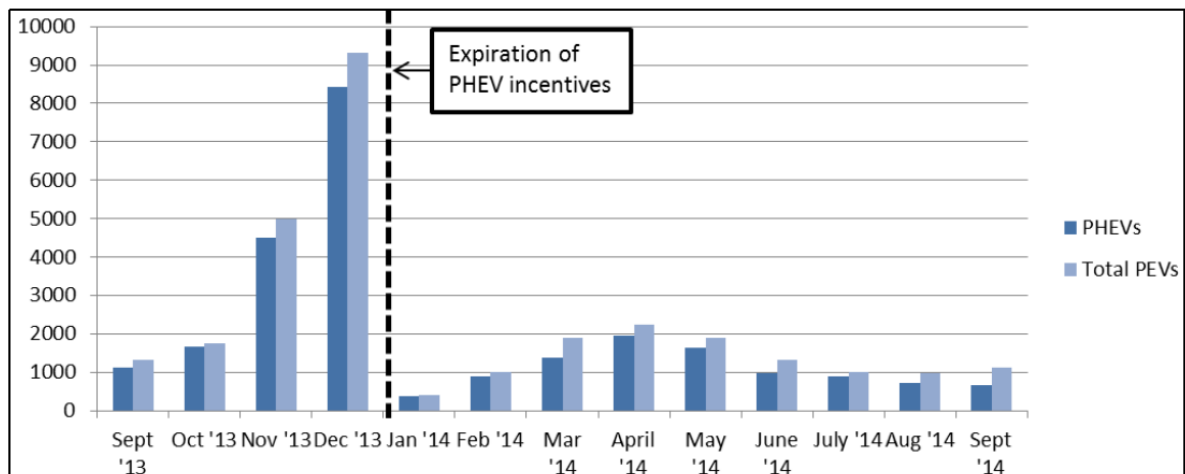


Figure 10: PHEV and PiV units sold by month in the Netherlands (Sept 2013 – Sept 2014) (Vergis et al., 2014)

To conclude on the issue of financial incentives, the evidence strongly suggests that financial incentives are one amongst several factors influencing uptake, and that these other factors can mediate the impact of a financial incentive. The evidence indicates that all countries with an EV market share of above 1% have had financial incentives in place for three or more years previously (Brook Lyndhurst, 2015). The example of Norway also suggests that very high financial incentives, in place for a longer time period, can contribute to a very high EV market share. However, the example of Denmark illustrates that generous financial incentives do not guarantee a high EV market share. Other factors (notably measures which accrue EV owners' ongoing benefits during ownership) and features of how financial incentives are designed can play significant roles in mediating the impact of financial incentives on EV uptake. Although sources have tended to look at the impact of different factors independently, the evidence also suggests that a package of well-designed financial incentives plus non-financial incentives (and possibly also investment in public charging) may be the most effective means of increasing EV uptake.

3.3.1.6 Studies with consumers examining the role of financial incentives

The logic underpinning incentive-based policies is rooted in rational choice economics and theories of utility maximisation which expect individuals to react strongly to price signals (Siddiki et al., 2015). While economic research proves this to be generally true and some evidence on the direct role of incentives is documented below, behavioural economics and social psychologists have uncovered an array of mitigating factors that reflect the normative and otherwise subjective perceptions/motivations that influence decision making in ways that are often not consistent with purely rational choice models of the individual. Some of this is highlighted in this section but returned to in section 3.3.6.

Private and fleet EV owners in the UK indicate the PiCG was important in reducing the upfront costs of EVs. In the research for DfT with PiCG recipients in 2013 (Hutchins et al., 2013), 84% of private participants stated that they had been aware of the PiCG when they first considered buying one. Less than 5% spontaneously cited the PiCG as a reason for buying an EV but in the qualitative element of the research: "many participants explained that they would not have been in a position to purchase their EV

had they not been eligible for the Grant” (p.44). When prompted, nearly 90% also stated that the PiCG had been very or fairly important in their decision to buy an EV.

There are similar findings from EV owners in California, when asked about the importance of the federal tax incentive of up to \$7,500 and the state rebate of up to \$2,500 in their ability to acquire an EV. These findings are useful in demonstrating that incentives do appear to be something most EV owners are conscious of when making the decision to buy an EV. In the case of private purchase they appear to have played an important role in reducing the existing price premium EVs have in comparison to ICE vehicles, and making it easier for them to be able to afford to buy one.

Bjerkan, Nørbech, and Nordtømme (2016) studied which groups of buyers responded to which groups of incentives in Norway. Exemptions from purchase tax and VAT are critical incentives for more than 80% of the participants. This is very much in line with previous research, which suggests that up-front price reduction is the most powerful incentive in promoting EV adoption. To a substantial number of BEV owners, however, exemption from road tolling or bus lane access is the only decisive factor.

The key limitations of this evidence are that it relies heavily on statements made by research participants who have already directly benefitted from these incentives, typically made sometime after they have been through the decision-making process of buying their EV. Research (Anable et al., 2014) has highlighted the complexity of this decision-making process, and the tendency of private purchasers to over or understate the importance of certain factors (e.g. fuel efficiency) before or after the event. Evidence of this type also provides little by way of counter-factual evidence – i.e. what EV uptake would have been if the incentives had not been introduced – or insight into what EV uptake would have been (or will be in the future) if the incentives were bigger, smaller or offered in different forms.

Diffusion scholars have established that adopters at different points on the trajectory are motivated by different factors and that the role of reducing costs through government incentives may be different for different stages of the adoption curve. For example, early adopters tend to be motivated by personal beliefs and intrigue in innovation; this is consistent with the idea of adopting given expressive (altruistic) or solidary (identity building) motivations. Later adopters are typically motivated by material or tangible (e.g. financial) benefits (Siddiki et al., 2015). The following study is interesting as it explores the dynamics of motivations as one major barrier is eliminated (price) what other factors may have been buried and come to the fore instead to suggest that it is not necessarily monetary motives that are being exercised: Siddiki et al. (2015) sampled 3,199 people intending to purchase or lease a new vehicle within two years across 32 US metropolitan states. They tested a number of price scenarios and sought to understand how the reduction in the cost of an innovative technology might facilitate the relative role of material and non-material motivations. They expected that when individuals are priced out of markets their revelation of other motivations is limited but when cost constraints are removed, individuals reveal other types of material and non-material motivations. They found that an individual who exercises their option to join a market for innovation adoption after being priced into the market is not solely acting on a material (monetary) incentive, but rather overcoming the financial barrier to adoption allows for those incentives to be realised. Those moving from a conventional to a plug-in vehicle were found to exhibit different motivations relating to functional aspects of the vehicle whereas those moving from HEV to EV were driven more by positive motivations related to social norms and identity.

3.3.2 Other monetised and non-monetised barriers and incentives

Section summary

- Evidence on the role of other monetary and non-monetary (policy) incentives is thin, context specific and sometimes verging on the anecdotal.
- Non-monetary incentives are always introduced in the context of other financial incentives and so their relative role can be very difficult to determine.
- There is consensus that circulation tax incentives (such as exemption from congestion charges) play a minor role in uptake, but the combination of purchase incentives in areas with additional incentives such as congestion or parking charge exemptions, can tip the balance in favour of EVs for some people in these locations.
- Thus, when undertaking research on the role of incentives, it is important to understand which factors place a critical or decisive role, rather than merely ranking the role of these incentives.

The evidence base on other monetary and non-monetary incentives is thin, context specific and in many cases verging on the anecdotal. In addition, there are no circumstances in which additional incentives such as EV access to bus lanes or exemption from road tolls has been introduced in the absence of more substantive financial incentives on purchase or running costs. It is therefore an impossibility to understand the unique influence of these initiatives. In this section we summarise the most recent evidence found on role of 'other' incentives vis a vis up front purchase and running cost incentives.

To be clear, most measures for increasing use and adoption of EVs are so-called 'pull' measures, encouraging EV purchase rather than discouraging use and purchase of ICE vehicles. There are also measures acting to specifically deter ICE vehicles in favour of EVs (e.g. Low emission zones; CO₂-based congestion charging). Naturally incentives favouring EVs will also function as disincentives for ICE vehicles but as most measures related to EV promotion target EVs explicitly we refer to them as *incentives*.

In summary, where these incentives have been examined, there is overwhelming consensus that they play a minor role *vis a vis* upfront purchase incentives and circulation taxes. The following study represents this consensus: Bakker and Trip (2013) reported results from a workshop where experts from five European countries rated ten policy measures for EV adoption according to effectiveness, efficiency and feasibility. The experts' cumulative ratings placed exemption from road tolling or congestion charging in the middle-bracket in terms of effectiveness, while access to bus lanes was found at the bottom of the list (Figure 11). They did not consider, however, the most prominent economic incentives such as purchase taxes and circulation taxes.

	Policy measures	Ave. score	Effectiveness	Efficiency	Feasibility
1	Lobby for EU-wide standards for plug sockets	4.27	4.14	4.50	4.17
2	Support and enable infrastructure build-up	4.17	4.33	4.17	4.00
3	Show political leadership (e.g. EVs in fleets)	4.03	4.33	4.17	3.60

4	Support car-sharing initiatives with EVs	4.00	4.00	3.75	4.25
5	Provide information to businesses and citizens	3.83	3.83	3.83	3.83
6	EV-readiness as a requirement for new property developments	3.74	4.00	3.83	3.40
7	Enable roaming between regions (billing)	3.63	3.86	3.71	3.33
8	Reserve on-street parking spaces for EVs	3.61	4.00	3.67	3.17
9	Exemption from tolls/congestion charges for EVs	3.33	4.00	3.40	2.60
10	Allow EVs to drive in bus/taxi lanes	3.20	3.80	3.60	2.20

Figure 11: Reproduced from Bakker and Trip (2013)

Nevertheless, also clear from the literature is the fact that these incentives have been found to have a decisive role to play for certain people in certain places:

- Bjerkan et al. (2016): In a study with 3,400 BEV owners in Norway, these authors sum up their findings, and essentially represent the evidence more broadly, when they say "*considering the generally marginal role of [bus lane access and road tolling exemptions], they cannot be considered effective in broad recruitment of BEV users, but could very well be the tip of the scale for potential BEV buyers not perceptive to normally critical economic incentives*" (p.176).
- Figenbaum and Kolbenstvedt (2013): Based on an extensive evidence review, the authors suggested that access to bus lanes has been as important to EV uptake in Norway as the main financial incentives for EVs in regions with large-rush hour traffic, because of the time-savings they afford EV owners.
- The evidence for high occupancy vehicle (HOV) lane access suggests they play a similar if not identical role to bus lane access. In a recent review of incentives across 50 US states, Jin, Searle, and Lutsey (2014) conclude that "*the most effective incentives in driving purchases are subsidies, HOV lane access, and exemptions from emissions testing. Public charger availability, home charger subsidies, license fee exemptions, and free parking do not appear to have as strong of an effect on BEV sales*" (p.26). HOV lane access is also the third most frequently cited motivation for buying an EV in California with over 90% of EV owners saying they have applied or will apply for the HOV lane sticker required to take up this option (Center for Sustainable Energy, 2015).

Caution must be exercised when extrapolating from research in Norway given the unique situation there: the purchase cost of BEVs have been reduced to be comparable to equivalent ICE vehicles through purchase incentives and exemptions from VAT at 25% for new vehicles. Nevertheless, it is fair to say that the majority of recent work on incentives to encourage EV uptake has been undertaken in the Norwegian context and, therefore, some of the more transferable results are reported here.

There is surprisingly little published evidence on the impact of the London congestion charge (LCC) on the composition of the vehicle fleet. The alternative fuel discount (AFD) comprised of a 100% discount on the Congestion Charge for vehicles powered by an alternative fuel, biofuel or dual fuel and not solely by diesel or petrol. The discount ran from February 2003 (the start of the congestion charge scheme) and was closed to new registrations on 24 December 2010. The AFD was replaced by the Greener Vehicle Discount which initially required that vehicles produce CO₂ emissions of 100g/km or less and also meet the Euro 5 standard for air quality.

There has been some analysis of the uptake of HEVs. For instance,

- Ozaki and Sevastyanova (2011) found that the exemption of HEVs from the LCC represented a salient issue in driver's motivations to purchase a HEV.
- Yet, Pridmore (2016, unpublished PhD Thesis) found only one third of HEV owners in one London Borough (Camden) to have been motivated upfront by the LCC, finding exemption from local parking charges to be a slightly higher motivation.

However caution is needed in seeking to extrapolate from effects on uptake of HEVs to effects on uptake of PiVs, given their very different utilities.

Börjesson et al.(2012) found that clean vehicles as a proportion of vehicles entering the Stockholm charging zone increased from 3% in 2006 to 14% in 2009 to 10% in 2011 (with the exemption being removed in 2008).

Ellison et al. (2013) evaluated the effects of the introduction of the low emission zone (LEZ) around London with specific attention given to the impact on the composition of the commercial fleet (i.e. light commercial vehicles and heavy goods vehicles). The results of their analysis indicate that the LEZ encouraged commercial fleet renewal, with registrations of commercial vehicles within the LEZ which were non-compliant to the LEZ's restrictions decreasing by 20% above the natural replacement rate.

Figure 12 is taken from Bjerkan et al. (2016) and shows how different ways of gauging importance or effectiveness of incentives can yield different results and that it is important to try and understand which incentives are *decisive or critical* in the purchasing decision. It shows that even where such strong purchase incentives can be benefitted from, some BEV users are persuaded by less prominent incentives such as bus lane access and road tolling exemptions. The study showed that despite these generous purchase incentives, participants show small differences when asked to rate their importance of incentives from 1 to 10 (1 = not important to 10 = very important) (diamonds on the graph). However, when asked to consider which ones are critical for purchasing a BEV, exemptions from purchase tax and VAT are decisive for more than 80% of the participants. As the authors note, this is very much in line with previous research, which suggests that up-front price reduction is the most powerful incentive in promoting EV adoption. These data further show that exemption from road tolling and reducing the vehicle licence are critical to half of the sample, whereas the remaining incentives are critical for more particular groups.

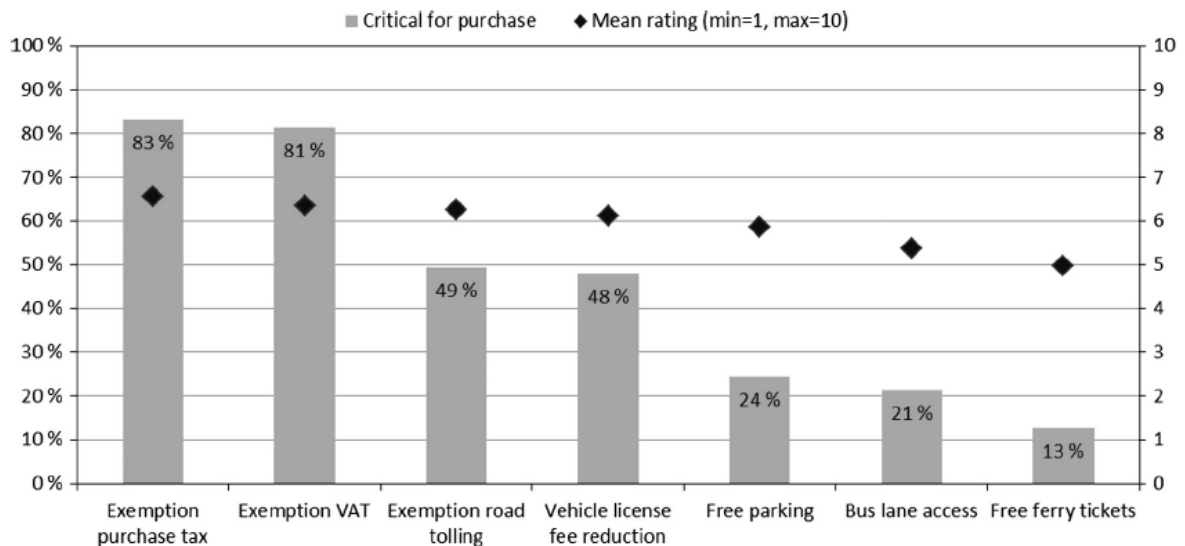


Figure 12: Role of incentives for BEV purchase in Norway taken from Bjerkan et al. (2016)

This same study goes on to question whether certain people tend to be persuaded by certain incentives. The study groups these incentives into (i) reduced fixed costs (ii) reduced use costs, and (iii) infrastructure priority (bus lane access). Using regression analysis the authors found interesting individual differences and spatial dependencies in the attraction of each incentive. Regression analysis was applied to three types of incentive and showed 'reduced fixed costs' are more critical to men, Tesla owners and those living outside the city of Oslo, but income levels do not significantly predict belonging to this group. Open ended responses corroborate this with participants saying incentives allow them to get more value for money on a fixed budget and to purchase a vehicle normally outside their price range. Incentives which reduce costs are predicted by (higher) education, lower income and participants living in or near the city (of Trondheim where road tolls are most prevalent). Infrastructure priority incentives are more attractive to lower income groups and those living in proximity to Oslo (where access bus priority lanes is an attractive feature due to a congested network).

The differential availability and attractiveness of these incentives potentially adds to the difficulty in detecting their influence as they may make a difference only under very specific circumstances for specific people. Vergis and Chen (2015) found that some factors that existing literature finds to be important in supporting PiV markets, including HOV lane access, fell out of their models during the backward stepwise process. They suggest HOV lane access is not exclusive to EVs in some states or may have limitations on the total number of EVs granted this exemption which may dampen its effect as an incentive. Therefore, the combination of other variables may be stronger correlated given that HOV lane access benefits are more unevenly distributed amongst consumers based on their routes and times of travel.

Despite recognising this uncertainty to some degree, Bjerkan et al. (2016) believe bus lane access can be regarded as a 'free' incentive that can be applied as part of a package of measures in smaller and medium size cities until the number of EVs reaches a level where it becomes a serious obstacle for public transport. This has now happened on one road in Oslo where it is now necessary to have at least one passenger in the car to use the lane.

3.3.3 *Technological perceptions and acceptance*

Section summary

- Range is often cited as a greater barrier than price in straightforward attitude surveys. For example, it remains a barrier in Norway where prices of BEVs are essentially the same as an equivalent ICE vehicle.
- Estimates of the implied value of range vary widely and depend on the extent to which compensatory factors are considered (e.g. cheaper running costs).
- This evidence points to the need to estimate the fraction of consumers/households who might consider purchasing a range limited vehicle and to understand psychological barriers, rather than estimating effective costs of range limitations.
- Key factors determining the response to range limitations include: the actual range of the vehicle; the availability of charging infrastructure; existing mobility patterns; the ability to adapt; experience of driving an EV; importance of the 'option value'.
- Willingness to pay for extra range is non-linear and is further complicated by purchase price and income. Willingness to pay is higher for increments from a lower maximum range.
- Range is sensitive to refuelling time and charging availability.
- Consumers' perception of the compatibility of EVs with their mobility needs is the most important determinant of EV acceptance.
- Availability of another vehicle or travel model is reflected in perceived self-efficacy (or perceived ability for an EV to fit into existing lifestyle). Therefore, the value of range can vary widely between people with different mobility needs and for whom the availability of other travel modes differs.
- Driving range has higher importance in the US than in Europe, presumably due to larger driving distances and fewer options to use public transport in the US.
- Range is widely assumed to be much less of a barrier for PHEVs as opposed to BEVs, but there is little direct evidence quantifying this.
- People do not deal with daily distance budgets with ICE vehicles and so do not have accessible and accurate representations of their needs. Control beliefs, ambiguity tolerance and coping skills play a role in the experience of 'comfortable' range. Perceived range barriers can be overcome with psychological interventions such as information, training and interface design.
- Experiencing an EV improves these perceptions and increases the WTP for extended driving range. However, this does not help the understanding of how prospective buyers with no experience overcome these anxieties.
- There is no meaningful published evidence available on the role of performance and the perceptions of performance. Although it could be said that this is because driving performance characteristics of EVs are already equivalent to ICE vehicles, this does not account for consumer perceptions and the role of uncertainty surrounding this attribute. The role of instrumental factors such as this is also entwined with symbolic motivations which need to be understood.

- There is limited evidence on the role of the choice of makes and models. Recent work in the UK (Element Energy, 2016) found a relatively high value to be placed on the availability of EVs in the consumers' preferred top three brands. This suggests that brand loyalty rather than extensive choice is the issue and this finding may explain why choice experiments that have used more generic metrics for the number of models available have found a limited effect of this attribute.
- Perceptions of a range of different aspects of owning and using an EV can change as a result of gaining some experience: performance and overall driving experience, comfort, fuel costs, home charging, flexibility, range, public charging and battery life, maintenance and resale value.
- Generally these changes are in a positive direction, but not exclusively. The importance attached to driving range and charging infrastructure for the EV can increase substantially.
- On balance, the literature suggests perceptions are improved after some experience is gained. Nevertheless, there is still some debate in the literature as to how this then translates into intention to purchase an EV.
- The relatively small body of literature on diesel and natural gas vehicle uptake provides some important lessons for the uptake of EVs, strongly suggesting that promotion and support by car manufacturers plays a significant role in the development of a market niche, as does the availability of transparent information to consumers and refuelling infrastructure. The role of tax incentives appears secondary to the influence of these elements.

3.3.3.1 *Range*

The barrier of reduced driving range and associated feelings of anxiety when the limit of comfortable range is reached (both being referred to as 'range anxiety') occupies much space in the literature on EV adoption. Much of the literature focuses on the 'paradoxical disparity' (Franke & Krems, 2013a) between the range needs of car drivers based on their current mobility patterns and the repeated finding that the same potential customers prefer vehicles with considerably higher average range.

It is difficult to isolate the effect of a limited vehicle range on the vehicle's adoption rate. However, there is no doubt that vehicle range is important to drivers. The question often asked is whether purchase price is more important than range anxiety, or vice versa; or what would people be willing to pay for additional increments of range? Straightforward surveys on the issue tend to find range (and the virtually inseparable issue of charging availability and associated time requirements) to be a greater first order 'deal breaker' than price (e.g. DfT, 2014 & 2015 – see Figure 6 above; Bunce, Harris & Burgess, 2014; Sierzchula et al., 2014; Bühler, Cocron, Neumann, Franke & Krems, 2014; Wardle, Hübner, Blythe & Gibbon, 2014). Even in Norway, where the EV market is more mature, range issues remain a barrier to further EV uptake (Figenbaum & Kolbenstvedt, 2013). However, the fact that there are consumers who have purchased such vehicles indicates that the magnitude of the barrier ranges from zero to at least comparable to the vehicle price (i.e. some consumers would not consider purchasing a vehicle with a very limited range regardless of the price) (Stevens, 2013), and, as a result, much literature is also dedicated to understanding why these variations exist.

Two major methodological approaches have been used to examine range anxiety. First, numerous studies used the direct stated preference approach, which requires participants to indicate a numerical range value that matches a certain utility level (e.g. minimum required range for purchase or minimum acceptable range). For instance, stated preference data across 8 EU countries found on average participants wanted 308km minimal battery capacity in order to consider buying an EV, with the highest in the Netherlands (389km) and the lowest in Sweden (212km), and 268km in the UK (Bunzeck, Feenstra, and Paukovic, 2011). In the UK, data from 350 drivers pre and post an EV trial found a day-to-day range of 83 miles would be ideal for private users, and a 230-mile range would be sufficient for all journey requirements (Burgess et al., 2013).

Second, studies have employed the indirect hypothetical approach with choice-based analyses (i.e. discrete choice experiments) or contingent ranking tasks that include vehicle range as a variable for all vehicle types and, from this, an implied value of vehicle range can be derived (Hidruue, Parsons, Kempton & Gardner, 2011; Daziano & Chiew, 2013; Hoen & Koetse, 2014; Bahamonde-Birke & Hanappi, 2016). A recent meta-analysis of 31 studies examining customer valuation of driving range (Dimitropoulos, Rietveld & Van Ommeren, 2011) reveals that the compensating variation for increasing range from 100 to 350 miles would be \$16,200. The authors conclude that EVs with a 100 mile range would have to be priced 50% cheaper than comparable ICE vehicles to be competitive. A similar pattern of results is revealed by Daziano (2013) who uses the function of range equivalency (i.e. the range at which an EV is perceived to be as attractive as a benchmark vehicle) and finds that an EV would only be perceived as equivalent to a conventional gasoline vehicle if its driving range were 330 miles, when cheaper EV operating costs are not considered. If operating costs are factored into the analysis, this estimate would drop to 180 miles (assuming the same purchase price for an EV and a gasoline vehicle).

The following have been identified as the key factors determining consumers' responses to issues about vehicle range.

3.3.3.2 The actual range of the vehicle

The relationship between willingness to pay (WTP) for driving range and the range of the vehicle may not be linear, and may be further confounded by purchase price and income.

- In a review of the literature, Stevens (2013) suggested an increase of 1 mile is twice as valuable to the owner of a vehicle with a 50-mile range as the owner of one with a 100-mile range, other factors being equal.
- In their meta-analysis, Dimitropoulos et al. (2013) found that studies employing a maximum driving range of 100 miles lead to considerably higher WTP estimates than studies allowing for higher maximum driving ranges. On the other hand, studies considering a minimum driving range of at least 150 miles result in notably lower WTP estimates than those considering lower levels of minimum driving range. This highlights the sensitivity of model results to the driving range levels considered in the studies.
- Similarly, Jensen, Cherchi, and Mabit (2013) found that the marginal utility of one extra kilometre is clearly much higher for the EV than for the ICE vehicle since the driving range is much smaller for the EV than for the ICE vehicle, this difference might indicate presence of non-linear effects in the marginal utility. They stress that this is important to interpret this as a non-linear effect and not

an effect of EV or ICE as these labels should not affect the participants' preferences for driving range everything else equal. The authors conclude: *"our results confirm that driving range is a major concern related to EVs but also reveal that the concerns that individuals have about low driving ranges are not due to misconceptions, but a true mismatch between the range they wish to have available in their everyday lives and what the EVs provide"* (p.31).

- Hoen and Koetse (2014) found that the effects of driving range are lower for the fuel cell car than for the electric car, which suggests that the effect of increasing driving range is smaller at higher driving ranges. The opposite holds true for the effects of charge/refuelling time reductions, that is, the effects are much larger for the fuel cell car than for the electric and plug-in hybrid car, while attribute levels for the fuel cell car are substantially smaller.

3.3.3.3 Availability of charging infrastructure and charging times

In a meta-review of studies examining consumer trade-offs between range and purchase costs, Dimitropoulos et al. (2013) remark that range is likely to be sensitive to changes in the levels of refuel time and availability of refuelling infrastructure as if the refuelling takes only a few minutes and the density of refuelling infrastructure is high, it is reasonable to expect that driving range becomes much less important. However, the authors observe a lack of attention to these interactions and call for further understanding of this: *"Even though most studies consider at least one of these two attributes in their attribute set, only a few go further to acknowledge the dependence of range valuation on the levels assumed for these attributes (e.g. Ewing and Sarigöllü, 1998; Hidrue et al., 2011; Segal, 1995). The practical consideration of the relationship between these three attributes in consumer's mind would imply a non-linear formulation of the utility function, including interaction terms between driving range, refuelling duration and the coverage of refuelling infrastructure. Surprisingly, however, none of the examined studies explicitly mentions testing for interaction effects among these attributes. This gap in empirical transportation literature suggests a promising opportunity for further research"* (p.34).

3.3.3.4 Ability to adapt

The availability of another vehicle or alternative travel modes can also be assumed to be a factor in the value of range to an individual consumer. This review found only one study directly examining the interaction between the availability of another vehicle or modes of transport with range anxiety based on experience after trialling a car: Jensen et al. (2013) found that the importance attached to driving range for the EV almost doubles after individuals have tried the car, but that this effect is much less prominent in multi-car households, because they can rely on the other car (that is an ICE vehicle) if need arises for longer trips. Nevertheless, the change in the direct elasticity with respect to driving range in fact doubles after the experience for both single and multi-car households. The same effect can be found in the WTP for driving range.

Other studies hint at the need to understand the mobility demands of people's everyday lives before being able to understand their acceptance of EVs by studying somewhat vaguer notions such as 'self-efficacy'. Bockarjova and Steg (2014) showed that alongside environmental risks, another important determinant of adoption is the higher perceived own capability to fit an EV to the travelling needs and perform charging routines (perceived self-efficacy). Self-efficacy was measured with eight items reflecting the

perceived ability to adjust one's behaviour so as to be able to drive an EV, including resourcefulness in finding alternatives like taking shorter routes, arranging alternative transportation for long trips, and charging such as readiness to make use of charging possibilities at home, at work and in public places. Higher self-efficacy is associated with higher policy acceptability, more positive EV evaluation, and higher intention to buy an EV.

Once again, Dimitropoulos et al. (2013) pointed to the gap in understanding: *"Other things being equal, consumers with lower incomes, shorter average travel distances, or higher within-household vehicle substitution possibilities are anticipated to have lower WTP for driving range than individuals with the opposite characteristics. In the context of the current meta-analysis, however, we cannot identify the impact of differences in such consumer characteristics on WTP variation. This is due to the lack of descriptive information about these characteristics in primary studies. Information about the average income or its distribution in the survey sample is unavailable in several studies, while very few of them provide adequate information about participants' car use and their households' vehicle holdings"* (p.40). Consequently, Stevens (2013) suggests that *"further work is need to better understand the dependence of the range-limitation barrier on these other factors, so that instead of assigning a single value to the severity, the potential market size can be estimated, and policies can be designed to lower this barrier in places where policies are able to act on the appropriate factors"* (p.19).

3.3.3.5 Drivers' mobility patterns

The value of range for vehicles with a very limited range (e.g. less than 100 miles) can vary widely between consumers who have different driving needs and for whom the availability of other vehicles or travel modes differ (Dimitropoulos et al., 2013). However, since the distance that passenger vehicles are driven each trip or each day varies widely between days and between drivers, it is not sufficient to examine average driving distances when considering whether a limited-range vehicle would meet drivers' range requirements. Instead, the distribution of trip distances must be considered and, because charging times for BEVs are typically hours, the distance driven between charges as well as the distribution of times when the vehicle can be charged must also be taken into account. This requires trip-by-trip data over many days, including information about the destination of each trip.

Unfortunately, trip-by-trip data and data on time spent at locations where vehicles can be charged are limited. Even if these data were available, this does not necessarily help to determine how drivers themselves assess their range requirements and therefore assess range alongside other vehicle attributes when making car choices. Franke and Krems (2013a) suggest that potential EV owners without EV experience anchor their preferences on their previous experience (e.g. of ICE vehicles) but that these assessments may not be entirely accurate and based more on highly accessible indicators, such as a critical destination or most recent holiday trip, which do not accurately represent usual range needs. No research was found which has explored these alternative reference indicators explicitly with drivers, but certain studies have nevertheless chosen different indicators such as: the longest daily travel distance per year (Pierre, Jemelin & Louvet, 2011), per week (Chlond, Kagerbauer, Vortisch & Wirges, 2012) or on a certain energy critical day (Sammer et al., 2011, cited in Franke & Krems, 2013a). These studies still show that the currently common 100-mile range of EVs is sufficient for a sizeable share of the car driving population.

From this, it can be seen that assigning a single utility value to range can be misleading. Stevens (2013) suggests that it would be of greater interest to examine how distributions of driving needs and assumptions about the utility of having a sufficient vehicle range affect the future adoption of range-limited vehicles by consumers (Lin and Greene 2010b, 2011) to estimate future market shares of EVs. However, such analysis has not been found in the literature. The closest has been Dimitropoulos et al.'s (2013) meta-analysis which compared results of valuations of driving range from different regions, with the majority of the studies they reviewed originating in either the USA or Europe. They found driving range to have much higher importance for Americans than Europeans with the average WTP in the USA more than twofold that in Europe. The authors suggest the higher importance of driving range in the USA might be due to the lower densities, higher distances travelled (reflected also in higher mileage per vehicle) and therefore higher range needs of Americans as well as the weaker emphasis they have placed on the development and use of transit. The divergence in driving range valuation between the two regions might also be partially attributed to the stronger association of feelings of freedom and independence with car trips in the USA than in Europe (FIA Foundation, 2003 cited in Dimitropoulos et al., 2013).

However, contradictory results are found in the literature. For instance, Adepetu et al. (2016), using survey data from Los Angeles, California, simulated different cases of battery costs and prices by means of an agent-based EV ecosystem model and found that even in Los Angeles, a geographically spread out city, the price of EVs is a more significant barrier to adoption than EV range. In fact, even a quintupling of battery size at no additional costs improved EV adoption by only 5%.

Other studies assess consumers' perceptions of how compatible EVs might be more broadly with daily mobility patterns and these studies find this to be the most important determinant of EV acceptance:

- Peters and Dütschke (2014) found perceived compatibility of an EV with personal needs seems to be the most influential factor on the stated willingness to purchase an EV.
- Hoen and Koetse (2014) undertook a mixed logit model from an online stated choice experiment of Dutch private car owners. They distinguished between HEV, PHEV, BEV, Fuel cell and Flexifuel vehicles. Results show that negative preferences for alternative fuel vehicles are large, especially for the electric and fuel cell car, mostly as a result of their limited driving range and considerable refuelling times. An interaction model reveals that annual mileage is by far the most important factor that determines heterogeneity in preferences for the electric and fuel cell car. When annual mileage increases, the preference for electric and fuel cell cars decreases substantially, whilst the willingness to pay for driving range increases substantially. Other variables such as using the car for holidays abroad and the daily commute also appear to be relevant for car choice.

3.3.3.6 Experience of driving an EV

It has been argued that people typically do not hold highly accessible, accurate representations of their usual range needs, as they do not deal with daily distance budgets in using ICE vehicles (Kurani, Turrentine & Sperling, 1994). However, when users deal with limited-range electric mobility, they have to manage daily distance budgets and develop heuristics to plan their journeys and should lead to more accessible, precise representations of usual range needs to construct range preferences

(Franke et al., 2012b). Therefore, the value placed on additional range also needs to be seen in the context of the overall high levels of satisfaction with the EV ownership experience.

Whilst range is considered a barrier by many, regardless of their level of engagement with EVs (Hutchins et al., 2013), and even experienced EV users 'buffer' their trips and so have range preferences higher than their usual range needs (Franke et al., 2012a), there is clear evidence to show that experiencing EVs increase the WTP for an extended driving range (and indeed other EV attributes) (Jensen et al., 2013). Franke and Krems (2013a) argue that examining the range preferences of participants without EV experience, as most previous studies did, may not be a useful approach for determining truly marketable EV range in more mature markets.

- Franke et al. (2012a) found that variables related to range anxiety are positively influenced by BEV driving experience such as the reduction in range safety buffers in the first three months. That is, users actively avoid critical range situations by reserving substantial range safety buffers. Their range comfort zone (i.e. 'comfortable range') is on average only about 80% of their actual available range).
- Franke et al. (2012b) found that whenever users interact with limited energy resources, they continuously monitor and manage the relation between their mobility needs (e.g. distance of next trip) and their mobility resources (e.g. remaining range). This ratio (i.e. the perceived available range buffer) is then compared to the user's preferred range buffer (i.e. the user's comfortable range) which they showed to vary considerably between users. The range appraisal (the experienced discrepancy between available and preferred range resource buffers) leads to a certain degree of range stress (i.e. range anxiety). The more range stress, the more likely the user will apply coping strategies (e.g. drive more economically, charge the car) to resolve the situation. Consequently, the users' comfortable range plays a key role in predicting the likelihood that a user will apply coping strategies (e.g. charging) in a given situation.
- Franke and Krems (2013a) went on to test whether the adjustment effect is even stronger with longer periods of driving experience. They collected data from 79 participants who had driven an EV for three months in a field study setting in Germany. Range preferences of those users were found to be substantially higher than their average range needs. Regression analyses indicated that higher average range needs, higher range of the driver's familiar combustion vehicle and greater experienced range anxiety were related to higher range preferences. However, they found that range preferences decreased over the first three months of EV use and indicators of average range needs were more strongly associated with range preferences as EV experience increased. They concluded that only customers with EV experience seem to rely on accurate estimates of their range needs when constructing their range preferences. They concluded that ownership of an ICE vehicle beforehand and particularly ongoing during the use of an EV will slow down the rate at which acceptance of range changes.
- Rauh, Franke, and Krems (2015) also found that BEV driving experience is an important variable to predict range anxiety. They compared 12 motorists in Germany with high BEV driving experience (M=60,500km) with 12 motorists who had never driven a BEV before on a test drive designed to lead to a critical range situation. Participants were tested for their range appraisal and range stress on

cognitive, emotional and behavioural factors. Experienced BEV drivers exhibited less negative range appraisal and range anxiety than inexperienced BEV drivers revealing significant, strong effects. However, the paper does not adequately address whether the experienced drivers had become adopters of these vehicles *because* they already had less range anxiety. This was partially taken into account by matching both study groups on a tried and tested scale to measure control beliefs in dealing with technology ('KUT values') which the authors suggest had been shown to be a robust predictor of smaller preferred range safety buffers (i.e. low susceptibility to range anxiety) in previous research (Franke & Krems, 2013a; Franke et al., 2012b). Nevertheless, it is understood that there is a difference between early vs mainstream adopters' approaches to range. Santini and Vyas (2005, cited in Anable et al., 2014) derived two estimates: one for the majority of the passenger vehicle market, and one for early adopters (i.e. consumers who are more apt to purchase vehicles with new technologies or functionalities). Their coefficient for the early adopter segment was a factor of 10 lower.

- Labeye, Hugot, Brusque, and Regan (2016) found that the majority of users adjusted to range in a few weeks. They examined the behavioural modifications brought about by daily use of an EV by 36 Parisian drivers at three different levels of driving activity: strategic, tactical and operational. Questionnaires were administered after 30 minutes of use and after 6 months of use. The results show that driving an EV requires a learning phase to acquire the skills and knowledge necessary to operate the vehicle. At the strategic level of driving, drivers take into account the restricted range of the EV, implement a daily charge process, and develop new behaviours related to trip planning. They found the time needed to get used to the restricted range and charging issues of the car required a maximum of a few weeks: for 44% of participants the habituation required on average 2 weeks; for 31% of participants 4 days; for 14% of them 2 hours and, for 11% of participants, habituation was reportedly immediate (see further results from this study under 'Usage patterns' in Section 3.3.8).
- Pichelmann, Franke, and Krems (2013) also found that adaptation to EV range seems to take several weeks. In response to this, Franke and Krems (2013a) ponder whether it might be that this time of adaptation (i.e. the learning process) can be shortened, for example, by motivating and supporting users to actively explore and exhaust the range. This could be achieved with advanced driver information and assistance systems that help users to extend the range and reduce uncertainty regarding the sufficiency of the remaining range for upcoming trips. A task for future research will be to examine in greater depth the changes (i.e. adaptation effects) in range preferences that are caused by EV experience.

3.3.3.7 *Importance of the 'option value' to individual consumers*

Several gaps in our understanding about range have been highlighted above. Arguably the greatest puzzle is the value not so much that people put on the range per se, but the option of having that range available *should they need it*. This understanding requires psychological approaches to the study of range, of which there are few in the literature. Franke and colleagues studied psychological barriers related to the *experience* of range among 40 EV users (Franke et al., 2012a, b; Franke, Cocron, Bühler, Neumann, & Krems, 2012). Control beliefs, ambiguity tolerance and coping skills played a substantial role in the experience of "comfortable range". The authors suggest that their results

indicate that perceived range barriers can be overcome with the assistance of psychological interventions such as information, training and interface design.

However, these psychological interventions were not tested and, in any case, would not address how *prospective* EV buyers think about range. This is important because studies show that there are many consumers who are unwilling to even consider a vehicle with a very limited range. As cited above, in the UK, data from 350 drivers pre and post an EV trial found a day-to-day range of 83 miles would be ideal for private users, and a 230-mile range would be sufficient for all journey requirements (Burgess et al., 2013). Similar previous UK trial findings suggest that on average people would consider a range of 60 miles “adequate” for an EV but that an “ideal” range of 206 miles would be necessary to enable them to meet all their travel needs (Carroll et al., 2013). Skippon and Garwood (2011) suggested that some consumers might start to consider EVs as second cars if they had a range of 100 miles, and as main cars if they had a range of 150 miles. They may be willing to pay modest premiums over conventional vehicles, equivalent to around three years’ running cost savings. However, this data is once again with drivers who have had some experience of EVs and does not further our understanding of the value drivers place on the option of having a higher range to address unexpected or less frequent long journeys. Overall, the literature is very thin on investigating individual differences (personality traits, trust in the BEV and its functions, risk aversion/range anxiety) in depth to gain an understanding of the different attributes of range on which different people place value.

3.3.3.8 BEV range vs PHEV range

Evidence of insight into how experiences and perceptions of range compare between BEVs and PHEVs is generally lacking. In the Brook Lyndhurst review (2015), as with this present review, the only evidence identified addressing this was in California (Center for Sustainable Energy, 2014). On average Nissan Leaf (a BEV) owners in the survey said they wanted to have an electrical range of 200 miles compared to the actual electrical range of 78 miles. For Chevrolet Volt (a PHEV) owners these figures were 100 miles and 38 miles respectively. Range is widely assumed to be much less of a barrier for PHEVs as opposed to BEVs, although there is little direct evidence illustrating or quantifying this. What there is suggests that there is a minimum acceptable amount of all-electric range of PHEVs, and this figure is 20 miles (Anable et al., 2014).

In summary, although vehicle range is clearly important to drivers, the value of it varies wildly depending on a combination of factors so that there are very substantial limitations associated with trying to assign a single monetary value to a vehicle range. From the evidence reviewed, rather than estimate a range of effective cost of the range limitation, it may be more useful to estimate the fraction of consumers or households who might consider purchasing a range-limited vehicle and further understand the psychological barriers to limited range vehicles.

3.3.3.9 Performance

This review found very limited focus on the role of performance or perceptions of performance in the recent literature on consumer acceptance of EVs, although earlier literature has suggested that performance is viewed negatively by drivers sometimes even after gaining experience in them (Burgess et al., 2013; Graham-Rowe et al., 2012).

Perhaps in recognition of this gap, Skippon (2014) set out to specifically understand how drivers construe vehicle performance and the implications for EVs suggesting *"to displace a significant fraction of conventional vehicles, [EVs] may need to offer consumer drivers specific advantages that offset these limitations. Better performance might be such an advantage"* (p.15). Importantly, this study found that perceived confidence in performance is key and that performance is not only about acceleration but also cruising experience.

Skippon (2014) suggests an important distinction should be made between performance (the way a vehicle responds to control actions by the driver, usually viewed as a set of objective properties of the vehicle) and driveability (the ability of a vehicle to respond satisfactorily to those control actions without noticeable demerits, defined in terms of the subjective experience of drivers). He studied 48 UK drivers of petrol and diesel cars using a qualitative repertory grid method in order to understand how drivers themselves construe vehicle performance. The findings are summarised in a conceptual model which suggests drivers construe performance in two main dimensions: dynamic performance, relating to control actions using the accelerator pedal, and cruising performance. For petrol cars, the top themes were Confidence in ability to overtake; Acceleration when pulling away; Mid-range acceleration; Smoothness when cruising; and Power. For diesel users, the top themes were Responsiveness; Smoothness; Comfort; Speed; Overall Acceleration; Low Noise; and Power.

One choice experiment (Bahamonde-Birke & Hanappi, 2016) included engine power and found that whilst engine power is an important factor that positively affects utility when the alternatives considered include at least one conventional vehicle, this effect either vanishes or is very weak when choices are being made between only electric propulsion. This chimes with Element Energy's (2016) approach to consumer attitude modelling for the UK Department of Transport where, in setting out their approach, they state: *"Several of the attributes used regularly in choice experiments are of limited relevance for forward-looking vehicle uptake models. For example, quantifying consumers' willingness to pay for increased engine power or acceleration is only relevant if there is likely to be a systematic difference in performance between different powertrains in the future. Since the driving performance characteristics of plug-in vehicles are already similar to, and sometimes exceed, conventional internal combustion engine cars, these attributes are a lower priority than assessing the impact of vehicle driving range or charging point availability"* (p.8).

In one integrative framework examining a whole array of attributes including perceived innovation characteristics alongside personal and social norms, no significant effect was found of physical as well as functional risk on attitude formation toward AFVs. In line with Element Energy's approach, the proposition was offered that concerns about performance for EVs are bound together with evaluations of the charging infrastructure making it redundant to include both in models (Petschnig, Heidenreich & Spieth, 2014).

This would clearly suggest that performance is a factor of lower importance in the consumer decision making process. However, this conclusion needs to be adopted with some caution as it is possible that the role of such instrumental attributes, like others, is intimately entwined with symbolic and hedonic attributes as Schuitema, Anable, Skippon and Kinnear (2013) showed. In addition, the important perceptions to be measured may not be absolute or even relative power, but *uncertainty* over performance (and reliability, safety) of the vehicle. The idea that performance (i.e. power) is also somehow bound up with evaluations of the charging infrastructure would need to be tested.

3.3.3.10 Choice of makes and models

Choice is another attribute with very little evidence attached as to its role in the adoption decision. Various contentions have been made by authors to suggest that the relatively limited set of EV models offered to consumers compared to their conventional gasoline counterparts hurts the technology's ability to appeal to diverse consumer preferences for vehicle features, sizes, and styles (NRC, 2015 cited in Krause et al., 2016). However, the only evidence that has been found is within the context of choice experiment studies:

- Element Energy (2016) found the willingness to pay for an EV available in the participants' three preferred models/brands (relative to three brands that they do not usually consider) was £1,285, implying a relatively high value placed on this attribute. Results also showed that participants did not value availability beyond their three preferred models, suggesting that what customers value is their preferred manufacturers offering EVs rather than extensive choice across all brands.
- Hoen and Koetse (2014): Element Energy's more nuanced analysis may explain why Hoen and Koetse found that the effects of including a rather general attribute to capture the number of models for each technology (4 attribute levels (1, 10, 50 and 200) were used for each AFV) were relatively limited and failed to offer any insight into preferences for supply and choice. The assumption was that participants would realise that a higher number of models implies more choice and increases the probability of finding their preferred brand and/or vehicle type.

DfT (2014, 2015) data suggest a reduction in the number of people citing 'lack of choice' as a barrier between 2014 and 2015, which may be a reflection of the increased number of makes and models appearing on the market during this period.

3.3.3.11 Unfamiliarity, uncertainty and satisfaction with user experience

The evidence with respect to range anxiety (see section 3.3.3.1) indicates that experience of driving an EV can be predictive of less range anxiety. The Brook Lyndhurst (2015) review identifies a range of different aspects of owning and using an EV which can change as a result of gaining some experience: performance and overall driving experience, comfort, fuel costs, home charging, flexibility, range, public charging and battery life, maintenance and resale value.

Of note are three recent in-depth studies that have set out to examine user experience:

- Labeye et al. (2016) offered an in-depth study of 36 Parisian EV drivers as part of a six month vehicle trial and document the behavioural modifications that resulted. Although the study reported positive experiences with respect to the driving experience and handling of the vehicle, the results showed that most participants needed time to master the vehicles' features, including their lack of noise production, as well as time to develop strategies to handle the range limitation which leads to new planning behaviours including when to charge and which trips to make in the vehicle.
- Jensen et al. (2013) used a two-wave stated preference experiment where data was collected before and after the participants experienced an EV for three months to investigate the extent to which experience affects individual preferences for specific EV characteristics, individual attitudes toward the environment, and the impact of the attitudes on the choice between an electric and a conventional vehicle. Individual preferences changed significantly with

respect to comfort with driving range, top speed, fuel cost, battery life and charging in city centres and train stations. For fuel price, the EV coefficient was stable between waves whereas the ICE vehicle fuel cost coefficient becomes more negative after the experience. They found that environmental concern had a positive effect on the preference for EVs both before and after the test period, but the attitude itself and its effect on the choice of vehicle did not change.

- Bühler et al. (2014): In a 6-month field trial, data from 79 participants who drove an EV in the Berlin metropolitan area were assessed at three data collection points (before receiving the EV, after 3 and 6 months of usage). They found that other perceived barriers are affected by experience as well, e.g. battery issues and the low noise level. Many advantages became even more salient (e.g. driving pleasure, low refuelling costs) and several barriers (e.g. low noise) were less frequently mentioned. Experience had a significant positive effect on the general perception of EVs and the intention to recommend EVs to others, but not on attitudes and purchase intentions.

However, not all studies have found that all aspects improve in acceptability after use:

- Schneider et al. (2014, cited in Peters and Duetschke, 2014) showed that user evaluations of several aspects of EVs became more positive once practical experience with EVs had been gained. In this study, however, two aspects (time for charging and public infrastructure) were rated more negatively *after* the trial had started compared to prior expectations.
- Jensen et al. (2013) found that the importance attached to driving range for the EV almost doubles after individuals have tried the car, which means that individual concern was confirmed by the characteristics of the EVs currently in the market. As would be expected, this effect is much less prominent in multi-car households, because they can rely on the other car (that is an ICE vehicle) if need arises for longer trips. The direct elasticity for EV with respect to driving range in fact doubles after the experience for both single and multi-car households. The same effect can be found in the WTP for driving range.
- Graham-Rowe et al. (2012) interviewed participants who trialled either a BEV (20 participants) or a PHEV (20 participants) in the UK. The aim was to explore beliefs about, and attitudes towards, plug-in EVs as expressed after psychological distance was reduced by their experiencing the use of a BEV or PHEV over a seven-day period. The results identified six categories of attitudes: 1) cost minimisation, some drivers frustrated that they did not get feedback (savings) on their driving style; 2) vehicle confidence – some drivers were not convinced of the range; 3) the effort involved in adapting; 4) environmental beliefs – some drivers were sceptical of the net environmental benefits of EVs; 5) impression management – dull design – ‘soulless’; 6) perception that EVs were currently a ‘work in progress’ – some drivers waiting for new developments.
- Although perhaps now dated, Kurani, Heffner, and Turrentine (2008) presented an in-depth review of experience of living with EVs. Early adopters of PHEVs in California were interviewed, and it was found that most of those interviewed wished that their vehicles performed better. Participants commonly hoped PHEVs could attain higher top speeds; several felt that interfaces were too complex, in some cases causing drivers to ignore fuel economy displays; and many owners attempted to drive PHEVs “like normal vehicle[s]” instead of employing techniques that would maximise fuel efficiency. The study also found that a

majority of owners preferred to charge their cars during the day rather than at night (some owners reported keeping their vehicles continually plugged in whenever possible); that most drivers did not calculate cost savings from operating their PHEVs; that many drivers found it embarrassing to ask hotel clerks, parking attendants, and property managers for permission to charge when needed; and that most were unconcerned with the prospect of operating their PHEV in a V2G configuration.

- Sovacool and Hirsh (2009) speculated as to whether any initial excitement dissipates and turn into disappointment as people gain real and extended experience with PHEVs. They pointed to official fuel economy metrics which may skew results in actual driving experiences because of their assumptions relating to straight roads, a top highway speed of 60mph, ideal weather, and moderate temperatures.

On balance, the literature suggests perceptions are improved after some experience is gained. Nevertheless, there is still some debate in the literature as to how this translates into intention to purchase an EV. Buehler et al. (2014) found that purchase intentions remained unchanged or even declined after participation in a trial, and Barth et al. (2016) also found that the positive relations between acceptance and personal experience had positive effects on the formation of goal intentions to use an EV above and beyond the parallel (and positive) effect of mere knowledge. The causal direction of the relationship between experience or knowledge on the one side and acceptance on the other is less clear. Gaining experience and knowledge about the new technology could dispel previous misinformation and prejudice which would lead to a more positive attitude and more acceptance. At the same time, greater acceptance could also lead to an increased motivation to search for additional information. It is also plausible that both variables influence each other and the relationship is bidirectional. The authors recommend that additional research is undertaken to better understand these relationships.

3.3.3.12 Lessons to be learnt from previous vehicle transformations

The major transformation of the European car market in the 1990s as diesel uptake took off rapidly is largely ignored in the literature among innovation economists and the like, but it is worth considering whether there are any lessons here to be learnt for the current transformations in fuels and vehicle technology.

Within a decade, the market share of diesels in Europe grew from about 10% to well over 50%, and even exceeding 70% market penetration in the popular midsize saloon segment. However, diesels failed in other markets, which is a significant characteristic of this particular transformation. The initial major growth in uptake occurred at the same time as fuel prices were relatively low. Nevertheless, there were cost advantages of diesel vehicles due to the following factors:

- It is commonly assumed that the reduced diesel fuel taxation is responsible for the large market penetration of diesel vehicles in Europe (Bonilla 2009).
- As diesel vehicles are generally only produced by European automakers, the emission policy employed by the EU provided European automakers with a significant competitive advantage over foreign imports in the domestic marketplace.

- The initial market niche developed through these tax and cost incentives meant that by the early 1990s there were plenty of mechanics trained in maintaining and repairing diesel vehicles and most forecourts across the continent included a diesel pump, thus reducing the cost of adoption for potential buyers.
- While diesels were less favoured when turbocharged direct injection (TDI) was introduced, the perception of this technology improved during the 1990s. Miravete et al. (2015) attribute this to possible learning spill overs as it became more common to encounter diesel vehicles on the road.
- European emissions policy aimed at reducing greenhouse emissions seems to have been a very effective tool to enable the popularity of diesel vehicles. Although both the US and Europe have set increasingly demanding standards, the US authorities have always been more concerned about NOx than CO2. The EU emission policy provided diesel automakers with a competitive advantage to protect the domestic automobile market from foreign competitors who had not invested in this technology, thus aligning the goals of CO2-focused environmental authorities and automobile manufacturers.

In contrast, the market share of natural gas vehicles (NGVs⁸) has lagged far behind expectations. With total cost of ownership being on average lower for NGVs than for gasoline and diesel vehicles. This has raised the question to a limited degree in the literature as to the existence of market failure in this market and the lessons to be learnt for EVs.

von Rosenstiel et al. (2015) combine quantitative data in Germany with insights from a multi-industry expert panel and in-depth interviews with experts from industry, government and civil society to assess the contribution of different elements to the German market for NGVs. They conclude that the failure was down to the following:

- A lack of coordination of the complementary markets of fuel infrastructure and car availability. They calculate the 'vehicle-to-refuelling-station index (VRI)', defined as the number of NGVs in thousands divided by the number of filling stations with compressed natural gas (CNG)-pumps and show that in Brazil and Argentina and Italy (high CNG demand) are shaped by a VRI of about one, in contrast to 0.1 in Germany and the US (low demand for CNG).
- An artificially created monopoly of service stations at motorways as the large petroleum companies owning filling stations are left to opt in to supplying gas fuel pumps. Gas companies depend on established filling stations in order to sell CNG because low sales numbers render investments in stand-alone filling stations unprofitable but oil companies use their power to suppress the supply of CNG, which competes directly with gasoline and diesel as fuel.
- Consumers have imperfect information, particularly on the price advantage of CNG over conventional fuels. Although the 2008 update of the Directive 1999/94/EG on information provision on fuel economy and CO2 emissions means

⁸ Natural gas can be compressed to become Compressed Natural Gas (CNG), and is probably the most widely adopted method of using natural gas as a vehicle fuel. It can also be super-cooled to liquid form to become Liquefied Natural Gas (LNG) but this poses a few challenges for use in vehicles. A by-product of the natural gas production process is LPG, also known as propane. LPG has also been used as a fuel for a variety of commercial vehicles such as delivery trucks or in-warehouse vehicles such as forklifts where vehicle emissions are desired to be kept to a minimum.

it is easier for consumers to recognise advantages in greenhouse gas (GHG)-emissions and fuel costs of NGVs, the price display of CNG at filling stations is per kilogram compared to per litre for gasoline and diesel. The fact that 1.0 kg of CNG contains the same amount of energy as 1.5 l of gasoline impedes a direct comparison of fuel costs. Retailers/dealerships were also not informing consumers of the availability and the characteristics of NGVs.

- Bounded consumer rationality means that consumers are constrained with respect to their attention, resources and ability to process information and to formulate and solve complex problems. Instead, they make use of heuristics when taking decisions, rather than employing a strict rule of optimization. Therefore, although theoretically, the demand for NGVs should increase with decreasing total cost of ownership, in practice, despite a tax reduction in Germany of 80%, most consumers do not fully take into account the cost advantages. Dutschke et al. (2011) undertake qualitative interviews relating to CNG vehicle uptake and conclude that the experiences communicated by other users seem to be important in improving the perceived reliability and safety of a technology.
- The market for NGVs is rife with principle-agent or social dilemma problems whereby agents are motivated only to act in their own interests. For instance, public purchasing departments often do not incorporate total cost of ownership or environmental considerations in their buying decisions, and car producers do not invest sufficiently into the development of green technologies.

Taken together, this relatively small body of literature on diesel and NGV uptake suggests that promotion and support by car manufacturers plays a significant role in the development of a market niche, as does the availability of transparent information to consumers and refuelling infrastructure. The role of tax incentives appears secondary to the influence of these elements.

3.3.4 Refuelling availability and charging time

Section summary

- Examination of the role of charging availability and charging time is split into studies which examine the impact on uptake of EVs and those which examine charging behaviour after adoption.
- No literature has been found on the impact of grants for the installation of dedicated charge points.
- Public charging infrastructure may have an equal or greater impact on EV uptake than financial incentives and there is a strong suggestion that this may only be true for BEV uptake rather than PHEV uptake, but the evidence for this comes with several caveats.
- Whilst macro studies of the relationship between charging infrastructure and EV uptake at the national or regional level suggest a link, this does not take account of temporal dependence or spatial dependence (i.e. which comes first: the charging infrastructure or the uptake) and how a heterogeneous distribution of charge stations might influence EV adoption.

- The perceived lack of public charging infrastructure has been frequently highlighted by non-EV owners as a barrier to EV uptake, but the evidence on the link is weak.
- The role of awareness of charging availability is not straightforward as there is strong evidence to suggest that the strength of the relationship depends on the number of chargers believed to be available, as awareness of a low or intermediate number has very little impact with regard to perceived charger *abundance*.
- Also, any statistical association between adoption and awareness may not be causal as participants with pre-existing EV interest might be more likely to have become aware of public chargers in the first place.
- In terms of the role of different types of charging availability (e.g. home vs. workplace; fast vs. slow), the acknowledgement by prospective consumers of availability of home-based charging is a consistently strong predictor of acceptance. However, there is still a dearth of understanding of the role of non-home charger locations as well as the details of charging such as speed, precise location, cost and charger design.
- No studies comparing the value of charging time for PHEV owners and BEV owners were found and little consideration has been given to the importance of charging from the perspective of PHEV ownership.
- There is general agreement in the evidence that charging behaviour is primarily driven by EV owner preferences, convenience and habit rather than the availability or cost of public charging infrastructure.
- Recent evidence is consistent with older evidence suggesting that private owners charge their EV mainly at home, on a daily basis, and generally in the evening.
- Low overall levels of utilisation of public charge points are likely to mask wide variations between charge points in different areas and at different types of venues.

Examination of the role of charging availability and charging time is split into studies which examine the impact on uptake of EVs and those which examine charging behaviour after adoption. Both of these literatures attempt to some extent to distinguish between different types of charge points (at home, work and public; fast versus slow), and there is some (though limited) distinction between BEVs and PHEVs. No literature has been found on the impact of grants for the installation of dedicated charge points.

3.3.4.1 Impact on EV adoption

Indicative evidence on the impact of charging provision on the uptake of EVs is available but does not provide many fine-grained insights. Previous reviews by Brook Lyndhurst (2015) and Anable et al. (2014) found evidence to suggest that public charging infrastructure may have an equal or greater impact on EV uptake than financial incentives – although again, the evidence for this comes with several caveats, and the strong suggestion that this may only be true for BEV uptake rather than PHEV uptake (Vergis, Turrentine, Fulton, & Fulton, 2014).

Study of the role of charging infrastructure falls into 'macro' and 'micro' approaches. Macro approaches examine the correlation of the availability of charging infrastructure with EV uptake at a national or regional level (e.g. Sierzchula, 2014 reviewed above in section 3.3.1.5; Jin et al., 2014). This literature finds a very strong correlation but needs to be heavily caveated as it infers causal inference without (i) including temporal dependence in the models (i.e. an assessment of which comes first – the charging infrastructure or the uptake?), and (ii) without taking account of spatial dependence (i.e. how a heterogeneous distribution of charging stations (many in one city, few elsewhere) might influence EV adoption). Stephens (2013) points out that if the 10%–20% of stations that offer fuel are located in only a few cities, consumers outside these cities (at least those beyond the vehicle range) are faced with no availability. However, he believes this spatial interdependence is rarely captured in vehicle choice models but would require modelling only a specific spatial area or explicitly modelling market segments or regions, each with its own measure of fuel availability. Therefore, because of the important role played by local municipalities in installing charging infrastructure, their allocation could have an important impact on a country's EV adoption rate (Bakker & Trip, 2013). Therefore, the above authors have suggested that future research focus on the relationship between the distribution of charging infrastructure within a country and its EV adoption rate.

Micro approaches attempt to place a value on the availability and awareness of different types of charging infrastructure to the prospective EV adopter. The perceived lack of public charging infrastructure has been frequently highlighted by non-EV owners as a barrier to EV uptake, but it has to be said that the evidence on the link is weak. Survey data in the UK suggests that anywhere from 30% (Bevis, Smyth & Walsh, 2013) to 60% (Bunce et al., 2014) of people feel the public charging infrastructure is not sufficient for them to consider buying an EV. Bevis et al. (2013) report that "*although public infrastructure provides only a small proportion of [...] charging, it nonetheless raises the profile of electro-mobility in a region, both practically and politically*" (p.19). These findings on infrastructure are replicated in studies abroad (e.g. Wardle et al., 2014; Rolim, Baptista, Farias, and Rodrigues, 2014).

In terms of the role of awareness of charging availability, all studies point to the fact that the role of charging availability is different depending on its degree of coverage so that perception of a few charge points is less important than the perceptions of charging opportunities at a variety of locations:

- Achtnicht, Bühler and Hermeling (2012) studied the impact of fuel availability on demand for alternative-fuel vehicles, using data from a survey including a choice experiment with ~600 potential car buyers in Germany. Applying a standard logit model, they showed that alternative fuel availability influences choices positively, but its marginal utility diminishes with supply. They derived consumers' marginal willingness-to-pay for an expanded service station network and demonstrated that consumers distinguish between types of fuel, even when all other vehicle attributes (including range) are identical.
- Bailey, Miele, and Axsen (2015) set out to understand whether the visibility of public charging stations has an impact on EV demand using 1,793 Canadian new car buyers. They found a significant bivariate correlation between public charger awareness and EV interest but when controlling for multiple explanatory variables (including the availability of charging at home, age and education) the relationship is weak or non-existent. The authors also noted that the statistical association may not be causal as participants with pre-existing EV interest might

be more likely to have become aware of public chargers in the first place. In addition, the unique contribution to the literature from this study comes from the distinction made between 'perceived public charger existence' and 'abundance'⁹. The strength of the relationship depends on the number of chargers believed to be available as awareness of just one charger has very little impact vis a vis perceived charger *abundance*. They noted that the notion of abundance might be more likely to serve as a significant factor in EV interest, which should be further tested and refined in future research.

- Bahamonde-Birke and Hanappi (2016) applied discrete choice modelling with a sample of 1,449 participants in Austria and suggested the existence of reliability thresholds concerning the availability of charging stations. The wide-spread availability of charging stations (not defined in the paper) positively impacted the utility ascribed to pure electrical vehicles whereas an intermediate level of charging station availability is not significantly better than a low availability level. The authors suggest that this phenomenon can be understood in light of the fact that at intermediate levels of service, the availability of charging stations is still unreliable and individuals would still most frequently charge their batteries at home, which suggests the existence of reliability thresholds.
- Bockarjova and Steg (2013) used a wide range of predictors based on protection motivation theory among a large sample of Dutch participants including perceived costs and perceived self-efficacy related to managing the behavioural adjustments required to cope with new charging routines and new trips. They also include the readiness to make use of charging possibilities in different locations including at home. Adoption intention is predicted by the higher self-perceived capability to fit an EV into travelling needs and to perform charging routines.

On the basis that more public infrastructure is needed to allay the range concerns of EV non-owners, various authors suggest that this infrastructure will need to be in highly visible locations.

- Bonges and Lusk (2016) examined charger design and placement, "EV only" parking, free charging, etiquette in unplugging another's vehicle, and legislation. Data were derived from academic publications, trade market press, conversations, personal observations, and legal documents. They concluded that chargers are often located in areas of car parks that are less visible or accessible and with access for only one vehicle at a time. The etiquette surrounding EV charge point behaviour is not yet established and legislation does not necessarily assist in this such as not allowing another person to unplug another person's EV when they are occupying a charger.
- Pierre et al. (2011) reported that "*it is vital to increase the volume of [charging] terminals in public areas*" and the Government of British Columbia (2014) reported that "*the foremost concerns upon immediate deployment are visibility*".

In terms of the role of different types of charging availability (e.g. home versus workplace, fast versus slow), the acknowledgement by prospective consumers of availability of home-based charging is a consistently strong predictor of acceptance.

⁹ The authors distinguish between these two as follows: "perceived charger existence as having seen a public charger in at least one location type, and perceived charger abundance as having seen PIV chargers in at least two location types, e.g. at a workplace and in a mall."

- Bailey et al. (2015) found participants with Level 1¹⁰ charger access at home were more likely to be interested in EVs in a large scale Canadian study. They found Level 1 charger access to be a key predictor of interest in EVs, being a significant predictor at a high significance level (99%) in all regression models.
- The results of a study by the Tokyo Electric Power Company (TEPCO) over the period of 2007–2009 suggested that the availability of fast charging stations will be essential in the successful development of EVs and will have a massive effect on user behaviour. It was observed that EV drivers using standard charge stations returned with, on average, 50% of remaining charge but that when using fast chargers, EV users came back with much less charge remaining in their batteries and also that driving distances increased.
- Element Energy (2016) placed specific emphasis on understanding the impact of the current rollout of rapid charging infrastructure on purchase decisions. They pointed out that *"the effects of rapid charge points based on major roads on purchase likelihood for EVs have not previously been assessed separately from the rollout of slow charge point (e.g. in city centres or supermarket car parks), even though the benefits to EV users are different in each case. This distinction is becoming increasingly important as high power charge points are being deployed across the UK's major road network, for example through the Rapid Charge Network"* (p.8). They implemented a choice experiment (online survey, February 2015, 2,020 new car buyers in the UK) which attempted to quantify the potential change in vehicle uptake for different densities of rapid charging points.

The cost of refuelling time due to behavioural adjustments associated with driving and charging can be estimated based on assumptions about the value of travel time. However, there is some debate over the appropriate value of time to use since charging can usually be done when the vehicle is not in use (e.g. overnight) (Stephens, 2013). The value of time spent charging that actually detracts from other activities is difficult to estimate.

Bailey et al. (2015) make some important observations about the state of the art with respect to understanding the role of charging infrastructure and areas for further research: *"Future research is required to better understand the potential importance of different types of non-home charger locations, such as workplace charging, as well as the specific charger details that may make PiVs more attractive, e.g. charging speed (Level 1, Level 2 or DC fast charging), location in parking lot, the cost charged to the driver, and the aesthetics of charger design. In addition, future research ought to investigate the differences between awareness of chargers in different locations relative to awareness of an overall large amount of chargers (regardless of location)"* (p.9).

There has also been little consideration to date in the literature on the importance of public charging from the perspective of PHEVs and, for example, whether the increasing number of PHEV models on the market mediates the need for additional public infrastructure to convince more car buyers to purchase an EV. Stephens notes that on the one hand PHEV owners tend to want to keep the vehicle batteries charged when possible to realise the benefits of electric operation, so faster charging would be valuable. On the other hand charge times for PHEVs are shorter than those for BEVs, and drivers have the option to use fuel, so the value of charge time to PHEV owners may be

¹⁰ Level 1 charging is referred to as 'slow charging' and is achieved through a standard 120 V AC, 15 A or 20 A, based on the vehicle technology, battery type, and capacity (Azadfar et al., 2015).

less than that for BEV owners. No studies comparing the value of charging time for PHEV owners and BEV owners were found.

3.3.4.2 Impact on charging behaviour after adoption

There is general agreement in the evidence that charging behaviour is primarily being driven by EV owner preferences, convenience and habit rather than the availability or cost of public charging infrastructure (see for example, Anable et al., 2014 and Azadfar, Sreeram & Harries, 2015). Brook Lyndhurst (2015) summarised the evidence by saying that various sources have found that private owners charge their EV mainly at home, on a daily basis, and generally in the evening (Azadfar et al., 2015; Element Energy et al., 2013; Pierre, 2011; Anable, 2014; Hutchins et al., 2013; Rolim et al., 2014). This is also fairly consistent between the UK and other countries:

- In Hutchins et al. (2013), 95% of private EV owners reported charging at home daily or weekly compared to 26% who reported charging at work daily or weekly and 12% who reported using public charging daily or weekly. No significant differences in charging behaviour were found in Hutchins et al. (2013) between the charging behaviours of private owners living in Plugged-in Places¹¹ (PiP) and non-PiP areas although this research was undertaken when public charging provision was considerably less extensive than it is now.
- Bruce et al. (2012) presented the evaluation of the UK CABLED trial involving 108 vehicles over a one year period. There were 36 non-domestic charging posts at 12 locations, six of which were free and six where a standard rate was levied for parking. The majority of charging was undertaken at home, which is perhaps no surprise given the limited non-domestic charging infrastructure. The private users with the home charging infrastructure completed the majority of their charging after 23:00, possibly related to tariff structures such as Economy 7.
- Robinson, Blythe, Bell, Hübner, and Hill (2013) analysed 31,765 EV trips and 7,704 EV charge events as part of the Switch EV trials in the north east of England comprising both private and commercial users. Private users' peak demand was in the evening at home charge points whereas individuals with company vehicles were charged primarily upon arrival at work. There were differences in the way in which the user types make use of public charging infrastructure. The individual with company vehicles revealed an early morning peak in demand whereas organisation pool-vehicle users saw a late afternoon peak in demand at public locations. Private users charging at public locations peaked at approximately 09:00 at work but at 20:00h in public locations. It was revealed through focus groups that some drivers with access to a home charge point instead make use of public posts near their home address on an evening and the authors speculated that this is because they had already paid a fee for parking and electricity through their membership of the trial¹².

¹¹ Plugged-in Places is a scheme to develop regional charging infrastructure networks in selected areas around the UK.

¹² Robinson et al. point out some comparisons between their results and those from the CABLED trial. Compared to CABLED, SwitchEV reveals more off-peak charging at work and public charging locations relative to home, probably accounted for by the different infrastructure provision. CABLED had a ratio of one public post for every three vehicles on trial. Half of these were levied a standard parking rate for their usage. This

- Morrissey, Weldon and O'Mahony (2016) used data on the usage of charging infrastructure for the entire island of Ireland since the rollout of infrastructure began (711 charge points were monitored, 83 of which were fast chargers between March 2012 and March 2015). For the household data available, it was found that EV users preferred to carry out the majority of their charging at home in the evening during the period of highest demand on the electrical grid indicating that incentivisation may be required to shift charging away from this peak grid demand period. The results show that the usage of the different charge point types varies during the day. Standard charge points were utilised more than fast charge points in the morning and fast charge points were utilised more than standard charge points at night with a peak at around 21:00 (thus showing some synergy with Robinson et al. 2013).
- Franke and Krems (2013b) examined 79 EV users in a six month EV trial and found that users charge on average three times a week with a large surplus upon charging. They used psychological and behavioural variables to develop a measure to assess 'user interaction charging style (UBIS)' which is related to users' mental model of range dynamics, the utilisation of range and excess energy from renewable resources. Combined with 'comfortable range' UBIS explains the charge level at which people typically charged. UBIS shows some cross device (i.e. with mobile phones) consistency.
- In the US, ECotality (2013, cited in Brook Lyndhurst, 2015) found that 80% of charging events by BEV owners were at home and 20% "away from home", compared to 86% and 14% respectively for PHEV owners.
- In Norway, 97% of EV owners charge at home daily or weekly compared to 51% at work and 20% using public charging (Figenbaum et al., 2014).

PHEV and BEV owners in the UK and elsewhere have been found to have similar charging behaviours. Both charge mostly at home but PHEV owners charge more frequently on average than BEV owners:

- In the US, BEV owners have been reported to carry out 1.1 charging events a day compared to PHEV owners who average carry out 1.5 charging events a day while the average distance driven between charges was comparable at approximately 28 miles for both (ECotality, 2013).
- No evidence was found which suggested that current PHEV owners under-use or ignore the electric capacity of their vehicle. The Anable et al. (2014) review concluded that most owners run their PHEVs on electricity as much as possible, and this is supported by US findings that suggest PHEV users run their vehicle on electrical power for 72.5% of the time (ECotality, 2013).

The above findings are reflected in the relatively infrequent use of public charging reported by charge point data showing low utilisation rates. Element Energy et al. (2013) report that "the low utilisation of public charge points is confirmed by recent European trials and on-going EV monitoring". However, other evidence sources suggest that low overall levels of utilisation are likely to mask wide variations between charge points in different areas and at different types of venues:

compares to five public/work posts for every SwitchEV vehicle. SwitchEV drivers also had unlimited access to non-domestic recharging infrastructure through a membership scheme.

- Bevis et al. (2013) reported that *"in parts of the UK we have very underused infrastructure, while in parts of London there are reports of "Charger rage" arising from demand exceeding available charging space"* (p.17).
- ECOtality (2013) also reported wide variations in utilisation rates between areas in the US and also reported how utilisation rates may vary at different venue types. For example, it suggested that, on average, charge sites at arts and entertainment venues are used most frequently, with roughly one charging event per day at each site. However, it also highlighted wide apparent variations between sites at the same type of venue – from less than one charge event a week to over a hundred. Two key factors unaccounted for in the analysis are the number of individual charge points at each site and where, geographically, each site is located.
- Morrissey et al.'s (2016) analysis of charge infrastructure use in Ireland revealed car park locations were the most popular location for public charging amongst EV users compared to petrol station locations, and fast chargers recorded the highest usage frequencies. The authors of this study conclude from this that public fast charging infrastructure is most likely to become commercially viable in the short-to medium-term, although it is clear that more evidence would be needed on costs of electricity, locations and capacity utilisation to add substance to this conclusion.

Brook Lyndhurst (2015) sum up the research as suggesting that, notwithstanding consistent findings about the primary role of home and workplace charging, research has consistently found that EV owners (especially fleet owners) want more public charge provision in order to enable them to undertake longer journeys (Azadfar et al., 2015; Hutchins et al., 2013). They cite Hutchins et al. (2013) as reporting dissatisfaction amongst EV owners with different aspects of the public charging provision available at that time, in terms of its location, usability and reliability and a desire more public charge points which enable fast charging at strategic locations (e.g. motorway service stations) and destinations (e.g. hotels and restaurants) rather than close to their home or in city centres. Brook Lyndhurst conclude by saying: *"What is acutely missing in the current evidence base, and which would help to inform future decisions about the location of public charging infrastructure, is analysis of utilisation rates of charge points in these different types of location. Ultimately more sophisticated analysis is required to understand how charge point usage compares between different kinds of locations"* (p.53).

3.3.5 Financing and ownership models

Section summary

- Limited statistics suggest that around 85% of privately acquired new cars are financed through mechanisms such as personal contract hire or personal contract purchase.
- Virtually no evidence was found on the impact of different ways of purchasing and financing vehicles on consumer behaviour.
- There is literature which focuses on business model innovation (particularly battery leasing) with little regard for consumer perspectives and data collected from consumers directly to test acceptance.

- One study was found which tested a buying scenario and a car sharing scenario of EV access. It found each to involve different predictors, with intention to buy predicted by personal knowledge, running cost savings and subjective norms but car sharing predicted by age and injunctive norms. Subjective norms can be said to represent feeling social pressure to behave a certain way. Injunctive norms are behaviours which are perceived as being approved of by other people.
- It seemed that social identity variables predicted acceptance above and beyond personal cost-benefit factors in both cases and that people seem to adhere to different kinds of norms when it comes to personal buying or collective sharing intentions.

The literature search as part of this review set out to specifically search for studies that have attempted to evaluate differences in the characteristics and behaviours of EV adopters with respect to the way in which the vehicle is paid for or accessed. This topic was not covered in the two 'reference' reviews (Brook Lyndhurst, 2015 & Anable et al., 2014).

Virtually no evidence was found on different ways of purchasing and financing vehicles despite this directed effort.

Firstly, it is worth considering the scale of financing mechanisms in the car market. There are a number of options available for how a vehicle is purchased/ financed, though information on the proportion of sales for private or fleet adopters or new and used vehicles is not easily available. Table 6 provides a breakdown of the finance options available for vehicle acquisition, differentiating between the options available for personal, fleet and employee adopters.

Table 7 provides an approximate breakdown from a compilation of sources as to the proportion of new and used vehicles secured using one form or other of these finance options. This table suggests the proportion of new cars acquired using some form of finance may be as high as 86% for private individuals or 36% for businesses. It is much lower for used cars as would be expected. These figures have been compiled from a range of different sources, however, and it is unclear how the Finance and Leasing Association categorise 'private' vs 'business' adopters and which finance mechanisms they include in their figures.

Table 6: Finance options for vehicle acquisition

Acquisition/ financing options	Vehicle ownership during contract	Description
PERSONAL ACQUISITION		
Outright purchase	Car buyer	Greatest control of what, where and how a vehicle is procured.
Personal contract hire	Leasing company	Essentially the same as fleet contract hire but applied to individuals. User hires a car for set period and mileage - fixed monthly rental - no option to buy at end of contract. No tax allowances or VAT recoverable.
Personal contract purchase (PCP)	Leasing company	A finance company will retain ownership of the vehicle until the customer has met all the conditions of the agreement. The final payment under a PCP agreement is normally a larger, 'balloon' payment which must be paid by the customer to settle the outstanding balance. Owned or exchanged at end.
FLEET ACQUISITION		
Outright purchase	Fleet owner	Greatest control of what, where and how a vehicle is procured. Vehicle usually regarded as a fixed asset for accounting purposes. Vehicle appears on company balance sheet.
Contract purchase	Fleet owner	Vehicle purchase via a series of monthly instalments - ownership passes to users at start or end of contract. Vehicle appears on balance sheet. Not VAT-efficient.
Hire/lease purchase	Fleet owner	Purchaser leases vehicle from third party with an option to purchase at end of the hire term. Usually deposit is paid at start, then monthly payments, with a balloon payment at end of term equivalent to residual value. Vehicle appears on company balance sheet. Not VAT efficient.
Contract hire	Leasing company	Most popular type of vehicle leasing. User hires a car for set period and mileage - fixed monthly rental - no option to buy at end of contract. Vehicles do not appear on company balance sheet.
Finance lease	Leasing company	User hires a car for set period and mileage - fixed monthly rental - option to buy or continue lease at end of contract. Vehicle appears on company balance sheet.
EMPLOYEE OPTIONS		
Employee Car Ownership Schemes (ECOS)	Employee	Employee chooses to purchase through a contract often with full maintenance, insurance, etc. Employee owns the car.
Company car	Employee	Employee receives vehicle from company (which acquires vehicle through purchase or lease etc.). As vehicle treated as a benefit-in-kind, employee pays CC-Tax; employer pays C1NICs - both based on CO2 and P11D (for cars).

Salary sacrifice	Leasing company	Usually based on an underlying contract hire arrangement between the leasing company and employer. Salary sacrifice is not a funding method of the car itself, but an arrangement for the benefit of a company car to be provided in exchange for a reduction in gross salary.
Cash for cars	Employee	Cash for car is an umbrella term that covers a raft of funding alternatives to the traditional company car. But in its simplest and most straightforward form, in lieu of a company car employees receive an adjustment to their salary to spend on a vehicle.

Sources: Adapted with permission from Ben Lane (Ecolane Ltd and NextGreenCar) from Energy, E. (2013). Pathways to high penetration of electric vehicles. Element Energy Limited: Cambridge, UK and using his significant prior effort to compile this using BVRLA (British Vehicle Rental and Leasing Association) Guide to Vehicle Funding 2013; Finance & Leasing Association (FLA) Guide to Title for Insurers, January 2012.

Table 7: Proportion of cars acquired in UK using some form of financing method (2013/15)

		All new registrations/cars sold in 2015	New cars (Private + business) bought on finance at the point of sale Aug 2015 - Aug 2016 ⁽³⁾	% cars financed
New cars registered in 2015	Private	1,209,000 ⁽¹⁾	1,040,519	86%
	Fleet + business	1,425,000 ⁽¹⁾	510,671	36%
	All New	2,634,000 ⁽¹⁾	1,551,190	59%
Used cars sold in 2013	Private	n/a	1,232,904	n/a
	Fleet + business	n/a	42,635	n/a
	All used	7,400,000 ⁽²⁾	1,275,539	17%
All cars sold ~2013/15	ALL cars	11,459,000	2,826,729	25%

Sources: ⁽¹⁾ Society of Motor Manufacturers & Traders (SMMT) 2016 ⁽²⁾ British Car Auctions (BCA) Used Car Market Report 2014 ⁽³⁾ Finance & Leasing Association Motor Finance Summary available at <http://www fla.org.uk/index.php/research/motor/#> [accessed October 2016]

Unfortunately, statistics for previous years are not easily available from the FLA and therefore it is difficult to gain a sense of the rate at which financing of vehicles is proving to be more popular. However, the latest spreadsheet from the FLA indicates a 10% increase in financing for private new cars in the previous 12 months to August 2016 alone, although only a 1% increase for businesses.

It is worth speculating whether the use of PCP type options has altered consumer behaviour in any way. For instance, might it have contributed at all to a growth in new car sales or more expensive cars than might have been the case? It is certainly plausible to assume that the availability of finance options is likely to alter the decision making process by impacting not only on affordability. For instance, considerations regarding payback times and residual value may be reduced given that the up-front cost burden is lower and the need to buy or sell at the end of the contract is not a concern (e.g. with options of exchange, return or pay back available with PCP).

Although financing now appears to be the acquisition method for a large proportion of new car buyers, it is still only a small proportion of used car buyers (17%). However, a recent survey by the BCA in 2014 suggested that 12% of used car buyers said 'they would 'certainly' think about buying a new car instead of a used one next time they change, if a low or 0% interest loan was on offer at the time. However, this was a drop of 5% on the previous year's figure. The results also showed that wealthier car owners are the most likely to consider buying a new car instead of a used one, 15% saying they would 'certainly' consider such a move if a suitable low or 0% loan was on the cards.

With respect to the implications for new vehicle technology, it would be interesting to explore the 'agreed mileage' terms and conditions often associated with this form of financing as well as some of the free servicing options as a way of removing perceived risk and developing awareness of the potential for plug-in vehicles as a lifestyle fit. It is also possible that those who like to change their car frequently and have the latest technology are more likely to acquire through PCP type schemes and this has obvious potential implications for the uptake of plug-in vehicles.

Where any literature was found it was generally focused on business model innovation (particularly battery leasing) in the automotive sector as opposed to understanding consumer issues relating to these models of finance and ownership. Only two pieces of literature were found which attempted to think about this in part from a consumer point of view albeit both without any data collected from consumers themselves:

- Lim et al.'s (2014) model represents the baseline case in which consumers own the entire vehicle and charge their battery mostly at home using regular overnight charging. They suggested this business model has been proposed mostly for urban drivers in the European market (Masson 2012). Three alternative models were tested: (i) a decoupled model in which consumers own the vehicle only and subscribe to a battery leasing service; (ii) the case in which battery enhanced charging service is made available through additional support infrastructure (this includes, for example, the quick charging stations that are being introduced in the U.S. by firms such as Chargepoint and NRG eVgo); (iii) consumers lease the batteries and are offered enhanced battery charging services such as the Better Place model (the authors liken this to Renault ZOE EV in Europe with battery leasing and the support of quick charging infrastructure). The model found that the battery leasing service improved the firm's profit due to greater level of surplus extraction from the secondary market, and neutralised the impact of resale anxiety. However, it was optimal when offered with the enhanced charging option. In summary, combinations of battery owning/leasing with enhanced charging service typically yield the best balance among the objectives of EV adoption, emission savings, profitability, and consumer surplus.
- King et al. (2015) tested a car sharing concept following a 'flexible access' model: *"When an EV is purchased, the new EV owner also automatically becomes a member of a car-sharing scheme, where a shared vehicle may be borrowed from a common pool on a 24 hour basis. The shared vehicles are large ICE-based vehicles suitable for long-range travel and with large goods transportation capacity"* (p.719). This testing, however, is based on a simulation exercise to determine if such a sharing concept could be deployed giving reasonable quality of service to the EV owner, without significantly increasing the cost of each vehicle. In other words, the study is not based on an examination of consumer acceptance of this type of ownership model. Instead, assumptions are made about the utilisation of each vehicle and the demographics of the members, partly based on data on Irish mobility patterns. The cost of this scheme was shown to be low when compared with current levels of subsidies to EV manufacturers.

Only one reference was found to explore the acceptance of EVs under different ways of *accessing* EVs including car sharing/car clubs. Barth et al. (2016) tested a buying scenario and a car sharing scenario of EV adoption/access on the basis that they may each change acceptance and willingness to adopt but may also involve different predictors. They found this to be the case with the following key results:

- The intention to buy could be predicted by personal knowledge, maintenance costs and the subjective norm, but these variables were not related to the car sharing scenario.
- The intention to use an EV via car sharing was uniquely predicted by age and injunctive norms (perceptions of which behaviours are approved of or not).
- In both scenarios, cost-related disadvantages, the provincial norm (the influence that the behaviour of others can have when those others occupy a comparable

setting) and collective efficacy (the belief that the group is capable of affective important aspects of the environment) were significantly related to intentions. Social identity variables predicted EV acceptance above and beyond personal cost-benefit factors in all analyses.

- Of importance for understanding social normative processes in both scenarios of EV use, it also turned out that people seem to adhere to different kinds of norms when it comes to personal buying or collective sharing intentions. Approval of EVs by single important individuals, such as close friends, seems to be important when a car is permanently purchased, but not in a sharing scenario. On the other hand, injunctive norms (i.e. what are the perceived rules in the community) were only related to sharing intentions but not to buying. Sharing economies are a relatively recent social phenomenon. Whether or not car sharing is perceived personally efficient (e.g. the availability of a close-meshed grid of sharing stations) depends on the expected participation rates in the community. Also, sharing is a genuinely collective endeavour. This may be why the perception of a greater societal consensus that sharing is approved of, but not the opinions of personally significant others, determine sharing intentions.
- They suggest that these results mean that EV use in different contexts might necessitate specifically tailored strategies to facilitate the acceptance of the new technology. For the cost/benefit factors, buying intentions were more strongly influenced by the lower maintenance costs of EVs than car sharing intentions. This seems plausible since maintenance costs are only relevant to owners of an EV, as they would not be responsible for the car's maintenance in a sharing scenario.

It is clear that car ownership and financing models are areas ripe for further research. There are now more and more cities with partial or all all-electric fleets in car sharing services, for instance Paris and London. Assessing these different 'products' will be a challenge given their wildly different attributes so that the intentions being examined will not only be related to the attributes of the EV but also to specific attitudes towards car ownership or towards a car sharing model (Barth et al., 2016).

3.3.6 Consumer psychology and wider societal processes

Section summary

- The greatest proportion of socio-psychological research in relation to EV uptake has been dedicated to an examination of the role of ethical motives of environmentally friendly buying behaviour. There are, however, mixed and somewhat confused assessments as to whether evaluations of the attributes of an EV as environmentally friendly are positively related to adoption indicators.
- Straightforward surveys of the motivators of EV adoption suggest that environmental benefits of EVs tend to only constitute a minor purchase motivation when ranked alongside other motives.
- An indication that environmental motives may be important in the purchase decision is not the same as suggesting that this is *the reason* for adopting an EV. A more useful understanding would be to measure the extent to which environmental motives are a deciding factor in adoption.

- Studies that have investigated the link between levels of awareness and acceptance of environmental problems suggest it is not enough for people to see a link between EVs and their environmental credentials, but must be aware and sympathise with environmental issues in the first place. They must believe that EVs are indeed pro-environmental and this must fit with their self-identity. In particular, studies acknowledge that environmentally significant behaviour is a mixture of self-interest and concern for others or the environment, and that it is insufficient to only look at one of these aspects. It is important to recognise the multi-faceted role of environmental attitudes.
- A person can be highly motivated by environmental issues, but if they do not believe EVs are a solution, this will not matter.
- Attitudes towards ICE vehicles (i.e. the 'pull' of their attractive features or the 'push' of their negative consequences) may be more important than the intrinsic benefits of EVs and so both of these must be understood.
- The diffusion of innovations model focuses on the trait of 'innovativeness' as the main determinant of purchase behaviour. However, this review suggests that a concept of innovativeness may be too vague to capture the motives related to any desire to be involved in new technology uptake.
- However, studies have found evidence that, for some, the opportunity to engage with a new, cutting-edge technology produces excitement which can be a key motivation for adopting an EV. For some, this can stand alone as a motive, but for others it is important only in combination with other attitudes.
- Overall the evidence might imply that communication about EVs to technology oriented-consumers may need to put less emphasis on environmental benefits of EVs and mainly focus on technological aspects of the innovation.
- An important generalizable omission in the evidence base is the role of emotions in EV adoption.
- Emotions can be broken down into visceral (perceptions of instrumental and visual attributes of EVs such as style, design, and size), behavioural (from using and experiencing driving EVs) and reflective (related to self-image and identity connected to driving an EV). More positive perceptions of instrumental attributes of EVs lead to more positive emotions towards EVs (perceived pleasure, joy, pride, (lack of) embarrassment), which in turn positively influence the intention to adopt EVs.
- Studies that have attempted to incorporate symbolic motives have 'suffered' from a form of social responsibility bias that has been empirically proven: that people fail to reveal symbolic meanings as important because they tend to emphasise instrumental and environmental attributes, especially when asked directly.
- In addition, studies have tended to narrowly concentrate on environmental symbolism, but some have explored patterns of lifestyle that represent: aspects of self-identity, being seen to be a 'car authority', interest in new technology, and independence from 'Big Oil'.
- Owners of different brands of EV associate different types of symbolic associations with their vehicle, but there is still a lack of knowledge on the potentially different symbolism of BEVs versus PHEVs.

- EVs do not currently have established symbolic meanings and these are likely to develop over time. This makes it all the more important to include a variety of measures of symbolism in any surveys to understand their emerging associations.
- Symbolic motives and self-identity are not expected to be a motivation to buy an EV in and of themselves. However, the evidence shows that collective norms and more personalised relationships that define people's social identity crucially facilitate the process of diffusion, whereby a new behaviour is adopted by increasing numbers of consumers as they see others around them adopting it.
- There are a number of different normative processes which could impact on the uptake of EVs. As a result, the evidence on their role is mixed as much depends on the definitions used. In some models, these predictors carry at least as much weight as personal cost-benefit factors in a model of EV acceptance.
- Perceptions of collective efficacy (belief that the in-group will affect the environment when they act together) have been found to be important; hinting to the need to make sure adoption of EVs is seen as part of integrated efforts to transition to sustainable electricity consumption.
- There is empirical evidence that social negotiation (i.e. discussing EVs with others) has been found to change individual perceptions of EVs, particularly where this process is reflexive.
- It is probable that the role of different norms will vary at different points in the adoption process. For example, it is possible that the absence of EVs on the roads may become more important as mainstream adopters are more reliant on what other people do as a source for their own decisions.
- The role of information provision (including improved awareness of charging infrastructure) is understudied. The most common form of information provision is directed at private functional motives (costs, performance and availability of charging infrastructure etc.) but evidence is very thin on what actually works to shift consumer attitudes.
- No studies were found assessing the impact of information attempting to convey issues of identity, status or group membership as a result of EV adoption or attempting to assess the impact of conveying issues relating to the potential environmental or energy security benefits of EVs.

The above sections represent the dominant focus on personal cost-benefit related factors that is prevalent in research on acceptance and uptake of EVs. However, numerous studies, with a growing number in the past two to three years, have specifically examined the potential for monetary and functional incentives to facilitate adoption in the context of a host of additional variables which include environmental attitudes, the role of innovativeness, symbolic motives, social norms and emotions. In addition, studies have gone beyond examination of EV adoption as a pure individual consumer choice issue to also consider interpersonal processes and collective motivations.

Whilst this literature is growing to provide a vital and important evidence base alongside the understanding of monetary and functional aspects commonly addressed, the literature is problematic in some ways. In particular, it draws upon numerous theories from social psychology and behavioural economics and therefore contains inconsistent

sets of constructs, often overlapping but not necessarily the same and elicited using a variety of measurement instruments. This presents some challenges in drawing generalizable conclusions from the results.

3.3.6.1 Pro-environmental attitudes

By far the greatest proportion of socio-psychological research in relation to EV uptake has been dedicated to an examination of the role of ethical motives of environmentally friendly buying behaviour. This is an important issue as policy makers and marketers make some assumptions as to the importance of this motive to car buyers. There is, however, mixed and somewhat confused assessments as to whether evaluations of the attributes of an EV as environmentally friendly are positively related to adoption indicators and how these motivators enter in to the decision making process.

Before summarising what the evidence suggests the role of environmental motives is, the following observations in the form of a critique of the literature are helpful to bear in mind when reviewing the evidence. Some of these observations are not specific to the understanding of pro-environmental motives, but impact on the state of knowledge surrounding EV adoption as a whole.

3.3.6.2 Failure to understand the role of environmental motives as a primary motivator

Straight opinion polling type studies offer mixed results not least due to the different ways in which factors involved in the adoption decision are 'measured' (e.g. the distinction between one of many motivating factors versus asking for the primary motive etc.). These results can be difficult to interpret as to their actual role in any adoption decision. An indication that environmental motives may be important in the purchase decision is not the same as suggesting that this is *the reason* for adopting an EV. A more useful understanding would be to measure the extent to which environmental motives are a deciding factor in adoption. This could be interpreted as a classic 'correlation not causation' mistake which can pervade this literature.

3.3.6.3 Assumption that EVs are indeed 'pro environmental'

One potential problem with the body of literature on the role of environmental motives is that much of it assumes that EVs are environmentally friendly and therefore take for granted that their adoption constitutes a 'green behaviour'. There can be a confusion here between what the EV actually is (does it have a net environmental benefit? Is it perceived to have a net environmental benefit?) and the intention to act green. Most of the time, the research does not check to understand whether participants actually believe the EV to be environmentally friendly, just merely whether their intrinsic motivations correlate with the intention to adopt.

3.3.6.4 The need to understand role of current incumbent technology

Linked to the above, many social-psychological approaches to EV adoption do not calibrate evaluations of environmental and other consequences of EVs against the 'incumbent' ICE vehicle technology. Instead, many studies adopt a binary 'intend to adopt/ not to adopt an EV' study design. Studies which take a much broader view and look at the *pull* of the ICE vehicle as well as the possible attraction of EVs *to overcome the negative consequences of ICE vehicles*, rather than focusing on the intrinsic 'greenness' of an EV on its own, provide a better understanding of what the

environmental motive actually is and the degree of 'urgency' linked to those attitudes as an indication of the strength of self-reported intentions. Thus, the perception of whether a particular technology is beneficial vis a vis conventional technology, particularly in the context of forever improving fuel economy of ICE vehicles, could be an important area for future research.

3.3.6.5 Different measures of adoption intention

Different variables are used to make conclusions about acceptance or adoption of EVs. This can plague all literature reviewed here, not just that looking at environmental motives. These can range from individuals' preferences for different vehicle attributes (e.g. energy source, range, and price), attitudes (e.g. perceived advantages and barriers) and direct questions regarding willingness to purchase or use an EV and the willingness to recommend an EV. It is worth noting that according to Schade and Schlag (2003), acceptance is one's attitudinal and behavioural reaction after exposure to a product. Prior to exposure, only 'acceptability' can be assessed, which is a pure attitudinal construct. Helpfully, Bockarjova and Steg (2014) distinguish between different types of adoption indicator which they place on a spectrum from 'close' to 'distant': (i) overall evaluation of EVs (ii) intention to purchase an EV (iii) acceptability of policies directed at EVs (iv) long run acceptability of EVs. Making these distinctions is once again important as the literature is muddled in terms of the adoption intentions actually measured and so the degree to which a certain functional or psychological construct may relate to adoption intention cannot necessarily be examined.

3.3.6.6 Distinguishing between different types of environmental impact

Studies are often vague about the 'environmental' impacts being addressed. Consequently, little is known about the relative importance of local air pollution, noise, carbon emissions and other issues such as resource depletion and energy security in terms of their effectiveness in promoting EV adoption. It has been argued that people tend to discount risks that will become apparent in distant future only (i.e. from 'slow onset environmental issues') and are less motivated by such future collective risks. Making this distinction could be especially important given the rise of public awareness of air pollution, at least partly as a reaction to recent media coverage of ICE vehicles and official test cycles. This also relates to the need to understand the link in car owners' minds between plug-in vehicles and the carbon content of the electricity consumed and the battery production and disposal process.

3.3.6.7 Distinguishing between those who already have an EV and understanding the motives of possible future adopters

Many studies attempt to evaluate the importance of environmental motives by asking those who have already adopted an EV whether environmental motives were important. It is questionable whether asking people after the event is valid as post-hoc rationalisation can occur (Thøgersen, 2011).

3.3.6.8 Distinguishing between BEVs and PHEVs

Most studies do not separate out attitudes to these technologies separately. Given that each one will represent different degrees of 'pro-environmental' behaviour, this should be a priority for future research.

3.3.6.9 *Understanding the interaction between the vehicle technology, the number of cars owned and the amount that they are used*

The environmental impact of a vehicle is only partially related to its powertrain technology, particularly when any associated electricity demand may not be generated from renewable resources. This review has not discovered any attempt to understand whether consumers consider their whole environmental footprint (total cars owned x amount driven) when drawing upon their environmental identity or motives in the decision making process.

Notwithstanding these concerns, the following observations can be made from the most recent literature reviewed here.

Straight-forward surveys of the motivators of EV adoption suggest that environmental benefits of EVs tend to only constitute a minor purchase motivation when ranked alongside other motives:

- DfT (2014 & 2015): In both 2014 and 2015, 'environmentally friendly' was the fourth ranking factor encouraging people to buy an EV in the UK. The proportion choosing this as a factor dropped from 17% in 2014 to 11% in 2015 suggesting that potentially other (more functional) factors may be rising in importance as we move out of the earliest adopter segment. However, several response options showed lower proportions of agreement, not just this one.
- Hutchins et al. (2013): Over 40% of the EV owners cited 'the environment' as a reason why they had chosen to buy an EV rather than an ICE vehicle. 17% also cited 'climate change/CO2', and 9% 'pollution/air quality'. In addition, 72% of the EV owners were also identified as being in the DfT segment 'Educated suburban families'. This segment is by far the most likely to believe that climate change is already impacting on the UK and expressed a greater willingness to change their behaviour than any other segment.
- Center for Sustainable Energy (2015): 22% of EV owners in California said 'reducing environmental impacts' was their primary motivation for buying an EV – making it the second most cited motivation. It has also previously been reported that 32% of EV owners in California have solar panels on their home and another 16% are planning to install them.
- Figenbaum et al. (2014): 33% of EV owners in Norway cited 'EVs are environmentally friendly' as being a very significant factor in their decision to buy one. 15% of EV owners in Norway are members of an environmental organisation, and overall, EV owners emerge as more environmentally friendly than cross-section samples from the population. Research in various other countries, including the US (Vergis and Chen, 2014), Norway (Figenbaum et al., 2014), Portugal (Rolim et al., 2014), France (Pierre et al., 2011) and the Netherlands (Velthuis, 2012, cited in Brook Lyndhurst, 2015) has come to similar conclusions.

One study did suggest that environmental motives are an independent predictor of EV uptake even when attitudes to the more functional and symbolic aspects of the cars are controlled for. Noppers, Keizer, Bolderdijk and Steg (2014) found that the more participants believed that electric cars have positive environmental attributes, the more they were interested in electric cars. However, more importantly, evaluation of the instrumental attributes of electric cars did not significantly predict the different indicators of adoption when evaluations of environmental attributes and symbolic attributes were

controlled for. As with all studies taking place with current non EV owners, however, these results can only be considered relevant for this early adoption phase of the market.

Studies that have investigated the link between levels of awareness and acceptance of environmental problems suggest it is not enough for people to see a link between EVs and their environmental credentials but must be aware and sympathise with environmental issues in the first place. This is a subtle but important distinction and has important consequences for what is measured by surveys. In particular, studies acknowledge that environmentally significant behaviour is a mixture of self-interest and concern for others or the environment, and that it is insufficient to only look at one of these aspects.

Several studies show that a positive attitude toward the environment tends to increase the willingness-to-pay for electromobility (Daziano & Bolduc, 2011; Jensen et al., 2013, 2014; Sexton & Sexton, 2014, Schuitema et al. 2013; Bahamonde-Birke & Hanappi, 2016).

Nayum, Klöckner, and Mehmetoglu (2016) showed that buyers of battery electric cars were better educated, and had a higher level of awareness and acceptance of environmental problems than others. However, a detailed examination of the results showed that the awareness of consequences, ascription of responsibility, and subjective social norm indicators, whilst higher than the reference groups, were lower than the other motivators such as perceived behavioural control and general attitude towards EVs.

Bahamonde-Birke and Hanappi (2016) is a rare example of where BEVs and PHEVs are looked at separately. They found that green-minded individuals ascribe greater utility to automobiles with electric engines but that pure EVs were preferred.

The role of environmental attitudes is most usefully understood in relation to a person's self-identity which represents a mental model that drives an individual to engage in specific behaviours. However, as discussed, green identity may only be one facet in a multi-layered concept of 'environmental attitude'. Here are examples of where the multi-layered nature of 'environmental attitudes' has been revealed:

- Schuitema et al. (2013), in their analysis of UK data from an online survey of new car buyers, found that people who believe that a pro-environmental self-identity fits with their self-image are more likely to have positive perceptions of EV attributes. This study separates out BEVs and PHEVs.
- A study by Barbarossa, Beckmann, De Pelsmacker, Moons, and Gwozdz (2015) revealed the motivational processes through which green identity works. They distinguished between green self-identity, care for the environmental consequences of using cars and green moral obligation, and found that they played significantly different roles in the formation of consumer attitudes and intentions toward the adoption of the electric car in three countries (Denmark, Belgium and Italy). Green self-identity can have a direct link to intention to adopt, but is also mediated by other factors. The direct effect of green self-identity on the attitude toward electric car adoption is highest in Denmark, explained by lower uncertainty avoidance and relatively higher long-term orientation. By contrast, high uncertainty avoidance in Belgium means that green self-identity only influences the attitude towards eco-friendly products provided it leads to the development of environmental care.

One study which took a broader view, with an attempt to understand attitudes towards ICE vehicles as well as EVs, suggested that views on the 'pull' of ICE vehicles and/or their negative consequences are more important than the intrinsic benefits of EVs. Bockarjova and Steg (2014) administered a questionnaire to a large representative sample of Dutch drivers using Protection Motivation Theory (PMT) in the survey design. PMT employs a wide set of predictors, such as the costs and benefits of current (maladaptive) behaviour (e.g. ownership of an ICE vehicle) as well as prospective adaptive behaviour (ownership of an EV). Participants were more likely to adopt an EV when they perceived the negative consequences caused by conventional vehicles as more severe, and when they expected EVs to decrease these consequences. The most important barriers for EV adoption – in addition to the perceived high monetary and non-monetary costs of EVs – were the benefits associated with the use of a conventional vehicle.

It is also important to understand the degree to which EVs are believed to be able to tackle environmental problems. A person can be highly motivated by environmental issues, but if they do not believe EVs are a solution, this will not matter. Bockarjova and Steg (2014) found that response efficacy, that is, the extent to which EVs are believed to be effective in reducing environmental and energy security risks, is positively associated with their adoption.

There is insufficient evidence to understand whether climate change, local air quality, noise or energy security issues are more important to people and therefore potentially motivating with respect to EV uptake. Bockarjova and Steg (2014) distinguished between different types of adoption indicator which they placed on a spectrum from 'close' to 'distant': (i) overall evaluation of EVs (ii) intention to purchase an EV (iii) acceptability of policies directed at EVs (iv) long run (range) acceptability of EVs. They found that environmental risks (combining air pollution, noise and CO₂ emissions) are more prominent in predicting close adoption indicators while energy security risks are more prominent in predicting distant adoption indicators. This is perhaps surprising as energy security risks connected to the dependence on fuel supply from politically unstable countries and high volatility of fuel prices is a somewhat 'closer' threat with more direct consequences for personal budget. But, overall, individual concerns (in particular perceived costs of driving an EV) played a more prominent role when predicting close measures of adoption (e.g. energy security risks), while collective concerns (e.g. perceived severity of environmental and energy security risks) played a somewhat more prominent role when predicting distant measures of adoption.

Axsen and Kurani (2013a) made a distinction between 'concern about the environment' (local environmental concerns) and 'concern about climate change', and found the former to be among the highest motivations in their investigation of potential uptake of EVs and green electricity. However, concern about climate change was absent in all cases.

Only one study was found which attempts to link the consumer motives in relation to both EV adoption and green electricity. Axsen and Kurani (2013a) implemented a web based survey with three US samples variously defined by the type of cars they own. They found that the link between EVs and green electricity is not presently strong in the consciousness of most consumers. Nevertheless, pairing an EV with a green electricity program increased interest in EVs in all three participant segments. Participants' reported motives for interest in both products and their combination include financial savings (particularly among conventional buyers), concerns about air pollution and the environment, and interest in new technology (particularly among PIV buyers).

3.3.6.10 *Interest in new technology*

One of the most popular models used to think about EV uptake is Rogers' (2003) 'diffusion of innovations' model, which separates potential buyers into innovators, early adopters, early majority, late majority, and laggards. This diffusion model focuses on the trait of 'innovativeness' as the main determinant of purchase behaviour. However, there is little confirmation in the literature to suggest this is either an easy trait to measure or something which can usefully predict EV uptake. Instead, in line with Axsen and Kurani (2012) and Axsen et al. (2015b), it appears from this review that a concept of innovativeness may be too vague to capture the motives related to any desire to be involved in new technology uptake, as confirmed by Morton, Anable, and Nelson (2016) who, in a questionnaire survey in two locations in the UK, applied a conceptual model centred around an attempt to measure various facets of innovativeness. A conceptual framework was developed which included measurements of innovativeness at both an actualised level (how many new technologies are already owned and how many are desired), and an innate level, by measuring psychological (curiosity, ambition, compulsiveness, receptivity) and sociological factors (social engagement, heterophily, information seeking, opinion leadership). The interaction with attitudes towards the functional performance of EVs was also examined. Results of the analysis showed only weak connection between actualised innovativeness (both total desired and total owned) and EV preferences. The findings may be due to measurement error, but the likelihood is that the emerging EV market may represent a unique environment for the expression of innovativeness and research requires a better domain specific expression of this trait to be developed.

Therefore, where a desire to be involved in new technology is measured more directly, and where the concept of 'innovativeness' is appreciated to touch upon a whole array of instrumental, symbolic and environmental motives, a much more useful understanding might emerge. Some studies have found evidence that, for some, the opportunity to engage with a new, cutting-edge technology produces excitement which can be a key motivation for adopting an EV:

- Hutchins et al. (2013) found that 28% of UK EV owners cited a 'desire to be involved in new/fun innovative technology' as a reason why they had chosen to buy an EV rather than an ICE vehicle.
- The Center for Sustainable Energy (2015) found that 5% of EV owners in California said 'a desire for newest technology' was their primary motivation for buying an EV – making it the fifth most cited motivation
- Figenbaum et al. (2014) found that 21% of EV owners in Norway cited 'I am interested in new technology' as being a very significant factor in their decision to buy one. 27% also said it had a large significance and 26% some significance.

However, one study which tried to use a domain-specific measure of interest in car technology did not find a relationship with EV preferences. In addition to environmental identity, Schuitema et al. (2013) considered car-authority identity as a subclass of technology orientation where individuals are experts on cars. However, car-authority consumers state neither positive nor negative perceptions of EV attributes and were not convinced about the environmental impacts of EVs.

The basic studies above suggest that interest in technology does not have to be present for EV preference to thrive, but is clearly a factor for some people. Other studies confirm this and suggest that for some it can stand alone as a motive, but for others it is important only in combination with other attitudes. Axsen, TyreeHageman, and Lentz

(2012) examined participants' interests in technology and degree of openness to change. The results suggested that EV preferences may be related to interest in technology, or to environmental motives, or both, as there are different clusters each showing different traits. They identified five clusters of potential adopters in the USA, namely engaged greens, aspiring greens, low-tech greens, traditionalists and techies. Techies show interest in technologies and thus are prone to adopt EVs for the technological reasons and not the environmental reasons. On the other hand, aspiring greens are less involved with pro-environmental practices and have less interest in technology compared to engaged greens but also show openness to change. Engaged greens are involved in pro-environmental and technology-oriented lifestyle practices and are open to change. The engaged greens and aspiring greens are more prone to adopt EVs according to the study. Low-tech greens showed the least openness to change and interest in technology, and compared to the last two clusters of greens, they are more likely to practice curtailment and non-consumption behaviour (driving less and use of alternative mode of transportation instead of driving) rather than adopting EVs.

Rezvani et al. (2015) reviewed studies on 'innovativeness' with respect to EVs and highlighted the Schuitema et al. (2013) and Axsen et al. (2012) studies cited above. In the former, 'car-authority' consumers demonstrate neither positive nor negative perceptions of EV attributes and were not convinced about the environmental impacts of EVs. In the latter, non-greens with technology oriented lifestyle are likely to adopt EVs. Rezvani et al. (2015) suggested that these results might imply that communicating EVs to technology oriented-consumers may need to put less emphasis on environmental benefits of EVs and mainly focus on technological aspects of the innovation.

Overall, however, EVs are not simply a new technology, but necessitate with it a whole array of behavioural adjustments related to everyday mobility. This points to caution required with respect to the importance of 'innovativeness' as is reflected in the following two studies:

- Schuitema et al. (2013) linked intention to adopt EVs to consumer innovativeness, which is defined as the tendency to buy new products relatively earlier than the majority of consumers. However, they did this by utilising three motivational reasons for consumer innovativeness, namely instrumental, hedonic and symbolic motives. Instrumental motives point to the consumer focus on functionality of the car. Hedonic innovativeness highlights the importance of anticipated emotions, such as pleasure from experiencing the car. Symbolic innovativeness indicates the significance of symbolic attributes of a car for the consumers.
- Peters and Dütschke (2014) utilised diffusion of innovation (DOI) theory (Rogers, 2003) to identify and profile early EV adopters. Rogers (1995, 2003) recognises five categories of factors that influence the adoption decision, namely relative advantage, compatibility, complexity, trialability and observability. Relative advantage is the degree to which the innovation is perceived to be better than the current product it is replacing. Compatibility determines the consistency of the innovation with values, experiences and needs of consumers. Complexity explains the degree of difficulty for the innovation to be understood and used by consumers. Trialability determines the extent to which the innovation can be trialled, modified, and experienced. Observability meanwhile is simply the visibility of the innovation in society. The study revealed that EVs are seen as a whole new mobility option and not just as a new propulsion system. From a

consumer perspective, the perceived compatibility with daily life is the most important predictor for the willingness to purchase an EV.

Finally, as noted in section 3.3.3, the 'newness' of the technology can also be a barrier. EV technology is new and therefore unfamiliar to many, and its novelty creates a barrier to acceptance.

3.3.6.11 Emotions

An important generalizable omission in the evidence base is the role of emotions in EV adoption. Rezvani et al. (2015) observed that *"although emotions are found to be important and influential in pro-environmental behavior (Bamberg and Möser, 2007; Steg and Vlek, 2009) and choice of cars (Steg, 2005), we are still lacking theorization of emotions in relation to pro-environmental behavior (such as adoption of EVs) and also the link of emotions with other factors such as values, beliefs, and norms"* (p.128).

Graham-Rowe et al.'s (2012) qualitative study found that participants who had driven BEVs and PHEVs for a trial period expressed various emotions. On one hand, 'feeling good' or 'less guilt' from driving a purportedly environmentally friendly car was mentioned by some consumers. On the other hand, some consumers stated the feeling of 'embarrassment' from driving a small and economical vehicle.

Schuitema et al. (2013) (based on Graham-Rowe et al., 2012) measured specific emotions (or hedonic attributes) such as pleasure, joy, pride, embarrassment in a quantitative study of new car buyers in the UK. The results showed that more positive perceptions of instrumental attributes of EVs lead to more positive emotions towards EVs, which in turn positively influence the intention to adopt EVs.

Moons and De Pelsmacker (2012) defined three emotional processing levels: visceral, behavioural and reflective. Visceral emotions are based on consumers' perceptions of instrumental and visual attributes of EVs such as style, design, and size. Behavioural emotions are related to consumers' emotions from using and experiencing driving EVs. Reflective emotions are related to self-image and identity connected to driving an EV. These emotional levels were measured by asking consumers about the extent of feeling positive versus negative emotions from the visceral, behavioural and reflective aspects of EVs. For potential buyers of EVs, the perception of positive feelings from driving an EV was positively correlated with consumer attitudes and intentions to adopt EVs. However, this study does not provide further information on the type of positive feelings that consumers anticipated to experience with EVs.

Rezvani et al. (2015) pointed out that another factor in emotional response to EVs is likely to be consumers' expectation of future events and consequent emotions. They base this hypothesis on a paper by Shih and Schau (2011) that found that the perceived rate of innovation, or rate at which consumers perceive technological conditions are changing in the market place, would result in anticipating regret and consequently delay the purchase of the technological innovation. They also suggest that *"communication messages, education and policies can create specific cognitive and emotional responses in consumers and consequently influence their decisions and behaviors. Understanding the cognitive and emotional responses can help marketing specialists and policy makers in designing their communication, education and policies to possibly overcome some barriers to adoption of EVs"* (p.134).

3.3.6.12 *Symbolic meanings*

Giddens (1991) and Dittmar (1992, cited in Rezvani et al., 2015) assert that individuals' choices such as purchase of a car are not only based on practical concerns or instrumental values but also on symbolic values and narratives of self which connect their choices with their self-identity. Whilst theoretically this link is quite clear, having reviewed the literature, Brook Lyndhurst (2015) describes the evidence on this as 'still subjective'. This is a fair assessment in that studies that have attempted to incorporate symbolic motives have either 'suffered' from a form of social responsibility bias or have narrowly concentrated on environmental symbolism.

The first issue (social responsibility bias) suggests that studies of EVs will 'naturally' fail to measure symbolic meanings or reveal them as important as people tend to stress instrumental and environmental attributes, especially when asked directly:

- Noppers et al. (2014) compared results of a small study in the Netherlands (N=105) after participants were asked to first directly indicate how important instrumental, environmental and symbolic motives were to them (i.e. those which reflect the impact of an EV on self-identity and social status, such as "the electric car shows who I am" and "the electric car enhances my social status") and then indirectly by indicating which attributes each vehicle has combined with indicators of adoption. They found that when asked directly, participants claimed that instrumental and environmental attributes were most important for their decision to adopt sustainable innovations, while symbolic attributes were rated as less important. However, evaluations of the symbolic and environmental attributes of sustainable innovations, but not evaluations of their instrumental attributes, predicted different indicators of adoption.
- Barth et al. (2016) found that both 'EV experts' and 'EV non-experts' considered cost-related factors as much more important than social identity processes, yet hierarchical regression analyses of their survey data (online, 601 potential EV buyers in Germany) showed that norms and collective efficacy have equal or even stronger effects on acceptance than cost-related factors.

The second issue (narrow focus on environmentalism) relates to the fact that the majority of literature examining symbolic motives has focused on whether the adopter or potential adopter has bought an EV because of concern for environment in relation to whether he or she may consider him/herself as an environmentalist or because they perceive that they are signifying this to others. Other studies have attempted to broaden the sociological approach to identity by exploring the need to engage in coherent patterns of lifestyle that represent aspects of self-identity (Axsen et al., 2012), being a car authority (Schuitema et al., 2013), interest in new technology (Graham-Rowe et al., 2012 and Axsen et al., 2015) and independence from Big Oil (Axsen et al., 2015b).

Schuitema et al. (2013) (in an online survey in the UK (n=2,728) of new car buyers) found that instrumental attributes are important largely because they are associated with other attributes derived from owning and using EVs, including pleasure of driving (hedonic attributes) and identity derived from owning and using EVs (symbolic attributes). Two different identities were examined, namely environmentalist and car-authority identity, in potential adopters of EVs. Consumers with pro-environmental identity were found to perceive EV attributes more positively than consumers who do not have such a self-identity. Nevertheless, consumers with a car-authority identity (who serve as authority figures for their peers concerning cars) have neither positive nor

negative perceptions of EV attributes. Thus, these authority figures are still not convinced that EVs offer environmental benefits.

Axsen et al. (2015) studied current EV owners (EV Pioneers) in Canada and asked them about the 'images' they associate with their vehicle (e.g. environmental, intelligence, sporty, powerful) to elicit symbolic value or benefit. The question was open ended but these were coded and quantified by owner group (Figure 13). Overall, most participants indicated some pro-social symbolic association with their EV, with many associating their vehicle with 'supporting the environment' (86%) and 'being responsible' (66%), as well as more private images such as being attractive (60%). There was also substantial heterogeneity among owner groups with respect to the number and type of image associations. For instance, Volt and Tesla owners were more likely to associate their PiV with a larger number of 'images' relative to Leaf owners; Tesla owners were by far the most likely to associate their vehicle with images relating to attractiveness, intelligence, sporty, exotic, powerful and successful. Relative to Volt owners, Leaf and Tesla owners were more likely to associate their vehicle with being pro-environmental and responsible.

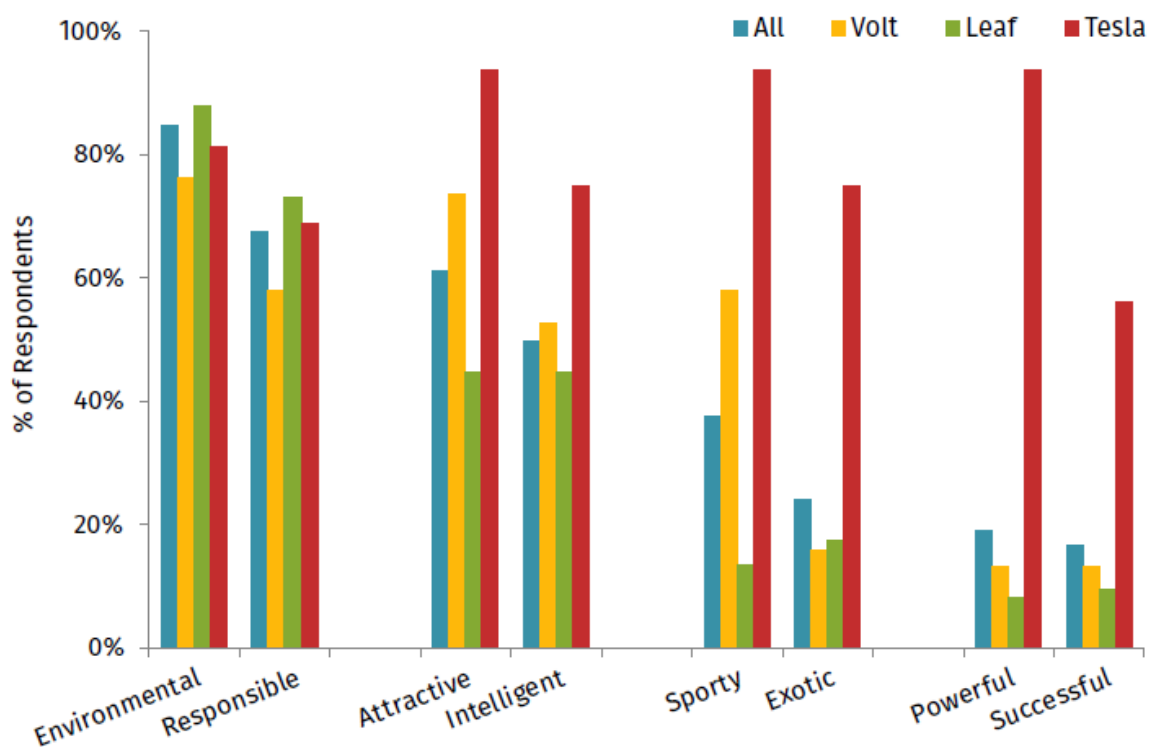


Figure 13: Image associations reported by owner group (from Axsen et al. (2015), p10).

Note that the above study is the closest found to attempting to identify different symbolic meanings attached to different EV types (BEVs and PHEVs). Rezvani et al. (2015) also suggested that identifying and examining the symbolic meanings of EVs for potential adopters in different countries should also be of interest and therefore effectively provide a word of caution that results on symbolic motives may not be transferable from country to country due to their context dependency.

As noted in previous reviews (e.g. Anable et al., 2014), the literature to date suggests that EVs do not currently have established symbolic meanings and these are likely to develop over time. This makes it all the more important to include a variety of measures of symbolism in any surveys to understand their emerging associations with which

include lower resource consumption, independence from petroleum producers, advanced technology, financial responsibility, saving money, opposing war, and environmental and/or resource preservation. Where these meanings relate to the prospective buyer's identity or values, they can form a motivator for the purchase decision.

3.3.6.13 *Social norms and diffusion through networks*

Symbolic motives and self-identity are catered for theoretically and operationally in surveys by referring to what is acceptable in collective norms and in more personalised relationships that define people's social identity. These influences are not expected to be a motivation to buy an EV in and of themselves but are a potentially important facilitator to the process of diffusion, whereby a new behaviour is adopted by increasing numbers of consumers as they see others around them adopting it.

Despite an overt recognition that people do not exist in a social vacuum and increasing visibility is a motivator to EV acceptance, there is little research which attempts to understand the interpersonal processes themselves and the role they play in EV uptake. If they have been addressed, they have rarely been examined in a differentiated way as there are a number of different norm processes which could impact on the uptake of EVs:

- *Injunctive norms* – perceptions of what other group members approve or disapprove of
- *Subjective (often just referred to as social) norms* – the same as injunctive norms but mores specifically referring to the approval or disapproval by close friends
- *Provincial norms* – the same as injunctive norms but more specifically referring to other people who live under similar conditions such as in the same town or in the same workplace
- *Descriptive (or behavioural) norms* – perceptions of what other group members actually do
- *Personal norms* - which are perceived obligations to act (and have been split by Thøgersen (2006) into 'introjected norm' (the person's feelings of guilt resulting from not owning or buying such a car), and integrated norm (the person's intrinsic feelings of obligation to own or buy such a car)).

Just as was observed in relation to symbolic motives above, one difficulty is that people themselves find these different norm processes difficult to recognise or admit to in interviews or surveys (Barth et al., 2016). The different types of norm are also potentially closely correlated with each other and this means that both the question wording and the results often do not allow clear distinctions to be made between them. Nevertheless, some studies have attempted to measure norms of different kinds and they have been found to contribute to explanations of EV adoption intentions over and above personal cost/benefit variables:

- Axsen et al. (2013) found that social negotiation (i.e. discussing EVs with others) can change individual perceptions of EVs and that participants were influenced by social interaction (see also Axsen & Kurani, 2011). The study took place in a workplace environment and surveyed perceptions, valuations, experiences and social interactions relating to EVs before and after around 50 people experienced a BEV. The majority of participants indicated that their BEV perceptions were "highly influenced" by at least one social interaction. They categorised social influence according to three processes: diffusion, the sharing of EV-related

information; translation, the discussion of uncertain BEV benefits and drawbacks; and reflexivity, the relating of BEV technology to self-concept. Findings suggest that participant perceptions change in part through social negotiation of meaning, lifestyle and identity.

- Klöckner (2014) monitored 113 people interested in the purchase of an EV for a period of two months. He found goal intention fluctuations by the same people at different time points can be explained more by personal norm activation as well as perceived social norms on the day at question than by positive emotions relating to EVs. They explain this by suggesting that the level of social norms a person perceives varies across days and might lead to different levels of activated personal norms. They suggest that in the pre-decisional stage, making social norms salient by showing how many people and who is driving an electric car already might have an activating effect.
- Petschnig et al. (2014) found that subjective and personal norms were positively related to the intention to use alternative fuel vehicles.

A recent study in Norway, however, found that personal norms were not found to be important for EV buyers. The authors speculated as to whether intrinsic motivations had been 'crowded out' by the level of incentives in Norway. Nayum et al. (2016) found that for all groups of car buyers (mid-sized family cars, large family cars etc.), environmental awareness but not personal and social norms could explain the specific regard to buying more fuel-efficient and environmentally friendly car. They stated that *"the apparent mismatch between the high level of environmental consciousness and the low level of normative concerns (or intrinsic motivation) might result from a defensive denial strategy... car buyers probably redefined the high-costs involving car purchase situation in such a way that the activation of personal norms did not seem appropriate. Moreover, the extrinsic incentives provided by the Norwegian government and its regulations might have resulted in crowding-out of consumers' "intrinsic motivation", hence reducing the likelihood of activated personal norms"* (p.18).

As this discussion already notes, the social processes potentially involved in new technology diffusion operate at multiple levels and directions of influence. Several studies chose to investigate this in relation to the collective actions involved in the successful adoption of pro-environmental practices on the basis that not only individual behavioural change, but also changes in collective customs are necessary to ensure a successful adoption of pro-environmental practices:

- Barth et al. (2016) measured 'collective efficacy', defined as the belief that the in-group is capable of affecting important aspects of its environment when they act together. They believed that it should foster individuals' actions towards collective goals by increasing their perception that their personal behaviour is a movement towards collective change, and they found it to have a strong and independent predictive effect on EV adoption intention. Part of their inspiration for this came from a study by Nolan et al. (2008) in the context of domestic energy conservation, which showed that the biggest changes in energy conservation behaviour came after receiving information about other community members' behaviour.
- Bockarjova and Steg (2014) used the concept of 'response efficacy' to capture collective efficacy and defined this as the belief that EVs can mitigate these collective environmental problems. In their study, response efficacy appeared to be particularly important in governing the 'distant' adoption indicators (i.e. long-

run EV acceptability and policy acceptability). As a result, they suggested that *"such scenarios can be considered as making adoption of electric vehicles a part of integrated efforts to move to a more sustainable society. Such efforts may include, among others, transition to sustainable electricity sources, decentralization of electricity production, off-peak electricity storage in the framework of security of electricity supply (such as vehicle-to-grid construction, Sovacool and Hirsh, 2009), and development of charging infrastructure"* (p.286).

Other studies have shown norms to be of secondary importance to personal cost/benefit factors and other factors, such as the emotions surrounding car driving:

- Moons and De Pelsmacker (2015) (online sample of 1,023 Belgians through snowball sampling) measured 'subjective norm peers' (interpersonal) and 'subjective norm media' alongside emotional reactions towards EVs and cars in general, and perceived behavioural control. Reflexive emotions towards car driving in general and the attitude towards the electric car are the strongest predictors of usage intention. The subjective norm of both reference groups (peers and media) is significant as well, but of secondary importance.
- Kim et al. (2014) estimated utility attributes, price, attitudes and social influence in a single integrated hybrid choice model of purchase intention among 726 participants in the Netherlands. Social influence was measured by indicating, in the choice experiment, the general public's opinions about EVs ('reviewers' opinions), which were categorised into four levels from 'only positive' to 'only negative' and market shares of the EVs for various social network types (i.e. friends, relatives, colleagues and peers). Results indicated that the model performs well. Cost considerations contribute most to the utility of electric cars. Social influence is less important, but there is also evidence that people tend to take it into consideration when there are positive public opinions about electric cars, and the market share becomes almost half of friends of their social network. However, reviewers' opinions tended to more strongly and significantly affect people's intention to purchase EVs than the share of EVs among people's social network members. The authors suggested that this may be due to the technological uncertainties of EVs which may tend to make the public reviews more reliable and important.

Although most of the cited research worked with one or two normative constructs at a time, only one study was found that incorporated all four types of norms (descriptive, injunctive, subjective and provincial) in the context of EV adoption to test whether all norms or just some of them have independent effects on EV adoption (Barth et al., 2016). If differential effects are found, this could help improve the development of strategies to increase EV acceptance via normative influence such as information campaigns and advertising, as the effects of descriptive norms and injunctive norms would need to be promoted in fundamentally different ways. Barth et al.'s (2016) regression model found personal costs and benefits (such as, for instance, those related to usability, monetary, or environmental issues) as important factors affecting EV acceptance. However, in the final step of the model they added all norm scales (injunctive norm, descriptive norm, provincial norm, and subjective norm) and collective efficacy. These 'social identity' predictors carried at least a much weight in the model. The final model accounted for 54% of the variance. All variables significantly predicted acceptance with two exceptions. Personal experience via test-drive only reached marginal significance. Descriptive norms (what others actually do) were not significantly related to acceptance of EVs (Barth et al., 2016).

The finding in the Barth et al. study that behavioural norms were not important is interesting and raises an important question about whether or not different norm processes are more important at different points in the adoption process at an individual level and at a societal level. The use of different measures of norms and the application of these measures to different samples (from 'revealed' early adopters through to potential adopters far into the future) means that it is not possible to come to a clear idea of which norms are important at which point in the process. The evidence on this still presents as speculative. The following authors have speculated to this effect:

- Barth et al. (2016) explained their finding of a lack of any descriptive norm effect in terms of the specific context of EVs as a technological innovation: "*In contrast to behavior that has been investigated in the literature on descriptive norms, electric vehicles are a very recent phenomenon. Their lacking presence on today's roads might not be perceived to be diagnostic for social disapproval as it would be the case with well-established behavior, such as using busses [sic]. People may discount descriptive norm information as a source for their own decisions, because they do not think that the current situation is diagnostic of the future development of the EV market*" (p.74). Consequently they believe that descriptive norms work against the earliest adoption and ask: "*Is there some kind of threshold, a moment in the diffusion process when the absence of EVs on Germany's streets becomes diagnostic and will then decrease personal EV acceptance? As soon as EVs are no longer conceived as novel or when a newly developed infrastructure will not be matched by a notable increase in number of users, descriptive norm information could become an obstacle to the formation of a positive goal intention*" (p.74).
- Klöckner (2014) proposed that social norms particularly influence goal intentions in the pre-decisional stage as people need social validation.
- Barbarossa et al. (2015) decided not to measure social norms in favour of green self-identity on the basis that Moons and De Pelsmacker (2012) found social norms to be of secondary importance. Nevertheless, they suggest "*with the progressive diffusion of eco-friendly electric cars in the market, these factors may play an increasingly important role. Therefore, in later electric car adoption stages, further investigation on the interplay between green self-identity, green social identity, social norms and facilitators or constraints is needed*" (p.157).

The evidence in relation to norms does not always take the form of theoretically embedded conceptual frameworks or measurements of interpersonal processes, but has been revealed through the study of how EV uptake has 'diffused' within social networks which tend to share the same demographics:

- In Norway, 36% of EV owners reported having friends and family who also own an EV and 38% report having family and friends who were considering buying one (Figenbaum et al., 2014).
- 32% of EV owners in California said they received information from family and friends before buying an EV and over half rated this as extremely or very important (Center for Sustainable Energy, 2015).

The 'neighbour effect' has been put forward as a strong potential future motivator of EV uptake. The theory is that as EVs become more widespread and more visible, people become more confident in the technology, as well as being influenced by the social norming effect (see Anable et al., 2014 for a review of this literature).

3.3.6.14 Role of information

The above sections on the role of perceived monetary and technological attributes of vehicles and the wider psychological and sociological processes lead to the question as to the role of information in altering consumer acceptance of EVs.

Axsen et al. (2015b) offer a helpful two-by-two attribute typology to distinguish between types of consumer perceptions: functional vs. symbolic, and private vs. societal (Figure 14). In this section this is used to evaluate the state of the art with respect to the role of information on EV adoption and to review the studies that have been found addressing each of these. However, as is seen below, by far the majority of research has been undertaken with respect to information provided on the functional private motives.

	Functional	Symbolic
Private benefits	<ul style="list-style-type: none"> › Save money › Reliable › Fun to drive (experiential) 	<ul style="list-style-type: none"> › Expression of self-identity › Convey personal status to others › Attain group membership
Societal benefits	<ul style="list-style-type: none"> › Reduce air pollution › Reduce global warming › Reduce oil use 	<ul style="list-style-type: none"> › Inspire other consumers › Send message to automakers, government, oil companies

Figure 14: Conceptualisation of benefits from EVs (from Axsen et al. 2015b, p.39)

3.3.6.15 The role of information provision on private functional motives

This is the most common form of information provision which attempts to address information deficits among consumers, or consumer biases that overvalue upfront investments as against future savings. It is typified by campaigns such as UK's Go Ultra Low consumer campaign introduced in 2014 to promote ULEVs and provide an online one-stop-shop for information about owning and running them, the makes and models available and the locations of public charge points. It is being delivered in partnership by the Government and ULEV manufacturers.

The research, however, is weak with respect to what actually works to shift consumer attitudes using this type of information. It is typical for many academic and other types of research publication which have studied consumer attitudes to EVs and acceptance of EVs to suggest that their results should inform information provision, but very little research has gone on to actually test out these propositions. A good example of this is Dumortier et al. (2015). They questioned whether consumers' misperceptions of the advantage of the total cost of ownership (TCO) of EVs (taking into account the need for a car loan, the interest rate and payback period of the loan, and a discount rate for future fuel savings over an assumed vehicle ownership lifetime) might be alleviated by providing a heuristic or as a way of doing the calculations for consumers, thus removing a barrier to rational decision-making. They used an online stated preference method to provide five-year fuel cost savings and TCO affects to test the purchase choice between a gasoline, conventional hybrid, plug-in hybrid, or battery electric vehicle. They found participant rankings of vehicles were unaffected by information on five-year fuel cost savings but that adding information about TCO increased preferences for a conventional hybrid, plug-in hybrid, or a battery-electric vehicle – but only by small/mid-sized car consumers. No such effect was found for consumers of small sport utility vehicles. They

suggested that this should lead to more informative designs of product labels. However, no research has been found testing these labels on the recent market for EVs and no account is taken of earlier research (i.e. Lane et al., 2012, which found that per month or per mile information would be preferred to annual costs).

A lack of awareness of charging stations or speculation about the role of additional visibility of charging stations also falls into this category of information provision – although the role of charging stations has also been speculated as fostering descriptive norms. However, the actual role of this awareness has rarely been studied directly. An exception is a study by Bailey et al. (2015) where awareness of charge points was not found to play an important role in EV acceptance. They assessed the current levels of visibility for public EV charging infrastructure within Canada (N=1739 in 2013) and identified whether or not a relationship exists between consumer awareness of public charging infrastructure and interest in purchasing a PiV. They found a significant bivariate relationship between public charger awareness and PiV interest. However, when controlling for multiple explanatory variables in regression analyses, the relationship was weak or non-existent. While perceived existence of at least one charger exhibits no significant relationship with EV interest, perceived existence of multiple chargers can have a weak but significant relationship. Thus, public charger awareness is not a strong predictor of EV interest; other variables are more important, such as the availability of level 1 (110/120-volt) charging at home.

A different type of study, albeit still not understanding 'real world' informational processes, sought to incorporate consumer learning (from information) through a reflexive lifestyle approach. Axsen et al. (2015b) started with the assumption that consumers construct their interests and preferences as they learn about EV technology – through social interaction, information provision or actual use – and that these interests may or may not be constrained by past or present driving patterns, charge availability or consumer motivation. Secondly they were aware that most potential (mainstream) EV adopters have little familiarity with EVs, and are particularly confused about the concept of a PHEV. Indeed, they assessed the initial awareness of what they grouped as 'Pioneer' and 'mainstream' participants to compare each sample's understanding of (or confusion with) EV technologies. Figure 15 shows that a high proportion of Pioneers demonstrated familiarity with major EV models (77–84%) but only a minority of mainstream participants were familiar with EVs (14–31%). Mainstream participants demonstrated a particular confusion about the idea of PHEVs. The survey work used the information on each participant about their current level of knowledge and experience with EVs to stimulate a learning process by providing tailored information then testing preferences in a visual design space that allows the participant to personalise a vehicle or charger style to match their exact preferences in response to the information.

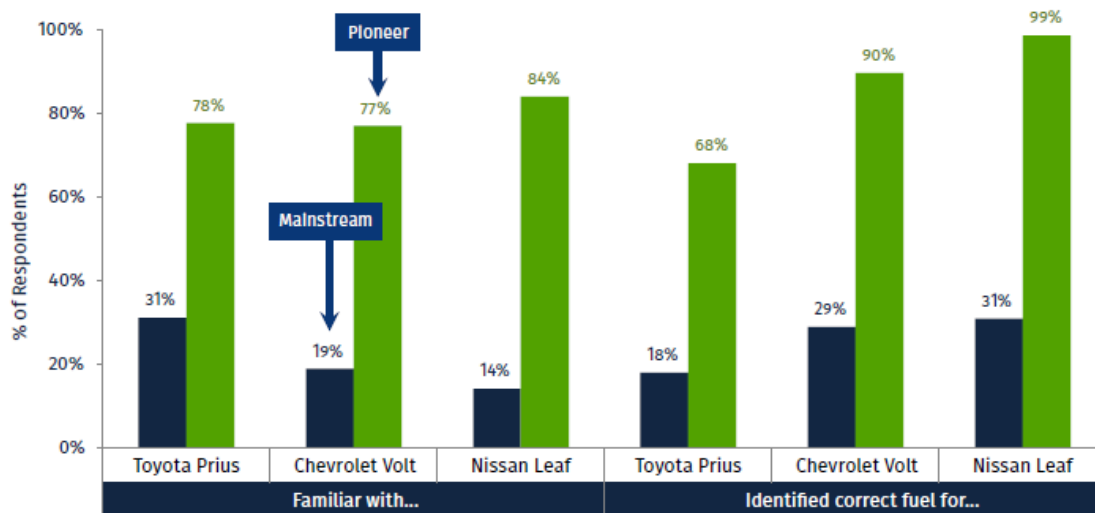


Figure 15: Comparison of EV familiarity and refuelling between 'Pioneer' and mainstream' participants in British Columbia (Axsen et al., 2015, p.87)

3.3.6.16 The role of information on private symbolic motives

No studies were found assessing the impact of information attempting to convey issues of identity, status or group membership as a result of EV adoption and use.

3.3.6.17 The role of information on societal functional motives

No studies were found assessing the impact of information attempting to convey issues relating to the potential environmental or energy security benefits of EVs other than Ohta, Fuji, Nishimura, and Kozuka (2013 – see below).

3.3.6.18 The role of information on societal symbolic motives

Barth et al. (2016) point to the positive role of social norms in their study to suggest that EV information campaigns should spread normative messages such as positive polling results or pro EV statements by national authority figures or celebrities. In addition, individual adoption of an EV could be framed as being part of a collective endeavour "with messages such as "Germany is going for the mobility revolution" (p.74). The only study found which touched on this type of information provision was Ohta et al. (2013) who found that information about costs and social merits of 'eco cars' did not have a significant effect on their acceptance, but factual information on their prevalence did.

3.3.7 Variation across social groups and space

Section summary

- There is not much difference between the key characteristics that emerge from studies of existing EV owners and from stated preference type surveys which attempt to identify the next tranche of early adopters.
- This may be due to the emphasis on identifying demographic indicators which the segmentation literature makes clear are not the best means by which to predict future mainstream EV adopters.
- Comparative data across countries seems to suggest that current EV owners

are predominantly male, middle aged, with above average education, affluent, family oriented, urban-based in multi-car households. However, these characteristics cannot be taken as definitive as the evidence is not strong enough to say whether the characteristics of EV owners are any different to new car buyers in general. There is also some suggestion that younger males are a key adopter group.

- There may be some consistency in findings to suggest that EVs are purchased mainly by multi-car households. However, this is not the same as understanding where the EV fits in to this and whether the characteristics of the household or the purchaser are different depending on whether they adopt the car for main or secondary usage.
- There is a general lack of understanding of household composition including the presence of children and employment status (and potentially occupation) of all the adults in the household. For instance, many studies cite 'multi-occupancy' households as being disproportionately represented among EV owners, but the presence of children is not investigated specifically.
- As the market for EVs grows, more evidence needs to be collected on the spatial distribution of EV adopters. Rather than crude urban-rural classifications, some indications of average journey lengths, accessibility, relationship to public transport networks etc. need to be understood.
- Details of pre-EV travel patterns are very limited. It is possible that numerous urban (shorter) trips correlate with EV uptake, but also that above average total number of miles is also related as drivers who drive longer distances pay more for fuel and stand to save more from BEVs.
- In the most mature EV markets, there has been a gradual widening of the demographic (in California) and a more marked change (in Norway) towards younger, single car households.
- Segmentation models can be split into preference-based approaches which characterise how consumer choices (outcomes) may differ among participants, and motivational- or lifestyle-based approaches which characterise how consumer motivations may differ. The former method resembles the traditional discrete choice type analysis which focuses on stated choice, whereas the latter is arguably more useful to understand the multiple groups which may exist with the same choice set.
- Both methods demonstrate that EV interest is generally associated with engagement in certain lifestyles and attitudes and therefore effective characterisation of consumer heterogeneity should address variations in consumer motivations as well as overall preferences.
- Segmentation in the EV literature is still largely reliant on Roger's diffusion of innovation model, by setting out to identify a single innovator and/or early adopter group and so on based on preferences, willingness or likelihood to adopt an EV. Segmentation models which recognise that there may be more than one early adopter group each motivated by different factors, based on a richness of demographic and socio-psychological data and which can provide vital information on which segments might adopt which cars (e.g. BEV vs PHEV), are still rare.

3.3.7.1 Characteristics of current and future owners

The literature on the characteristics of EV owners can be separated into attempts to extrapolate from analysis of current owners (essentially the earliest adopters who are not necessarily representative of later adopters) or from stated preference type surveys which attempt to identify the next tranche of early adopters. In summary, however, there is not much difference between the key characteristics that emerge from both of these types of data.

Overall, this section and the following section ('segmentation') will make it clear that demographic indicators are not the best means by which to predict future EV adopters. In the UK, data on the characteristics of EV owners is collected on PiCG recipients, although this data is not made public annually. The last published information was based on 2013 data (Hutchins et al. 2013). Although the research was undertaken at an early point in the development of the EV market in the UK (only 0.16% of new cars sales in 2013 were EVs) and had a modest sample size (n=192), the findings are the richest of any published data source relating to UK EV owners. These findings were reported in detail in Brook Lyndhurst (2015) and are reported below. Based on Hutchins et al. (2013), current UK EV owners or near-term prospective owners tend to have the demographics summarised in Table 8.

Table 8: Demographic characteristics of early adopters of EVs in the UK

Dominant characteristic	Current EV owners in the UK (from Hutchins et al. 2013)
Male	69% male
Middle aged	75% aged 40-69 years
Well educated	69% with a degree or diploma
Affluent	72% in the DfT segment "Educated suburban families" with majority annual income of £35,000+ and for over a quarter it is £60,000+.
Urban or suburban	17% urban – London 46% urban – other 18% town and fringe 11% hamlet/village/other
High social grade	34% A (upper middle class) 32% B (middle class) 25% C1 (lower middle class)
Ability to charge at home	97% of participants said they had charged EV at home, suggesting almost all had the ability to charge at home.
Two or more cars	80% 2 or more cars 20% 1 car
Pre-EV mileage	This was not asked in the survey but 72% of participants were identified as being in the DfT segment "Educated suburban families". This segment has a relatively high annual mileage – 30% between 5,000-8,999 miles and 47% over 9,000 miles. ¹³

¹³ DfT (2011) Climate change and transport choices: segmentation study.

The majority of these characteristics are repeated across countries. For instance, the evidence found in the literature on current EV owners (Figenbaum et al., 2014) or prospective near-term owners (Barth et al., 2016; Plötz, Schneider, Globisch & Dütschke, 2014; Hackbarth & Madlener, 2013; Hanappi et al., 2012) supports the above findings. Whilst the apparent 'consensus' in findings across countries might appear to provide a robust analysis of the characteristics of likely EV owners, there are some important inconsistencies or omissions from our understanding of the demographic characteristics of both current and potential EV adopters:

- *Age*: There is some difference in the degree to which younger age groups as compared to middle-age groups might be more interested in EVs. The UK data suggests EV owners are even more heavily concentrated in the 40-69 age group than new car buyers in general. However, Hanappi et al. (2012, cited in Hjorthol, 2013) showed affluent *young* males to be the most likely to purchase an AFV (not just EVs). This survey showed that with increasing age the probability of car buyers choosing an alternative powered vehicle drops. Older people are most sceptical of gas powered vehicles, followed by ethanol and EVs. In addition, Hackbarth and Madlener (2013, Germany, n=711 people having bought a car in the last year) and Hidrue et al. (2011, USA, n=3,029) found younger people to be the most sensitive age group. Barth et al. (2016) also only found a weak positive correlation with age. Sentio Research Norway (2012) (cited in Hjorthol, 2013) carried out an online survey with a random sample of 1,000 Norwegians aged 18 years and older about whether they thought an EV could satisfy their transport needs. Those who answered 'to a large degree' tended to be 30 years and younger.
- *Income*: There is some doubt as to the strength of the relationship between income and EV ownership in the literature. First of all, income is often not measured directly and is therefore inferred from other variables (e.g. Hutchins et al. 2013). Secondly, some of the samples are undertaken on buyers of new cars which tend to be the more affluent sections of society in the first place and do not find a relationship with income (e.g. Barth et al., 2016; Aksen et al., 2015b (Canada) citing Carley et al. (2013) and Krause, Carley, Lane, and Graham (2013) as having found the same effect). This was also the case in the previous ETI study which also found a weak relationship with income among the sample of new car buyers for the purchase of an EV as a main vehicle, although was predictive of adoption as a second car (Anable et al., 2016).
- *Comparison to new car buyers in general*: As the issue in relation to income highlights, studies tend not to reflect on whether the characteristics of EV adopters in their study are any different to the characteristics of new car buyers in general in their country. One issue here is that statistics on the demographics of new car buyers can be difficult to find (Anable et al., 2014).
- *PHEV vs BEV owners*: Aside from Anable et al. (2016), only one study was found which distinguished between the (potential) characteristics of PHEV vs BEV owners: Hanappi et al. (2012, cited in Hjorthol, 2013) found the income effect is greater for PHEVs.
- *Second-hand car purchasers*: No studies were found which have attempted to identify the characteristics or potential characteristics of buyers of second-hand EVs.

- *Purchase as the main car or second car:* There may be some consistency in findings to suggest that EVs are purchased mainly by multi-car households. However, this is not the same as understanding where the EV fits in to this and whether the characteristics of the household or the purchaser are different depending on whether they adopt the car for main or secondary usage.
- *Pre-EV car ownership:* Other than multi-car households being over represented among (potential) early adopters, there is little understanding of previous car owning history and detail about the types of cars currently owned.
- *Detailed household composition:* There is a general lack of understanding of household composition including the presence of children and employment status (and potentially occupation) of all the adults in the household. For instance, many studies cite 'multi-occupancy' households as being disproportionately represented among EV owners, but the presence of children is not investigated specifically. Again, one exception is Hanappi et al. (2012) who observe a tendency for children to be present in would-be EV owners' households. Plötz et al. (2014) found technical professions were over represented.
- *Spatial distribution:* As the market for EVs grows, more evidence needs to be collected on the spatial distribution of EV adopters. Rather than crude urban-rural classifications, some indications of average journey lengths, accessibility, relationship to public transport networks etc. need to be understood. Unlike the urban bias found in the UK and overwhelmingly in Norway, Plötz et al. (2014) found potential EV owners among rural or suburban multi-person households in Germany. If these different spatial distributions exist, it will be useful to understand the factors that explain these different patterns.
- *Travel patterns:* Detail of pre-EV travel patterns is very limited. Hackbarth and Madlener (2013) found that the group most likely to adopt alternatively fuelled vehicles in general undertake numerous urban trips. Hidrue et al. (2011) found that having to make at least one drive per month that is longer than 100 miles was correlated with EV acceptance. The last finding is counterintuitive, but the authors noted that drivers who drive longer distances pay more for fuel and stand to save more from BEVs. They also found no significant correlation with being a multicar household.

In an effort to think about whether the characteristics of future EV buyers might change from the profile we are seeing today, Brook Lyndhurst (2015) looked at California and Norway (currently two of the most developed EV markets in the world). Interestingly they found that there has been a gradual widening of the demographic in California but a more marked change in Norway towards younger, single car households:

- California – some change in characteristics over time – people below the age of 34, women, people without a degree or equivalent, and people a lower income all represented a larger proportion of new EV owners in 2014 than in 2012. However, the scale of these changes is relatively small, suggesting a gradual widening of EV ownership rather than a radical shift from one demographic group to another (Center for Sustainable Energy, 2013).
- Norway – one pronounced change was the increase in single-car households from 9% in 2012 to 25% in 2014. Additional findings in Figenbaum et al. (2014) suggest these 'EV-only' households are on average younger and more likely to be single than other EV owners in Norway but in other respects share the same broad demographics.

3.3.7.2 Segmentation models

Segmentation in the EV literature is still largely reliant on Rogers' (2003) diffusion of innovation model by setting out to identify a single innovator and/or early adopter group and so on. These in turn are often defined by some kind of indicator of preference, willingness or likelihood to adopt an EV. Segmentation models which recognise that there may be more than one early adopter group each motivated by different factors, based on a richness of demographic and socio-psychological data and which can provide vital information on which segments might adopt which cars (e.g. BEV vs PHEV), are still rare.

Axsen, Bailey, and Castro (2015a) provided a very useful contribution to the segmentation literature by contrasting, with the same sample, two different ways of providing insight into consumer heterogeneity. They used 1,754 new car buying households in Canada in 2013, to contrast two ways of segmenting their participants:

- (i) A preference based approach which identified segments with very different preferences for HEVs, PHEV and BEVs. 'PiV-enthusiast' (8% of the sample) with extremely high valuation of PiVs and a broader 'PHEV-oriented' segment (25%) that expressed moderately positive valuation of PHEVs (vs 'HEV oriented', 'HEV leaning' and 'CV oriented'). Preference-based segments also varied by participants' valuation of specific attributes e.g. PiV-enthusiast participants are the most likely to also engage in technology-oriented lifestyles and the PHEV-oriented group places the highest value on fuel cost savings (more than five times that of the HEV-oriented class). Interestingly, the fuel cost coefficient was not significant for the PiV-enthusiast class, suggesting that those participants' PiV interest is not financially motivated.
- (ii) A lifestyle-based¹⁴ approach which identified segments based on a subset of potential early PiV buyers (33% of the total sample). The pro-environmental category includes the 'Strong Pro-environmental' cluster (17% of PiV-designing participants) where participants had higher than average engagement in environment-oriented lifestyles, higher environmental concern, and are highly liminal (open to change). Participants in the 'Tech-enviro' cluster (12%) had high levels of engagement in both the technology- and environment-oriented lifestyles, while participants in the 'Concerned' cluster (19%) only tended to have a high level of environmental concern (as indicated by the NEP scale). The 'Non-environmental' category included the 'Techie' participants (17%) that only have a high level of technology-oriented lifestyle, and the 'Open' cluster participants (18%) that have a relatively high degree of lifestyle openness. The 'Unengaged' participants (18%) are lower than average on all four variables. The six lifestyle-based clusters varied in engagement in environment- and technology-oriented lifestyles, environmental concern and openness to change but in some cases held very similar EV preferences. Overall preferences were fairly similar across the clusters, though apparent motivations varied substantially by cluster as indicated by their differing engagement in lifestyles and environmental concern.

¹⁴ The authors base lifestyle theory on "Giddens' (1991) notion that lifestyles are collections of related practices that reflexively relate to an individual's self-concept. Giddens (1991) postulates that in a modern world lacking the clear expectations previously provided by tradition, consumers must actively create their identity through the activities or practices they engage in. Identity is reflected, maintained and created through engagement in lifestyle" (p.192).

In the Axsen et al. (2015a) study, their former 'preference-based' approach helped to characterise how consumer *choices* (outcomes) may differ among participants. The latter 'lifestyle approach' served to better characterise how consumer *motivations* may differ. The former method, however, resembled the traditional discrete choice type analysis which focused on stated choice, whereas the latter is arguably more useful to understand the multiple groups which may exist with the same choice set. Nevertheless, both methods demonstrated that EV interest is generally associated with engagement in certain lifestyles and attitudes and therefore effective characterisation of consumer heterogeneity should address variations in consumer motivations as well as overall preferences.

Another example of a recent segmentation based on attitudes rather than preferences involved a quantitative survey (N=2,020) to gather data on car choice and purchasing behaviour by UK new car buyers (Element Energy, 2016). These data were to input into Element Energy's Electric Car Consumer Model used by the DfT. The questionnaire used attitudinal and behavioural questions designed for the ETI PiV study (Anable et al., 2016). The consumer segmentation resulted in six clusters (as contrasted to the eight found in the PiV study which included a distinctive PHEV segment and a company car segment which this study did not) (Figure 16), with:

- A small but clear *Innovator* segment representing the ones most likely to consider EVs in their purchase decisions in the short term. This group had a significantly higher likelihood of BEV adoption than the other segments due to their interest in new technologies
- The Innovators had similar demographics to the segment at the other end of the likeliness to adopt spectrum (*Car-loving rejecters*) – high income and employment status and predominantly male, emphasising the point that demographics are not a good indicator of uptake.
- *Cost conscious greens* represented the next early adopters (20%) but unlike the Innovators, they were motivated more by the environment and efficiency than the technology and tended to drive smaller cars.
- *Unmet needs* had attitudes and relatively high expenditure on cars to favour EV purchase, but were less likely to adopt them due to practical concerns, potentially because of high annual mileage and a high frequency of long trips.
- *The Pragmatists* were interested with 'conductive' travel patterns and car purchasing behaviour but were essentially 'waiting and seeing'.

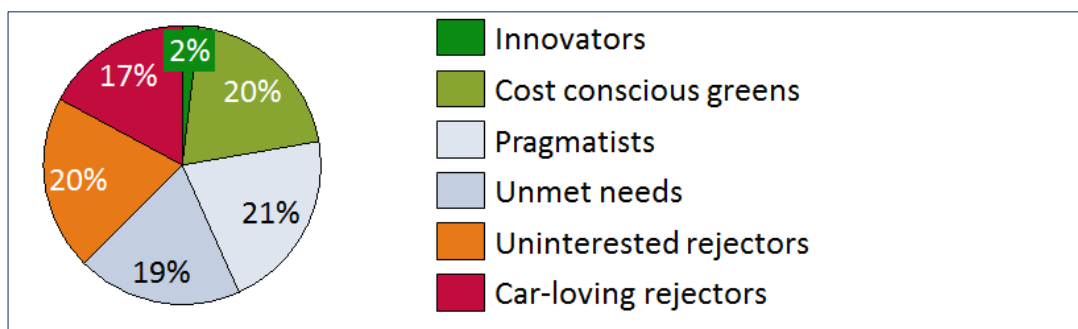


Figure 16: Segmentation of UK new car buyers based on attitudes to cars in general and EVs in particular (from Element Energy, 2016, p.17)

The above segmentations based on attitudes suggest that different factors are important for motivating people at different points in the adoption process. A unique perspective on this was adopted by Klöckner (2014) who followed 113 people interested in the purchase of an EV over the period of two months. The participants were administered with a questionnaire every second day. Klöckner adapted a stage model of behaviour change proposed by Bamberg (2013) that included the pre-decisional stage, the pre-actional stage, the actional stage and the post-actional stage. Individuals move from one stage to the other by forming specific intentions (e.g. a goal intention for transition from the pre-decisional stage to the pre-actional stage, or a behavioural intention for transition from the pre-actional to the actional stage). Each type of intention is influenced by specific variables. Certain variables become important at one stage of the process but are no longer influential at another stage e.g. personal norms play an important role in goal intentions. Klöckner found that half of the participants did not change between different stages during the course of two months and others oscillated up and down.

The above examples of segmentation approaches to understanding EV adoption have some important lessons for future research and policy: (i) people with the same adoption intentions/preferences (and all of them early adopters) can be motivated by different factors, (ii) that preference based segmentations (i.e. those based on stated likelihood to adopt) fail to provide insight about the different motivations to adopt, (iii) that membership of adoption segments defined by motivations are not well predicted by demographic factors, and (iv) that we need to understand what motivates people to move from one segment or stage in the adoption process from the other because different factors will be more important at different times.

3.3.8 EV usage patterns

Section summary

- Forecasts of future ownership and use are based on assumptions that EVs will mainly be used as a second household car. However, to the contrary, EVs are typically being used as the main car, relied upon for the majority of day-to-day journeys to work, education and other local destinations. Other cars in the household are typically being used for infrequent, longer journeys.
- Recent research with current EV owners in the UK and elsewhere indicates EVs are being driven for comparable mileages to ICE vehicles.
- It is possible that there is a lifestyle learning process whereby drivers learn about the unique attributes of an EV and incorporate these discoveries into their lifestyles, or routine practices. Drivers take into account the restricted range of the EV, implement a daily charge process, and develop new behaviours related to trip planning.
- There is some evidence to suggest that travel patterns of EV owners start to change upon adoption, possibly even increasing the number of trips undertaken by car. But the evidence on whether public transport use increases or decreases after adoption is mixed. One study suggests its use is reduced, another hints that incentives which encourage the joint use of EVs and public transportation are not attractive, and another suggests that public transport usage increases after EV adoption which would be in line with findings that EV users enter in to more planning of journeys.

- Compared to those examining trip patterns, many more references exist relating to changes in driving style after adoption. These findings are much more consistent, tending to suggest that driving behaviour changes to become more economical.

The vast majority of the literature presents the adoption of EVs as a pure consumer-choice problem such that very little is addressed, with the exception of subsequent charging behaviour, about how they might be used once acquired. This could include making more or fewer trips by car, changing routes and destinations and therefore driving distances, changes to car occupancy and changes within the household as to who uses which car. The implicit assumption is often that an EV will be a like-for-like replacement for an existing ICE vehicle in a household. The evidence to confirm or refute this proposition is limited. However, we attempt to examine this interaction between adoption and use in this section.

Forecasts of future ownership and use are based on assumptions about EVs as mainly being used as a second car in the household. Brook Lyndhurst reviewed the literature as it stood in 2015 and concluded that to the contrary, EVs are typically being used as the *main* car in private owners' households, relied upon for the majority of day-to-day journeys to work, education and other local destinations. Other cars in the household are typically being used for infrequent, longer journeys. This current review has not found any additional evidence on this and reports the studies found in the Brook Lyndhurst review:

- The Hutchins et al., (2013) study of UK EV owners up to 2013 found that the EV was reported to be the only car in 20% of private owners' households but even amongst private owners with more than one car in the household, most described the EV as the main car. This study found some variation between PHEV and BEV owners. First, 29% of PHEV owners said they had no other cars in the household compared to 17% of BEV owners. Second, a higher proportion of PHEV owners in multi-car households described it as their main car than did BEV owners (Hutchins et al., 2013).
- In recent surveys in Norway, EVs have been reported to be the only car in 25% of households (Haugneland & Kvisle, 2015) and to be used much more than other cars in multi-car households (Figenbaum et al., 2014).
- The proportion of California households relying solely on an EV (Center for Sustainable Energy, 2013) is lower than in the UK or Norway but the high mileages reported for EVs in the US (see below) suggest they are being relied upon for the majority of car journeys in multi-car households.
- Rolim et al. (2014) found that owners in Portugal used their EV as a replacement for their conventional everyday vehicle, even though most still owned at least one ICE vehicle.

With respect to usage, early predictions that EVs would only be driven for low mileages are being put in some doubt by recent evidence. Anable et al. (2014) cited previous research by Element Energy (2009) which concluded that EV owners typically have lower mileages than the population overall and Carroll et al. (2013) reported lower than average daily and weekly mileages amongst private trial participants. However, more recent research with current EV owners in the UK indicates EVs are being driven for comparable mileages to ICE vehicles. Hutchins et al. (2013) found that where an EV was being used as the main car in the household (as it was in most households) the average

annual mileage was approximately 8,850 miles. This was compared to the estimated national average for all cars (based on 2010 National Travel Survey data) of 8,430 miles. The average annual mileage reported by PHEV owners was higher than BEV owners, with over a quarter (28%) saying this was 12,000 miles or more, compared to 18% of BEV owners. The composition of this mileage nevertheless remains understudied. It could be the case, for instance, that once an EV is added to a multi-car household that the distribution of mileage across these cars changes as the EV is preferred for a greater share of journeys than its predecessor. However, as we emphasise below, the utilisation patterns of EVs and household car fleets is a significant evidence gap.

This evidence is based on self-reporting by EV owners, likely to be prone to human error and/or bias, but similar findings from EV owners in other countries give some confidence in these findings:

- ECOTALITY (2013, cited in Brook Lyndhurst, 2015) showed that the reported mileage of EVs in the US is lower than the average for all passenger vehicles but only by 6% in the case of PHEVs. On average, BEV owners were estimated to have an annual mileage of 11,500 km and PHEVs an annual mileage of 15,900 km. This compared to the average annual mileage for passenger vehicles in the US of approximately 17,000 km.
- Figenbaum et al. (2014) showed that in Norway, on the basis of survey and in-car mileage data, the annual driving length for EVs with the latest technology is about the same as for new ICE vehicles.
- The Hutchins et al. (2013) UK study suggested EVs are being used much less frequently for longer journeys (e.g. for holidays and business trips) and journeys involving motorway travel. Overall, 27% of EV owners had not used their EV on a motorway at all. This was higher for BEVs (31%) than PHEV owners (16%).

However, there is also some evidence to suggest that travel patterns of EV owners start to change upon adoption, possibly even increasing the number of trips undertaken by car:

- Rolim et al. (2012) studied EV users after five months of EV use and reported that, even though 64% of the participants considered that the adoption of the EV had no impacts on their daily routines, 36% mentioned the opposite, by making more trips (36%), changing the type of road driven (27%), different trip management (9%) and on the number of persons on board the vehicle (9%).
- Bailey et al. (2015) interviewed participants in Canada and found that they indicated a tendency to increase the number of trips they make since purchasing a EV due to three main reasons: reduced operating costs, interest in further using the technology, and 'feeling better' (or less hypocritical) about driving a EV relative to a conventional gasoline vehicle.
- Labeye et al. (2016) collected and analysed the self-reported behaviours (via questionnaires and travel diaries) of 36 Parisian private EV drivers, each of whom drove for six months an electric MINI E prototype. The study focused on the adaptive behaviours in planning travel across all modes as well as charging the vehicle. Analysis of travel diaries revealed that the number of trips involving a car significantly increased between 0 and 6 months, from 81% to 90%. The author explained this increase *"by the ecological nature of the electric car. When participants were asked to evaluate the major advantages of the electric vehicles, the environmental point of view (the fewer localised carbon emissions while*

driving and the fewer carbon emissions in general if the electricity is produced by renewable energy) was the main reason chosen, which removes any guilt of participants in using more frequently their electric vehicle. Of course, it is also possible that the increase in use of the EV is due to the novelty of the vehicle and the impact of the monthly fixed payment schedule or the cheap charging process (around 1 euro for 100 km, against 5 euros with a fuelled vehicle)” (p.32). The study went in to some detail about the adaptive behaviours surrounding trip planning and range management. The results showed that limited range involves re-definition of routes, development of a strategy for planning charges, and reconsideration of choice of using different modes of current transport.

It is possible that the location of charging stations is a factor in any alteration to driving patterns, but again, evidence of this has not been found and this is reflected in modelling studies where the interactions between planning decisions for charging stations and the long-term adoption of EVs are not modelled. The exception is a modelling study by Avci et al. (2014 cited in Lim et al., 2015) which modelled the environmental impact of EV adoption with a battery swapping service. Focusing on the business model introduced by Better Place¹⁵ they showed that although this business model can increase EV adoption, it also induces higher driving volume.

The authors of the most comprehensive recent study about adaptation (Labeye et al., 2016) cite Woodjack et al. (2012) who put forward the notion of a lifestyle learning process to suggest that drivers learn about the unique attributes of an EV and incorporate these discoveries into their lifestyles, or “routinised practices”. The Labeye et al. (2016) study indeed suggested that driving an EV requires a learning phase to acquire the skills and knowledge necessary to operate the vehicle. At the strategic level of driving, drivers take into account the restricted range of the EV, implement a daily charge process, and develop new behaviours related to trip planning.

The evidence on whether public transport use increases or decreases after adoption is mixed. Perhaps consistent with the above evidence that car use increases, one now dated study was found which indicated that its use is reduced and another which hints that incentives which encourage the joint use of EVs and public transportation are not attractive:

- Rødseth (2009, cited in Hjorthol, 2013) studied two groups of participants (600 owners of an EV and 600 random sampled licence holders in Oslo, Bergen and Trondheim). This found that commuting was an important travel purpose of the EV. On trips to work, 83% of the EV owners went by car (16% ordinary car and 67% EV) vs 47% in the random sample. EV owners increased their car-use after they had acquired the EV. In this case there had been a change from public transport to use of the EV.
- Bahamonde-Birke and Hannapi (2016) established that whilst investment subsidies to support private charging stations increased the WTP for EVs, policy incentives which aim to encourage the joint use of EVs and public transportation had no positive effect.

To balance this, however, one study was found which suggested that public transport usage potentially increases after EV adoption which would be in line with findings that EV users enter in to more planning of journeys (Labeye et al. 2016) but this still remains

¹⁵ A now bankrupt company that developed and sold battery-charging and battery-switching services for EVs

speculative: Pierre et al.'s (2011) in-depth study from France of 30 EV owners in 2006 and 10 in 2008 showed that among owners of EVs there is both the exclusive motorist (only the electric or petrol car) and the multimodal user, who combines use of the car with use of other modes. They suggested that "... *the use of an electric car encourages a more rational use of the car and sometimes multimodal behaviour ...Users are multimodal rather than convinced ecologists*" (p.514).

Compared to those examining trip patterns, many more references exist relating to changes in driving style after adoption. Unlike the latter, these findings are much more consistent, tending to suggest that driving behaviour changes to become more economical:

- Rolim et al. (2012) found that, when questioned about the impacts of the EV on their driving style, 73% of the participants considered that their driving style had changed, mentioning that they would speed less (75%), were less aggressive (25%) and had a more economic driving style (13%). 27% mentioned that there were no changes to their driving style.
- Labeye et al. (2016) also examined driver behaviour at the tactical level, in terms of driver interactions with other road users to deal with the silent nature of the EV, and at the operational level of driving, in terms of braking behaviour to master the regenerative braking. Participants reported that the silent function involved appropriate anticipated driving behaviours and could identify typical risky situations where they were more attentive, modifying the tactical level of EV driving. Concerning the regenerative braking function, the majority of participants claimed to have modified their driving style and some to have driven in a more flexible way. The self-reported behaviours of drivers indicated manoeuvre control was rapidly enriched at the operational level of driving and the regenerative braking function was used very frequently (around 90% of the braking situations) and that this acquisition was very quick. Overall, the authors suggested the results confirmed that, even if learning to operate the EV is relatively simple, driving efficiently seems not to be spontaneous: a period of handling would be necessary to implement more effective behaviours at all levels of the electric driving activity.
- Franke, Arend, McIlroy, and Stanton (2016) examined HEV vehicles only (but cited here as this represents a robust and recent study). Interviews were conducted with 39 HEV drivers who achieved above-average fuel efficiencies. Regression analyses showed that technical system knowledge and ecodriving motivation were both important predictors for ecodriving efficiency. Qualitative data analyses showed that drivers used a mixture of ecodriving strategies and had diverse understandings regarding aspects such as the efficiency of actively utilising electric energy or the efficiency of different acceleration strategies.

3.3.9 Evidence gaps and research recommendations

3.3.9.1 Evidence gaps

Areas for further investigation have been highlighted in various sections in the above text. These specific areas for research are synthesised below. This section begins with a review of the state of the evidence and therefore returns to the literature review produced for the previous ETI funded consumers and vehicles study (PiV). In the literature review for this study (Anable et al., 2014), the 'state of evidence' was

reviewed with a list of observations. We repeat these observations and comment on whether recent literature has addressed any of these issues (Table 9).

Table 9: Review of 'State of the evidence' observations in relation to those found in the PiV study (Anable et al., 2014)

State of the Evidence observations in Anable et al. 2014 (review carried out in 2010/11)	Updated observations based on the current literature review
<p>The literature falls into four broad categories:</p> <ul style="list-style-type: none"> (i) revealed and stated preference surveys of consumer behaviour regarding a variety of vehicle powertrains (ii) qualitative and conventional questionnaire surveys eliciting consumer attitudes and perceptions of vehicle attributes, alternatively fuelled vehicles and policy incentives (iii) evidence of consumer responses to EVs before and after small-scale vehicle trials (iv) theoretical texts relating to socio-technical transitions, symbolic behaviour and consumer segmentation 	<p>This four-fold categorisation of the literature still stands. However, it is possible to say that there is now slightly less emphasis on (i) and more emphasis on (ii) with respect to quantitative surveys undertaken with either the general driving population or new car buyers. There is a proliferation of online administration of surveys through survey companies. There is, however, still very little in-depth qualitative study. Surveys tend to generate correlational designs which only enable the maximal strength of any possible effect of predictors on the some measure of EV acceptance to be detected, not any final certainty about causation and the direction of any effect. There is much less literature based on experimental designs where one or more of the predictors are manipulated to explore their effects on acceptance of EVs. This would also allow for the investigation of more complex processes, such as mediation and moderation models. In addition, the effects of social norms and collective efficacy need to be tested in different stages of the decision-making process with real behaviour instead of hypothetical behaviour as the dependent variable.</p>
<p>The dominance of stated preference surveys is due to the attempt, since the early 1980s, to overcome the challenge of asking consumers to predict their interest in a radically new product that does not yet exist in the marketplace. However, much of this literature is US dominated and often based on a limited number of attributes and powertrains. Consequently, apart from offering insight into vehicle attribute measurement, the specific modelling results provide little useful prediction of likely UK consumer response to EV products and incentives.</p>	<p>This literature has not been reviewed in detail here. However, the stated preference and choice modelling literature is still predominantly US-based, although studies from Asia and Europe have also been published in recent years. Whilst participants are becoming more familiar with EV technology, the studies can still lack any attempt to mitigate against a lack of baseline awareness of the vehicles which has been well documented in other studies. There is also little attempt to incorporate heterogeneity, temporal or spatial dynamics into the models. On the other hand, the technologies and attributes tested and attempt to tailor these to participants' current ownership or travel patterns can often be sophisticated.</p>
<p>Many relevant attributes such as size, performance, range and refuelling/ charging time have been poorly measured in both stated preference and more standard qualitative and quantitative survey techniques. Consequently we have a very poor understanding of the role that these instrumental factors may play in EV uptake.</p>	<p>Certainty the non-linear relationships and dynamic trade-off between these attributes is still unclear. For instance, range is likely to be sensitive to changes in the levels of refuel time and availability of refuelling infrastructure as if the refuelling is short and the density of refuelling infrastructure is high, it is reasonable to expect that driving range becomes much less important. Very few studies look at these</p>

	interaction effects.
Private consumers have difficulty in providing answers to willingness to pay questions in surveys as very few currently know their fuel consumption and calculate their vehicle running costs.	This remains a valid and important concern with respect to how much of the 'evidence' on the importance of monetary incentives are evaluated. Various pieces of literature have demonstrated in basic but vital ways that consumer awareness of EVs, particularly the difference between BEV and PHEVs even after some information, is limited or confused. The fluctuation in oil price and the lack of transparency and understanding of electricity pricing adds to the inability for consumers to thoroughly think through the consequences of ownership in terms of monetary savings. Having said that, there is also a lack of evidence directly evaluating the implications of the way in which total cost of ownership is conceptualised and the impact of tailored information to this effect.
Value placed on fuel economy and different vehicle technologies is influenced by symbolic, affective as well as instrumental factors. These include anticipated driving affect (i.e. the emotional pleasure derived from driving), expression of the person's position or social status and the expression of personal identity and values, including environmental values. We have some understanding of the importance of these factors, but there is little indication that symbolic and instrumental factors have been considered in parallel or that attempts have been made to incorporate this understanding into predictive modelling of EV uptake.	A greater proportion of studies published since ~2010 have taken symbolic and affective factors into account than hitherto. Affective factors (emotions) and the expression of personal identity in relation to environmental values have been examined. There is some understanding of the interdependence between these factors and functional/ instrumental attributes – i.e. that instrumental attitudes are themselves a factor of symbolic and affective motives. However, this is a particular area of understanding that suffers from the focus on early adopters with a lack of consideration on how symbolism and symbolic motives might evolve over time.
Evidence on the role of policy incentives is fragmented and largely US focused.	The dynamic market for EVs in Europe over the past 5 years underpinned by a variety of policy packages means more analysis has been undertaken within individual European countries or at a global comparative level. However, the European literature is dominated by studies from Norway which has a very unique context whereby BEV purchase costs are subsidised to be roughly the same as an equivalent ICE vehicle. In addition, most studies on the role of national or local policy incentives conclude that it is too challenging to isolate the impacts of these policies. Nevertheless, the literature has become less US focused and, taken as a whole, some key findings are emerging.
Recent work originating from EV vehicle trials in the UK and elsewhere has provided invaluable evidence on charging patterns and expectations, driving behaviour and some attitudinal data. However the evidence base does not help us to predict the likely impact of EV uptake on travel patterns or car ownership.	Unfortunately this critique still stands. The focus in trials and through other methods is very focused on acceptance and adoption. This literature is itself very narrow in that it largely fails to address issues of second or additional car ownership. The literature on how travel patterns might adapt subsequent to adoption is very poor.
Attempts to segment consumers with respect to EV uptake have largely been restricted to the crude early adopter/early majority model rather than a finer grained classification based	Unfortunately this evidence gap still stands. Segmentation models which recognise that there may be more than one early adopter group each motivated by different factors,

on an understanding of motivations and preferences.	based on a richness of demographic and socio-psychological data and which can provide vital information on which segments might adopt which cars (e.g. BEV vs PHEV), are still rare.
There is a lack of application of social and behavioural psychology to understand impulsive individual processes and social dynamic effects. The lack of evidence is most apparent in relation to the processes thought to take place at the interpersonal, community or societal level as opposed to the individual level. Sociological theories that stress the interpersonal environment offer key insights of the attitude-behaviour link and account for the role of social factors, peer effects, social networks, imitative and learned behaviours.	Whilst there are rich and relevant insights into EV adoption coming from the social science disciplines, despite an overt recognition that people do not exist in a social vacuum and increasing visibility is a motivator to EV acceptance, there is still little research which attempts to understand the interpersonal processes themselves and the role they play in EV uptake.
Likewise, there is an almost complete absence of qualitative data to gain insight into the psychological processes guiding the formation of beliefs and preferences with regard to EVs.	This gap still stands entirely.
There is very little evidence relating to the decision making processes underpinning the adoption of EVs into public and private sector vehicle fleets.	This has not been the scope of this review. See deliverable D2.2 for more detail on fleet decision making.

3.3.9.2 *Research recommendations*

Additional research is needed to understand the differences between BEVs and PHEVs - in terms of who buys them, the motivations for adoption, and how they are used and experienced. This will help to inform future infrastructure provision. There is also a real lack of insight into how attitudes, usage, and the impact of policy interventions compares between BEVs and PHEVs. This is applicable among all of the research recommendations that follow.

This list represents a comprehensive agenda for further research filling gaps identified by the literature review. It is not feasible to address this comprehensive list of potential areas for further research within the scope of the Stage 2 Trials. Certain research questions have been identified as being critical to grounding the analytical framework in more valid data on PiV adoption. Those research questions are set out in separate deliverable report D1.4, "Trial Design, Methodology and Business case".

- Overall, there remains a considerable gap in understanding around the implicit discount rates consumers use and the payback periods consumers consider acceptable for AFVs.** Questions still remain about the relative role of purchase cost against other monetary and non-monetary vehicle and contextual characteristics, as well as how purchase price is taken into account in the car buying process. The evidence suggests that concern and uncertainty over functional and symbolic considerations of EVs may currently trump price concerns given findings in choice experiments where: (i) EVs are still less popular than ICE vehicles under price and even range parity scenarios, (ii) the disutility of the purchase price associated with conventional vehicles is smaller than the disutility ascribed to the EVs, (iii) surveys indicate that the vast majority of participants believe that fuel economy is an important vehicle attribute but they do not necessarily find that this leads to EV adoption intention.

- **The state of knowledge on how different running costs are considered is poor and these costs tend not to be examined separately or put in TCO models to test with consumers.** The majority of studies focus on fuel costs despite the fact that running costs comprise of a number of different types of expenditure including annual circulation taxes, servicing, insurance etc. The testing of a TCO model with consumers which includes a variety of running costs including depreciation, interest rate payments and maintenance costs would be a challenging computational task for consumers due to bounded access of relevant data and uncertainty over future conditions. Also, in reality, consumers do not undertake TCO calculations. However, the evidence suggests that presenting information in this way may be more effective than mere fuel cost savings.
- **Very few studies separate out residual value to test its specific impact, even if an assumption for depreciation is included in TCO calculations is to be tested.**
- **Perceptions of current absolute and relative prices of petrol/diesel and electricity and the role of uncertainty about these prices in the future need to be understood.**
- **The evidence is still weak on both the impact that incentives might have as the market matures and what might happen when existing incentives are removed.** The key limitations of this evidence are that it relies heavily on statements made by research participants who have already directly benefitted from these incentives, typically made sometime after they have been through the decision-making process of buying their EV. Later adopters may be more motivated by material and tangible benefits and so incentives may become more important in the market place.

Incentives

- The evidence base on other monetary and non-monetary incentives is context-specific and therefore it is **important to investigate their role in the UK context alongside packages of incentives on offer nationally and locally and other relevant contextual factors.** Where these incentives have been examined, there is overwhelming consensus that they play a minor role *vis a vis* upfront purchase incentives and circulation taxes, but different ways of gauging importance or effectiveness of incentives can yield different results. Therefore **it is important to try and understand which incentives are *decisive or critical* in the purchasing decision** for different people in different places.

Non-cost barriers

- Whilst it is important to examine changes (adaptation effects) in range preferences that happen as a result of experiencing an EV, it is more pressing to understand more about those with no experience. It is not sufficient to examine average driving distances when considering whether a limited-range vehicle would meet drivers' range requirements. Unfortunately, trip-by-trip data and data on time spent at locations where vehicles can be charged are limited and, in any case, even if this data were available, this does not necessarily help to determine how drivers themselves assess their range requirements and therefore assess range alongside other vehicle attributes when making car choices.

- **There is still a lack of a nuanced understanding of how consumers benchmark their range requirements and the option value of having longer range available to them should they need to perform unexpected or longer journeys.**
- Consumers' perceptions of how compatible EVs might be more broadly with their daily mobility patterns have been found to be the most important determinant of EV acceptance. This is tied to their **current mobility patterns and availability of a second car, both of which need much more research in relation to intention to adopt EVs.**
- **There is a lack of testing for interaction effects among range, refuel time and availability of refuelling infrastructure.** However, the evidence points to the need to estimate the proportion of consumers/households who might consider purchasing a range limited vehicle and to understand psychological barriers, rather than estimating effective costs of range limitations.
- The role of instrumental factors such as (perceptions of) performance is entwined with symbolic motivations. **These symbolic motives, as well as the role of uncertainty related to these attributes, rather than the intrinsic value of the attributes themselves, needs to be understood.**
- **Brand loyalty and availability of EVs among those brands may be more valuable to consumers than extensive choice among all brands. More research could be useful on this issue.**
- The evidence suggests that **perceptions are improved after some experience is gained. Nevertheless, there is still some debate in the literature as to how this experience then translates into greater intention to purchase an EV.**

Charging infrastructure

- Indicative evidence on the impact of charging provision on the uptake of EVs is available but does not provide many fine-grained insights. Macro approaches examine the correlation of the availability of charging infrastructure with EV uptake at a national or regional level. This literature finds a very strong correlation but needs to be heavily caveated as it infers causal inference (i) **without including temporal dependence in the models (i.e. an assessment of which comes first – the charging infrastructure or the uptake?),** and (ii) **without taking account of spatial dependence (i.e. how a heterogeneous distribution of charging stations (many in one city, few elsewhere) might influence EV adoption).** This spatial interdependence is rarely captured in vehicle choice models but would require modelling only a specific spatial area or explicitly modelling market segments or regions, each with its own measure of fuel availability.
- The **perceived lack of public charging infrastructure** has been frequently highlighted by non-EV owners as a barrier to EV uptake, but the evidence on the link is weak. Research is needed into the existence of reliability thresholds concerning the availability of charging stations and the importance of the notion of 'abundance' as a significant factor in EV interest.

- Research is required to **better understand the potential importance of different types of non-home charger locations**, such as workplace charging, as well as the specific charger details that may make EVs more attractive, such as specific location in parking lots, the cost charged to the driver, and the aesthetics of the charger design. This would be aided by **analysis of utilisation rates of charge points in these different types of location**.
- There has also been little consideration to date in the literature on the **importance of public charging from the perspective of PHEVs** and, for example, whether the increasing number of PHEV models on the market mediates the need for additional public infrastructure to convince more car buyers to purchase an EV.

Models of ownership

- **It is clear that car ownership and financing models are areas ripe for further research.** There is virtually no evidence on the role of these in car uptake in general or for EVs in particular. Given the emphasis on the role of purchase cost, there is very little available evidence on how these costs are serviced in the literature and their role in relation to government incentives and the car purchasing decision.
- **New mobility services or Mobility as a Service (MAAS) are a very important part of future mobility and the link with electrification is inevitable but unclear.** There are now more and more cities with partial or all-electric fleets in car sharing services. Assessing consumer acceptance of these different 'products' will be a challenge given their wildly different attributes, so that the intentions being examined will not only be related to the attributes of the EV but also to specific attitudes towards car ownership or towards a car sharing model.

Consumer psychology

- An indication that environmental motives may be important in the purchase decision is not the same as suggesting that this is *the reason* for adopting an EV. **A more useful understanding would be to understand the extent to which environmental motives are a primary or deciding factor in adoption.**
- Research must **understand the interactions between beliefs that EVs are actually environmentally friendly and intrinsic 'pro-environmental' motivations.** In addition, many social-psychological approaches to EV adoption do not calibrate with evaluations of environmental and other consequences of EVs against the 'incumbent' ICE vehicle technology. This accounts for other attributes of the vehicles being evaluated so that **studies should look at the pull of the ICE vehicle as well as the possible attraction of EVs to overcome the negative consequences of ICE vehicles**, rather than focusing on the intrinsic 'greenness' or other benefits of an EV on its own.
- In any research on EVs it is important to **distinguish between different types of adoption indicators which can be placed on a spectrum from 'close' to 'distant'**: (i) overall evaluation of EVs (ii) intention to purchase an EV (iii) acceptability of policies directed at EVs (iv) long term acceptability of EVs.

- **Little is known about the relative importance of local air pollution, noise, carbon emissions and other issues such as resource depletion and energy security in terms of their effectiveness in promoting EV adoption.** Making this distinction could be especially important given the rise of the local air pollution issue up the agenda, at least partly as a reaction to recent issues linked to diesel cars and inadequate test cycles. This also relates to the need to understand the link in car owners' minds between plug-in vehicles and the carbon content of the electricity consumed and the battery production and disposal process.
- There should be an attempt to understand **whether consumers consider their whole environmental footprint (total cars owned x amount driven) when drawing upon their environmental identity or motives** in the decision making process.
- **The role of interest in new technology needs more research.** The review suggests that a concept of innovativeness may be too vague to capture the motives related to any desire to be involved in new technology but where this desire is measured more directly, and where the concept of 'innovativeness' is appreciated to touch upon a whole array of instrumental, symbolic and environmental motives, a much more useful understanding might emerge.
- An important generalizable omission in the evidence base is **the role of emotions in EV adoption** and the way in which communication messages, education and policies can create specific cognitive and emotional responses in consumers and consequently influence their decisions and behaviours.
- Symbolic meanings relate to more than pro-environmental self-identity. **It is important to include a variety of measures of symbolism in any surveys** in order to understand their emerging associations for different powertrains. These might include lower resource consumption, independence from petroleum producers, advanced technology, financial responsibility, saving money, opposing war, and environmental preservation.
- Despite an overt recognition that people do not exist in a social vacuum and increasing visibility is a motivator to EV acceptance, **there is little research which attempts to understand the role of different interpersonal processes in EV uptake.** It is also necessary to understand **whether or not different norm processes are more important at different points in the adoption process** at an individual level and at a societal level.
- Evidence is very thin on **what actually works to shift consumer attitudes using information** of any type but particularly that which attempts to convey issues of identity, status or group membership as a result of EV adoption and use issues relating to the potential environmental or energy security benefits of EVs.

Characteristics of EV adopters

- The evidence is still not strong enough to say **whether the characteristics of EV owners or prospective owners are any different to new car buyers in general.**
- No studies were found which have attempted to **identify the characteristics or potential characteristics of buyers of second-hand EVs.**

- The evidence suggests that EVs are purchased mainly by multi-car households but **more understanding is required on where the EV fits into this household and whether the characteristics of the household or the purchaser are different depending on whether they adopt the car for main or secondary usage.**
- There is a general lack of **understanding of household composition including the presence of children and employment status** (and potentially occupation) of all the adults in the household.
- As the market for EVs grows, **more evidence needs to be collected on the spatial distribution of EV adopters.** Rather than crude urban-rural classifications, some indications of average journey lengths, accessibility, relationship to public transport networks etc. need to be understood.
- **Details of pre-EV travel patterns** are very limited.
- Segmentation in the EV literature is still largely reliant on Roger's diffusion of innovation model by setting out to identify a single innovator and/or early adopter group and so on. These in turn are often defined by some kind of indicator of preference, willingness or likelihood to adopt an EV. **Segmentation models which recognise that there may be more than one early adopter group each motivated by different factors, based on a richness of demographic and socio-psychological data and which can provide vital information on which segments might adopt which cars (e.g. BEV vs PHEV), remain a priority for research.**

How are/will EVs be used after adoption?

- The implicit assumption in much modelling work is often that an EV will be a like-for-like replacement for an existing ICE vehicle in a household. The evidence to confirm or refute this proposition is very thin. **More research is needed on what the EV is used for once it is adopted, whether it is used more or less than originally intended and the overall impact on usage for all cars in the household fleet and mobility patterns for all household members.**
- **The learning and adaptation process over time** as drivers take into account the restricted range of the EV, implement a daily charge process, and develop new behaviours related to trip planning need to be investigated.

3.4 Review 2: Consumer attitudes to managed charging

To our knowledge, a literature review of the role of fuel pricing, energy demand management options (also 'Demand Side Response' (DSR) or managed charging) in the uptake of EVs and their subsequent charging behaviour has not been attempted. We set out to find any literature on this topic using the search terms and quality criteria set out in 3.2.1.

The result was a very limited number of studies relating specifically to demand management and plug-in vehicles. Whilst some literature is emerging on the possible role of different charging tariffs on charging behaviour and the degree of control on consumer acceptability, there is virtually no evidence on the role that these tariffs have in the adoption decision in the first instance. Consequently, this review is considerably shorter than the previous review and relies on some studies which did not include EV

adoption or charging as part of their investigation in order to provide a broad overview of the evidence on consumer demand-side response. These latter studies, however, appeared through 'snowballing' and this therefore cannot be considered to be a systematic review of this literature.

3.4.1 *The acceptability of various types of pricing structure/tariffs and methods of billing*

Section summary

- Perhaps surprisingly, a number of trials in the UK and further afield found consumer feedback on tariffs and interventions aimed at encouraging DSR to be generally positive with consumers broadly accepting automation and direct control. However, the evidence is still limited with respect to testing the range of types of pricing (static vs dynamic), tariff structures and degrees of automation. In addition, any bias introduced by small, self-selecting trial participant samples may reduce the generalisability of results to some degree.
- In a recent trial in the UK for general electricity demands, the majority of UK participants said they did not want to switch to a ToU tariff. Dynamic pricing (day-to-day) was the least popular. Adding the option of automation had little effect on the popularity of the static ToU tariff, but made the dynamic ToU tariff more attractive. Direct load control in return for lower flat rate was the most popular a tariff (with caveats).
- Most Economy 7 consumers in the UK already allow remote control of their electric storage heaters and this indicates that some consumers are willing to accept a degree of automation of their electricity use. These people were more likely to say they would switch to the next generation static ToU tariff. However, the implications for EV owners of this finding would need to be tested as these are lower income people who are less likely to be early EV adopters.
- Behavioural theory would suggest that automation could be popular as it eliminates the need for consumers to repeatedly go through a previously described process, and often requires no action at all on the part of end-users. On the other hand, theory would also suggest that, to gain greater acceptance, direct control systems should cultivate a sense of consumer control in order to foster environmental identity. This would require greater consumer engagement in the behaviour, not less.
- This theory is backed up to some extent as evidence shows that initial doubt about participation can be mitigated by providing consumers with the options to override any automated response, be flexible with curtailment levels and pre-programme charging sessions. Accordingly, direct control programs that do not foster a sense of control will likely have lower program enrolment compared to programs that do so.
- The willingness to accept tariffs and shift time of use varies according to what the electricity is being used for. However, overall there is limited evidence on the way consumers shift their electricity use in response to incentives and, with the exception of air-conditioning, storage heating and dishwashers, it is not clear which appliances consumers are willing to use in a flexible way (including EVs).
- After automation, the literature suggests that a combination of economic

incentives and enhanced information generally delivers the greatest demand response.

- In addition, there is debate over the longevity of any behaviour changes and whether behaviours persist over time if DSR is not automated or directly controlled.
- There is limited evidence to suggest that EV owners may be more willing than the average consumer to accept various types of tariff, but this may apply more to innovators than mainstream adopters.
- There is also limited evidence to suggest the acceptability of tariffs may be related to the travel patterns and flexibility of consumers.
- Exploration of the financial incentives necessary to encourage EV owners to participate in demand response programs is even more limited.

Findings are first presented from studies unrelated to EV electricity use to set the general context on consumer response to demand management. The few studies which have investigated this specifically in relation to EV charging behaviour are then presented.

3.4.1.1 Findings related to non-EV electricity use

This section draws heavily from two studies in the literature. The first (Fell, Nicolson, Huebner & Shipworth, 2015) report the results of a trial of tariff design and marketing on consumer demand for demand-side response tariffs based on two randomised controlled trials in the UK, each having divided participants into groups that saw different tariff design and marketing messages. The second, Frontier Economics and Sustainability First (2012) reviews 30 trials of DSR in the domestic electricity sector, most of which tested more than one intervention to promote DSR. The trials covered different geographies, seasons, types of appliances and market arrangements.

Fell et al. (2015) wanted to test whether consumers across Britain will voluntarily switch to different tariffs (static, dynamic time of use and direct load control) once they become commercially available. The effect of offering an automated response to price changes in the time of use tariffs was also tested (i.e. including the possibility of setting an automated response to price changes for example by pre-heating while prices are lower), resulting in five tariffs in total for electricity use being tested (Figure 17).

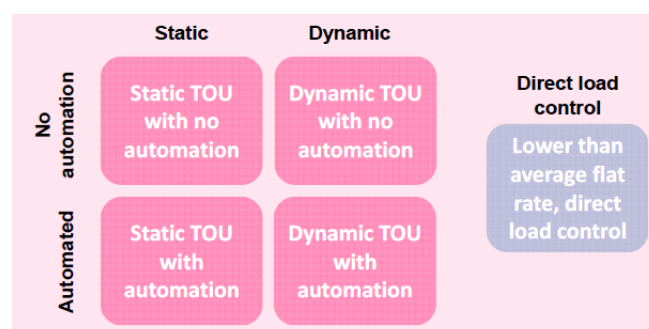


Figure 17: The five groups into which participants were divided for the Fell et al. (2015) study

The Fell et al. (2015) study in combination with the Frontier Economics and Sustainability First (2012) review lead to the following observations about the acceptability of different tariff structures:

- Frontier Economics and Sustainability First (2012) found their review of the evidence to suggest that, in general, consumer feedback on tariffs and interventions aimed at encouraging DSR was positive and in some cases, perceptions of the tariff types were more positive after the trials than before.
- Fell et al. (2015) found, for general electricity demands, the majority of UK people said they did not want to switch to a ToU tariff. Dynamic pricing (day-to-day) was the least popular. Adding the option of automation had little effect on the popularity of the static ToU tariff, but made the dynamic time of use tariff more attractive.
- A further study by Kaufmann, Kuenzel, and Loock (2013) uses an integrated social acceptance and customer perceived value theory perspective to model the importance of customer value of smart metering using a choice-based conjoint experiment with Swiss private electricity customers (n=87). The study found that overall customers value smart metering and are willing to pay for it. Based on a cluster analysis of customer preferences, four segments were identified, each with distinct value perceptions of smart metering: "risk-averse", "technology minded", "price sensitive", "safety-oriented" each possibly implying four different service bundles. This study did not test tariff structures although a similar approach could usefully do so to segment the population based on these social acceptance criteria.

Most Economy 7 consumers in the UK already allow remote control of their electric storage heaters and this indicates that some consumers are willing to accept a degree of automation of their electricity use. This was confirmed by Fell et al. (2015) who found that people who were on a 'legacy' time of use tariff (such as Economy 7) were consistently more likely to say they would switch to the next-generation static ToU tariff than the general population. However, the implications for EV owners of this finding would need to be tested as these are lower income people who are less likely to be early EV adopters.

Whilst some research suggests that people often have significant concerns about technology in their homes being directly controlled by third parties, the key evidence reviewed for this study suggests that consumers generally accept automation and direct control. In Fell et al.'s (2015) study, direct load control in return for a lower flat rate was the most popular tariff. However, it should be borne in mind that their study restricted this to heating only and a maximum of 1 degree centigrade impact on temperature, and with unlimited override potential.

The popularity of direct control is explained in a review of the application of behavioural science to the study of smart grid technologies. Sintov and Schultz (2015) suggest that automation may be popular as it eliminates the need for consumers to repeatedly go through a previously described process, and often requires no action at all on the part of end-users. "Even when applying effective tools of persuasion, voluntary curtailment still relies on consumers to undertake a series of decisions and actions, including: (1) attending to the alert, (2) mentally cataloguing energy use in home, (3) deciding what action(s) to take to reduce energy use, (4) executing such actions, and (5) maintaining this lower level of use over some period of time. This multistep process requires mental, physical, and additional resources, and must be repeated for each DR event" (p.3). They

cite research from the field of Behavioural Economics which has demonstrated that people are significantly more likely to select default options, including those related to electric power (Pichert & Katsikopoulos, 2008), and direct control DR systems leverage this principle.

However, the above study also suggests that there may be benefits to this repetition as they cite previous work which has found that people look to their own past pro-environmental actions as a signal of their own environmental identities, potentially fostering environmental identity and leading to the performance of other environmentally beneficial behaviours (Van der Werff et al., 2014). The authors suggest that this means consumer engagement must be enhanced from one-way, utility-to-consumer approach to a more interactive relationship.

The results of some trials suggest that initial doubt about participation can be mitigated by providing consumers with the options to override any automated response, be flexible with curtailment levels and pre-program charging sessions. Accordingly, direct control programs that do not foster a sense of control will likely have lower program enrolment compared to programs that do so (Sintov & Schultz, 2015).

- Leijten et al. (2014) administered a questionnaire study among 139 Dutch citizens (aged 18–85). Participants rated the acceptability of energy systems made up of four varying system attributes: type of energy (renewable or fossil), price (remains stable vs. 25 % increase), adjustments in use (convenience technology or consumers themselves decide on what to change), and production level (energy is produced at a central vs. community vs. household level). They found that consumers preferred the option of choosing how to curtail consumption to direct control technologies. These findings are in alignment with the Theory of Planned Behaviour, which states that perceived control is an important predecessor of behaviour.
- US Department of Energy (2014) found that customers took advantage of time-based rates to save on overnight residential charging. Participants generally preferred charging their cars overnight at home. Time-based rates encouraged off-peak charging and provided savings for overnight chargers. The rates were especially convenient when customers could pre-program charging sessions to start when off-peak rates came into effect.

The willingness to accept tariffs and shift time of use varies according to what the electricity is being used for. However, overall there is limited evidence on the way consumers shift their electricity use in response to incentives and, with the exception of air-conditioning, storage heating and dishwashers, it is not clear which appliances consumers are willing to use in a flexible way (including EVs).

- Frontier Economics and Sustainability First (2012) cite a study of consumer acceptance of smart appliances (household appliances whose operation can be automated in some way) that provides evidence on consumer attitudes to automation and direct control (Wilma, 2008). The survey data, phone interviews and focus groups in Austria, Germany, Italy, Slovenia and the UK (although skewed sample towards educated and technical participants with no children) found that consumer acceptance of smart appliances was high among this group, averaging over 90%. The degree of demand shifting that was acceptable varied across household appliances – highest for dishwashers (at least three hours) and slightly less for washing machines and dryers, with some objections to fridges and freezers due to safety concerns.

- On the other hand, a UK public opinion survey found willingness to accept automation scenarios (interruptions in exchange for 5% discount) was highest for fridges/freezers and lowest for cookers (Platchkov, Pollitt, Reiner & Shaorshadze, 2011).

After automation, the literature suggests a combination of economic incentives and enhanced information generally delivers the greatest demand response. There is evidence that a pivotal part of user involvement is the way users and the system interact. The extensive literature on feedback is not reviewed here. Suffice to say that refinement of social feedback tools requires a better understanding of several potential moderators: type of social feedback (behavioural vs injunctive normative feedback), household characteristics (e.g. household size), sociodemographic considerations such as income, and psychosocial factors such as group cohesion (Faruqui & Palmer, 2012; Geelen, Reinders & Keyson, 2013; Sintov & Schultz, 2015). In addition, there is debate over the longevity of any behaviour changes and whether DSR persists over time if it is not automated or directly controlled.

- Frontier Economics and Sustainability First (2012) believe it is plausible that the strength of the economic signal would become more important over time as consumers learn about the effect of their changed behaviour on their bills.
- Due to a lack of long term experiences it is yet unclear to what extent these effects are temporary or lasting, with users are returning to their old habits (Verbong, Beemsterboer & Sengers, 2013).
- Sintov and Schultz (2015) suggest demand response technologies may fall into the category of 'efficiency' behaviour if they require infrequent actions on the part of the consumer and/or primarily involve utility direct control of equipment (i.e. direct control demand response, smart automation, EV adoption, and solar panel installation), or the 'curtailment' category if they require ongoing participation by consumers to achieve energy reductions (i.e. voluntary curtailment demand response, time-of-use pricing programs, energy feedback, disaggregated feedback).

3.4.1.2 Findings related to EV electricity use

Whilst limited, the literature suggests that EV owners may have above average tendency to accept various types of tariff:

- Fell et al. (2015) found that existing EV owners are more likely to switch to static ToU, although they present no information on EV owners' attitudes to direct load control.
- Bailey and Axsen (2015) used a web-based survey of new vehicle buyers in Canada (n=1,470) to assess consumer acceptance of a form of utility-controlled-charging (UCC), where the utility company controls the charging with a nightly charging program to control home charging of EVs according to different factors (e.g. availability of renewable energy). The method used a choice experiment with four attributes (i) guaranteed minimum charge (ii) % Green Electricity (iii) source of Green Electricity (iv) monthly electricity bill (the user's current electric bill plus the expected cost of charging a vehicle multiplied by a scalar). Once explained, the majority (60%) of participants interested in purchasing an EV (i.e. Pioneer and mainstream EV adopters) support UCC, but also observe concerns with privacy (24%) and loss of control (38%). The probability of enrolment was

higher the greater the potential decreased electricity bill, the greater the proportion of renewable electricity and the greater the 'guaranteed minimum charge' each morning. UCC acceptance is higher among EV Pioneers than mainstream adopters where EV Pioneer participants are, on average, willing to pay 50% more for guaranteed minimum charge, and 4 times more for increased renewables. The model identified four distinct participant groups ('Anti-UCC' (21%), 'Charge focused' (33%), 'Cost motivated' (28%), and 'Renewables focused' (17%)). These groups differ by socio-demographic variables, lifestyle, and values. The Anti-UCC class was more likely to be significantly older and less highly educated than members of the other classes. The authors suggest that acknowledging the various motivations and concerns of each vehicle buyer segment is important to achieve maximum acceptance of UCC among potential EV buyers.

- My Electric Avenue (Fisher, Gammon & Irvine, 2015) worked with specially created volunteers (~100) in clusters of neighbourhoods in England who chose to lease an EV (BEV or PHEV) for 18 months with technology which would monitor and control the electricity used when their car was being charged. The findings of the consumer work showed that there was no change in attitude to EVs related to the introduction of controlled charging. In addition, the acceptability of controlled charge was not related to 'curtailment', at least for those charging exclusively at home. Those happiest with curtailment were generally more flexible in general about trip planning, had greater confidence in finding charging locations away from home and were more comfortable with lower levels of battery charge. There was a desire for more information (e.g. a text message) indicating charging/not charging. No one mentioned electricity pricing or any other financial incentive as a way of making curtailment more acceptable.

More detailed exploration of the financial incentives necessary to encourage EV owners to participate in demand response programs is even more limited. However, one study (US based) found that upfront purchase rebates for PHEVs were more effective than energy use rebates:

- Mallette and Venkataramanan (2010) use a case study based on existing ToU rates in the Madison (USA) Gas & Electric service territory. The study investigates how much of an incentive is required in order to make participating in a demand management scheme attractive to a PHEV owner. In order to determine the financial incentives necessary to entice PHEV owners to participate in ToU programs, the life-time fuel savings of a single vehicle was compared to the purchase premium associated with PHEVs. On this basis, simple payback periods for various future tariffs were calculated and the impact of (i) an upfront rebate following purchase of an EV and (ii) the reduction in off-peak electricity prices for the charging of PHEVs was assessed. In each of the cases considered in this analysis, upfront rebates were more effective than energy usage rebates. Note that in some cases, these upfront rebates actually reduce the initial upfront purchase price below that of a conventional internal combustion vehicle). However, the effectiveness of each proposal was highly dependent on both gasoline prices and the electric range of the vehicle.

3.4.2 The impact of different tariffs/ demand management on charging (and driving/usage) behaviour

Section summary

- The key behavioural responses to tariff structures relate to the extent to which electricity demand is shifted in time or reduced, the extent to which any behavioural shifts remain over time and the extent to which people override the signal, where this is possible. Absolute reductions in demand can also result.
- The empirical evidence for each of these behavioural impacts in response to financial stimuli through different tariff structures is at best mixed.
- There is a general consensus in the literature that time-based rates are successful at encouraging greater off-peak charging.
- There is limited evidence on the role of the strength of the price signal. Evidence on the importance of the size of peak to off-peak price differentials is mixed for ToU tariffs, but points towards higher differentials resulting in higher peak demand reductions for critical peak tariffs.
- There are very few studies examining the behavioural response of EV owners to different electricity tariff structures.
- A study with very engaged energy consumers in the US showed that whilst EV owners can shift their behaviour, they are likely to revert to daytime charging if tariffs are removed and have a less consistent response to critical peak pricing events than non-EV owners.
- In the UK, evidence suggests the pricing tariffs of public and workplace charging points can be managed to influence demand.

3.4.2.1 Findings related to non-EV electricity use

In addition to the evidence (above) relating to the acceptance of different tariff structures, the key behavioural issues relate to the extent to which electricity demand is shifted in time or reduced, the extent to which any behavioural shifts remain over time and the extent to which people override the signal, where this is possible. The empirical evidence for each of these behavioural impacts in response to financial stimuli through different tariff structures is at best mixed.

There is a general consensus in the literature that time-based rates are successful at encouraging greater off-peak charging. As Frontier Economics and Sustainability First (2012) conclude, evidence from the water, telecoms and rail sectors indicates that consumers do respond to both economic and non-economic signals by shifting their demand away from daily peaks. However, results across trials as to the extent of the behavioural shifts in domestic electricity consumption from different tariff structures (and what makes the difference) are varied:

- A review of the literature by Verbong et al. (2013) suggests that trials show a mixed picture. Trials in the US demonstrate a demand reduction between 4% and 15%, but similar experiments in the Ireland and the UK resulted in a reduction of only 3% (citing Hardy, 2012).
- However, a study by the Irish Commission for Energy Regulation found that peak usage was reduced by 8.8% and overall usage by 2.5% (CER, 2011).

- Nemtzw, Delurey, and King (2007) reviewed results from more than 100 DR programs in the US and found the programmes had a 'conservation effect' of between 20% to minus 5% (i.e. an increase in use). They report findings from a day-ahead hourly pricing pilot run by the Community Energy Cooperative in Chicago. The 1,400 households who took part in the Energy-Smart Pricing Program (ESPP) pilot for three years did not just shift their time of use, they also used less electricity; a 3 to 4% average reduction of overall electricity consumption.
- Frontier Economics and Sustainability First (2012) conclude from their review "testing of real-time pricing for households has not produced robust results to date". They compare across tariffs with different aims, and find that critical peak tariffs have a greater impact than ToU tariffs on peak demand on the days that the response is called.
- Frontier Economics and Sustainability First's (2012) review reveals that interventions to automate responses tend to deliver the greatest and most sustained household shifts in demand where consumers have certain flexible loads, such as air conditioners or electric heating.

This mixed evidence on the overall impact of different tariffs is accompanied by little evidence on the role of the strength of the price signal:

- Frontier Economics and Sustainability First (2012) suggest that consumers may be responding to the introduction of a signal to shift demand, as well as to the strength of the signal itself but find there is little evidence from the UK on whether consumer responses to price signals differ according to the strength of the price signal. Evidence on the importance of the size of peak to off-peak price differentials is mixed for ToU tariffs, but points towards higher differentials resulting in higher peak demand reductions for critical peak tariffs. They believe it is plausible that the strength of the economic signal would become more important over time as consumers learn about the effect of their changed behaviour on their bills.
- Faruqui and Palmer (2012) surveyed the results from 126 pricing experiments across three continents with dynamic pricing and time-of-use pricing of electricity. Data from 74 of these experiments were sufficiently complete to allow them to identify the relationship between the strength of the peak to off-peak price ratio and the associated reduction in peak demand or demand response. They showed that the amount of demand response rose with the price ratio but at a decreasing rate. They found that approximately half the variation in peak period demand reductions recorded in ToU and Critical Peak Pricing trials could be explained by variations in the peak to off-peak price ratio.

3.4.2.2 Findings related to EV electricity use

There are very few studies to have examined the behavioural response of EV owners to different electricity tariff structures.

The most comprehensive study is US based with a (purposefully) skewed sample of energy-engaged householders. However, this study demonstrates that whilst EV owners can shift their behaviour, they are likely to revert to daytime charging if tariffs are removed and have a more variable response to critical peak pricing events:

- Zarnikau, Zhu, Russell, Holloway, and Dittmer (2015) studied 62 participants who were offered electricity at experimental rates during different months in a neighbourhood in Texas where more than half had PHEVs or BEVs and most had photovoltaic systems. All participants could view the electricity usage of their major appliances and circuits within their home over the internet and most had remotely programmable thermostats. Their homes were built to highly energy-efficient standards. The authors justify this skewed sample by suggesting these highly engaged energy consumers will be the norm in 20 to 50 years from now. Price signals were tested which offered a discounted price charged during 'wind enhancement periods' and high prices during summer critical peak periods. In response to traditional time-of-use (ToU) pricing, many of the 30 participants with EVs moved their charging to the night time wind enhancement periods. For the group exposed to the ToU pricing, the energy consumed by EV charging during the night-time increased from 32% prior to the pricing experiment to 55% during the months with ToU pricing. There was a marked reduction in daytime charging by PHEV owners when the ToU wind pricing was in effect, taking advantage of very inexpensive overnight charging but there was a partial rebound in daytime charging during the summer months when wind pricing is not in effect. The authors suggest this rebound may be partially caused by the longer daylight hours and increase in evening activities in the summertime, calling for increased seasonal afternoon charging due to the short range of PHEVs. But some participants stated in their final survey response that they went back to charging as convenient (including during daytime hours) when the pricing was not in effect. For the full electric EV owners there was also a marked reduction in daytime charging when the ToU wind pricing is in effect but the summer rebound is not seen in this case, likely because full electric EVs often have the range needed to handle the evening tasks, allowing charging to be scheduled for overnight. Response to the ToU pricing was very pronounced for PiV owners as a group, resulting in greater than a 50 percent reduction in daytime charging and 4 p.m. to 7 p.m. charging. Night-time charging nearly doubled. Changes in charging behaviour were found to be persistent over the period of this study for most participants as they became part of the daily routine.

In the UK, evidence has been gathered from EV drivers who had membership to SwitchEV (UK) had unlimited usage of (certain) public charging points and evidence from workplace charging suggests the pricing tariffs of public and workplace charging points can be managed to influence demand.

- In the north east of England, a charging membership scheme charges users a fixed annual rate for unlimited parking and electricity. Focus group discussions indicated that drivers' use of the parking and charging was influenced by the fact that they view them as a 'free' resource (Robinson et al., 2013). This was because there was no additional out of pocket cost at the point of use. Free parking at the point of use is perhaps a bigger incentive than free electricity. Some drivers reported that it was cheaper for them to pay the monthly lease cost for an EV and the subsequent scheme membership fee than it was for them to pay to park their current petrol/diesel vehicle. The data showed that this membership resulted in increased daytime usage, during peak periods, compared to those who used public pay-as-you-go points. Private users (who did not have smart meters) tended to plug in their EVs when they got home (~6pm), during peak periods. The authors made the recommendation that private users are

equipped with smart meters, and public charge points are made pay-as-you-go, in order to reduce load on the grid at peak times.

- In the US a survey of plug-in electric vehicle owners was conducted focusing on workplace charging (Nicholas & Tal, 2013). Increasing prices for using workplace chargers would be likely to encourage more EV owners to charge at home, reducing demand for popular workplace chargers (USA). Answers indicated that four chargers would be needed for every 10 vehicles if free, versus 1 charger for every 10 PiVs if the price were double (assuming 1 charger serves 2 cars/day). This usage pattern suggests that simply charging a small fee could encourage more efficient use of infrastructure.

3.4.3 Energy tariffs and EV adoption

No evidence was found regarding the impact that consumer energy tariffs may or may not have on EV adoption. It might be speculated that at present the variation of energy tariffs available to consumers is too limited to offer EV adopters options that might impact their decision.

3.4.4 Evidence gaps and research recommendations

The literature search on managed charging and EVs resulted in insufficient evidence to answer the research questions set for this review. There are therefore priority areas for further research.

The Stage 2 Consumer Charging Trials have been designed to address the key gaps among those identified below that are most critical to grounding the analytical framework in more valid data on charging behaviour, and responses to managed charging propositions. The specific research questions to be addressed in those Trials are set out in separate deliverable report D1.4, "Trial Design, Methodology and Business case".

EV adopter response to demand management

There is substantial evidence on demand management in the context of general electricity usage. The issue for this review is that (i) this evidence has often been gathered in a trial setting but with limited use of randomised controls (ii), has not been undertaken with EV users to understand the acceptability of tariffs in relating to charging behaviour.

The following areas need particular attention in future research:

- The role of previous experience with any ToU tariffs such as Economy 7. Are these consumers more likely to accept the next generation of static ToU tariffs? Are these the same people who might be interested in EVs?
- Are EV owners more willing than the average consumer to accept some of these tariffs? Does this only apply to innovators?
- The investigation, within a social psychological framework, of the role of automation and the ability to override in easing the passage to behavioural adjustment for consumers or hindering its uptake by fostering low perceived behavioural control and pro-environmental self-identity.

- Which appliances are consumers willing to use in a flexible way or relinquish direct control over? How do they/ are they prepared to change behaviour? Where do EVs fit among these appliances?
- Does any behavioural adjustment prevail over more than the short-term if it is not automated or directly controlled? Does the strength of the economic signal would become more important over time as consumers learn about the effect of their changed behaviour on their bills?
- How is the acceptability of different tariffs related to (i) BEV vs PHEV adoption (ii) the additional car ownership, travel patterns and flexibility of consumers?

Impact of different tariffs/ demand management on charging (and driving/usage) behaviour

More detailed exploration of the financial incentives necessary to encourage EV owners to participate in demand response programs is even more limited. Very few conclusions could be drawn about the impact of different tariffs on EV charging behaviour and use. The following areas are priorities for further research:

- The key behavioural responses to tariff structures relate to the extent to which electricity demand is shifted in time or reduced, the extent to which any behavioural shifts remain over time and the extent to which people override the signal, where this is possible. Absolute reductions in demand can also result. All of these responses need to be examined in relation to EVs, with PHEVs and BEVs examined separately.
- What is the role of the strength of the price signal vis a vis (i) other costs (ii) the control element) (iii) the size of peak to off-peak price differentials? Does the strength of the price signal become more important over time as the signal to shift demand wears off?
- How does the way in which consumers pay (e.g. subscription basis vs flat rate charge) alter the perception and consideration of these prices?
- What happens to behaviour over time and once the tariff structures are revised or removed? How long does any change in behaviour last for if not automated or directly controlled?
- What is the relative impact on in-home and out of home charging and how does this relate to tariff structures experienced at public charge points?

EV uptake and the consumer proposition

To the extent that any evidence exists on the demand management topic in relation to EVs, it examines whether EV ownership might make it more likely to adopt a certain tariff, rather than the role the tariffs might play in EV adoption. Hence the priority for research is to examine:

- Will existence of demand management + lower tariffs make uptake of EVs more attractive (rather than other way around)?
- Which moderating variables differentiate the impacts of types of consumers, demand management strategies, and contextual influences on technology adoption is a growing area to which behavioural science can contribute.

3.5 The TRL–Shell study: a randomised controlled trial of mainstream consumer drivers’ responses to Battery Electric Vehicles

The literature review highlighted that, despite many studies of the potential uptake of EVs, there remain substantial weaknesses in the existing picture.

First, many of the studies have relied on quantitative surveys or choice experiments with participants who have not had any direct experience of EVs on which to base their responses. Assessment of consumers’ preferences for “really new” product categories can be methodologically challenging (Hoeffler, 2003). Construal Level Theory (Liberman, Trope, & Stephan, 2007; Liberman & Trope, 2003) proposes that psychological distance affects the level of abstraction with which a product is construed. An object is psychologically distant when it is detached from a person’s direct experience: the more psychologically distant an object, the more it is construed in high-level, abstract terms, rather than low-level, concrete terms. This suggests that research in which participants have not directly experienced EVs may be subject to large uncertainties.

Second, those studies where participants have been provided with a direct experience of using an EV have frequently involved biased samples that are not representative of mainstream consumer drivers. The most common sample bias has been that participants have either been amongst the first owners of EVs, or people especially motivated by and interested in them – i.e. actual and prospective PiV Innovators. There is no *a priori* case to assume that their responses will be representative of the general car user population. Indeed in the ETI PiV study segmentation analysis (Anable, Kinnear, Hutchins, Delmonte & Skippon, 2011), attitudes towards EVs differed substantially between segments. The attitudes of the “Pioneer” segment were very much more favourable to EVs, and very un-representative of those of the other segments. This suggests that findings from early Innovator samples have limited validity in relation to the wider population.

Third, most trials have been vulnerable to “Hawthorne” effects. These occur when participants change their behaviours, attitudes or preferences because they are aware they are participating in research, rather than in response to the research stimuli. Controlled studies (in which a control group participates, but does not receive the stimulus) mitigate confounding Hawthorne effects. However they are rare in transport research (Graham-Rowe, Skippon, Gardner & Abraham, 2011), and so far absent from the EV literature. The study by Jensen et al (2013), for instance, while measuring changes in preferences after experiencing use of a BEV, did not control for Hawthorne effects. Because of their vulnerability to Hawthorne effects, the results of uncontrolled studies can be misleading: Graham-Rowe, et al. found that apparent effect sizes in uncontrolled studies were substantially higher than those in controlled studies investigating similar effects.

To address these weaknesses, TRL (commissioned and funded by Shell) carried out a randomised controlled trial (RCT) investigating mainstream consumer responses to 2012 model BEVs. Psychological distance was reduced by providing an Experimental group of 200 participants with direct experience of a 2012 model Nissan Leaf for 36 hours, including one overnight charging experience at their homes. Sample bias was substantially reduced by recruiting a sample of mainstream consumer drivers, carefully stratified by age, gender, and home location (urban vs rural) intended to be as representative as possible of the UK car user population. The RCT design controlled for Hawthorne effects: responses of the Experimental group were compared with those of a similar-sized Control group who had exactly the same participation experience, but received an unfamiliar equivalent ICE vehicle (Ford Focus diesel) instead of the BEV. The

RCT design ensured that any differences between the responses of the Experimental and Control groups could be causally attributed to the experience of using a BEV compared to an unfamiliar equivalent ICE vehicle.

The findings discussed below are reported in Skippon (2014) and in a journal paper by Skippon, Kinnear, Lloyd, and Stannard (2016) submitted for publication.

3.5.1 Willingness to consider having a BEV as a main or second household car

Section summary

- The finding that mainstream consumers' willingness to consider a BEV falls after direct experience, particularly when the effective range on a full battery is relatively short, contradicts the picture that emerged in the literature review, largely from research with PiV Innovators. As in the ETI's PiV study, we see that the responses of PiV Innovators are not representative of the responses of mainstream car users. **This highlights the critical importance of valid, unbiased sampling of the mainstream car user population if we are to use research findings to assess the potential for EV uptake in that population.**
- The finding also suggests that models of uptake of BEVs based on research with mainstream consumer car users who have not themselves had direct experience of using a BEV may over-estimate such uptake. **This highlights the critical importance of basing models of EV uptake by mainstream car users (such as ECCo) on data obtained from samples of mainstream car users who have had direct experience of using modern EVs.**
- The ETI PiV study choice model (from which ECCo was developed) showed that over much of the period to 2050, PHEV uptake would substantially exceed BEV uptake – thus PHEVs would be the dominant type of EV in use by mainstream car users. At the time of the TRL-Shell study there were no PHEVs available on the UK market, so the study was necessarily focussed only on responses to BEVs. **There remains a substantial gap in knowledge of mainstream car consumer attitudes to PHEVs, particularly from those who have had direct experience of using them.**
- It follows that to maximise the validity of models of EV uptake by mainstream car users, further research is needed. That research should sample the mainstream car user population, rather than PiV Innovators; should take the form of an RCT in which mainstream users' psychological distance from EVs is reduced through direct experience; and should provide participants with direct experience of both a modern BEV and a modern PHEV, along with an equivalent control ICE vehicle.

Figure 18 shows the proportion of participants who would choose a BEV as their main household car, as a function of the range the car would travel on a fully charged battery. Before the experiment, the percentage of participants who would consider owning a BEV as their main household car was similar for both groups at all range values. It was very low for 50 miles range (the realistic extra-urban driving range of the BEV used in the experiment) but increased for higher ranges. At every range the percentage of participants who would consider choosing a BEV decreased after the experiment. The decrease was larger in all cases for the experimental group who experienced using a

BEV, compared with the control group (the between-groups difference being statistically significant for the 150 mile range).

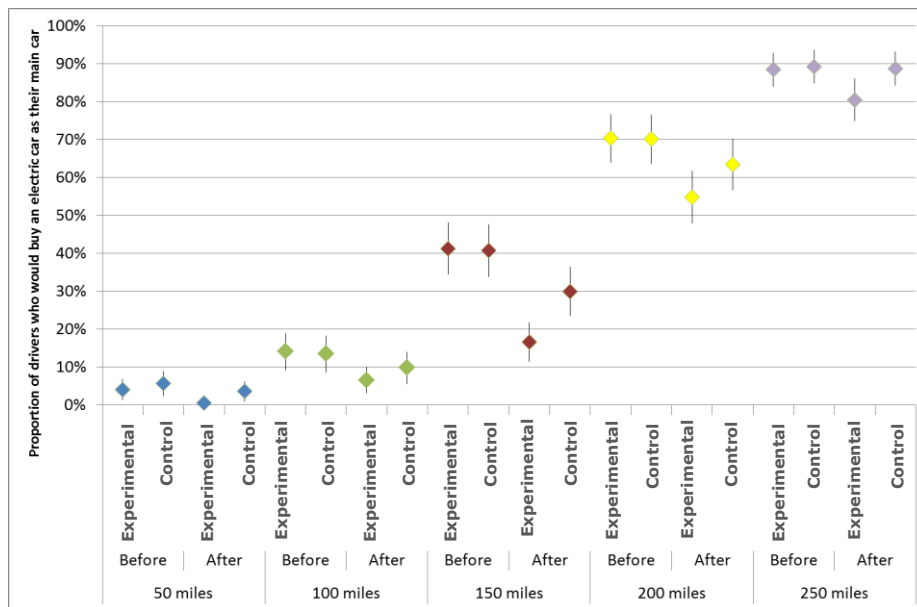


Figure 18: Percentage of participants who would consider owning an electric car as a main household car for various possible ranges on a fully charged battery, before and after experiment, in experimental and control groups.

Figure 19 shows the proportion of participants who would choose a BEV as their second household car, as a function of the range the car would travel on a fully charged battery. The broad patterns were the same as for a main car. Before the experiment, the percentage who would consider owning a BEV was approximately the same for both groups, starting very low for 50 miles range but increasing as the range increased. The percentage of participants responding positively decreased after the experiment, and for the lower three range categories the decrease was larger for the experimental group (the between-groups difference being statistically significant for the 100 mile range, and almost so for the 50 mile range).

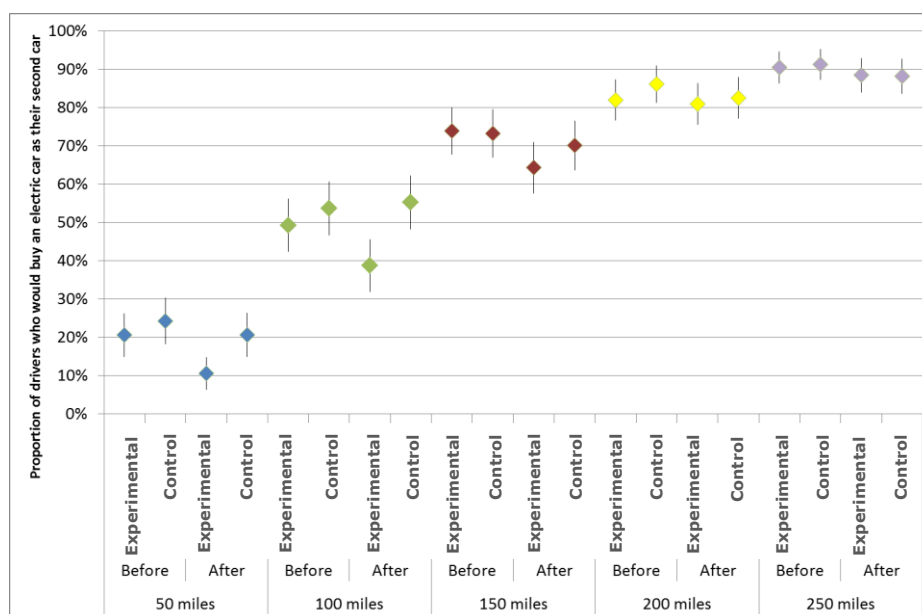


Figure 19: Percentage of participants who would consider owning an electric car as a second household car for various possible ranges on a fully charged battery, before and after experiment, in experimental and control groups

However the percentages who would consider choosing a BEV as a second household car were considerably higher for all ranges than they were for a main car, suggesting that lower ranges were considered more acceptable for a second car.

These results contradict the general sense in the literature reviewed, that experience of using a BEV increases willingness to consider. Much of that literature was based on research with biased (PiV Innovator) samples: the difference in findings from a controlled study using a mainstream consumer sample highlights the critical importance of doing so if the data is to be used to model potential uptake by the general car user population.

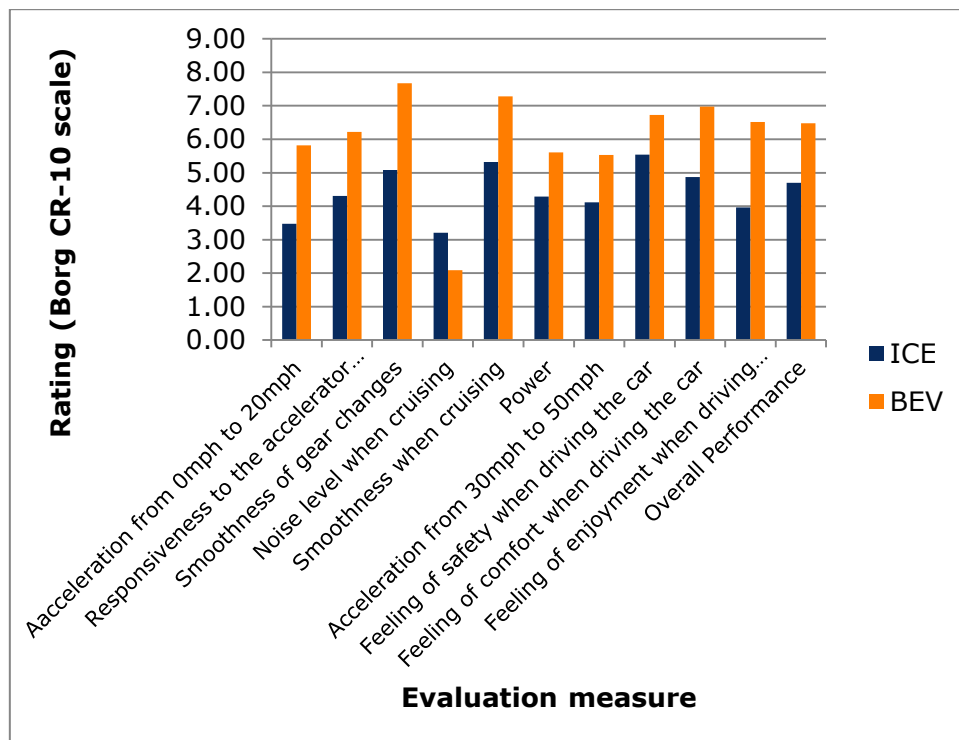
3.5.2 Evaluations of BEV performance compared to ICE vehicles

The literature review found little evidence of studies investigating participants' evaluations of the performance of EVs. Performance was evaluated by the experimental group in the TRL-Shell study, and compared with evaluations of the performance of the comparison ICE vehicle by the control group. The performance attributes evaluated were based on those identified by Skippon (2014) and reflected the distinction between dynamic performance and cruising performance.

Figure 20 shows how participants in the experimental group evaluated the performance of the BEV, and the experience of driving it, compared with the same data from the control group concerning their evaluations of the Ford Focus diesel control vehicle.

The pattern of results was particularly clear: the BEV was rated as having significantly better dynamic performance (acceleration from 0 to 20 mph, acceleration from 30 to 50 mph, smoothness of gear changes, responsiveness, and power; and significantly better cruising performance (smoothness when cruising, and lower noise when cruising). Overall performance was also rated higher.

Other aspects of the driving experience – feelings of comfort, enjoyment, and safety – were also rated higher for the BEV than for the ICE vehicle.



Note: for Noise level when cruising (only), a higher value is a demerit (noisier)

Figure 20: Evaluations of performance and driving experience: BEV (Nissan Leaf) compared with conventional ICE vehicle (Ford Focus diesel)

Thus both dynamic and cruising performance of the BEV was evaluated as better than those of the equivalent ICE vehicle.

3.5.3 Symbolic meaning and the influence of self-congruity on willingness to consider

As highlighted in the literature review, consumer car choice is determined not just by instrumental (functional) motives but also by symbolic ones, concerned with what owning or using the car will signal about its user (to others, and also the user themselves). The extent to which a particular car supports symbolic goals depends on its symbolic meaning (what signal about its user the car sends). Most studies in the EV literature have focused on EVs as signals of pro-environmental identity that may have most relevance to Innovators, and have neglected any wider meanings that EVs might convey for mainstream users.

The TRL-Shell study provided a more comprehensive, theoretically-grounded characterisation of the symbolic meanings of BEVs using an “attribution-vignette” method developed by Skippon (2014b). This approach is based on Miller’s (2009) evolutionary perspective that the ultimate symbolic meanings of a consumer product are the personality traits of its users, because products act in modern cultures as costly signals of reproductive fitness. The method quantifies the symbolic meaning of a product in terms of public attributions of personality traits using the five-factor model (Costa & McCrae, 1995; McCrae & Costa, 2003), plus status, gender, age, relationship investment, and physical attractiveness to a typical user.

Figure 21 and Figure 22 show the results: the study found that a typical BEV user would be significantly higher than average in the five-factor traits openness, conscientiousness and agreeableness, and no different than average in extraversion and neuroticism.

He/she would be of higher than average status, more likely than average to have high relationship investment, and more likely to be older than 35.

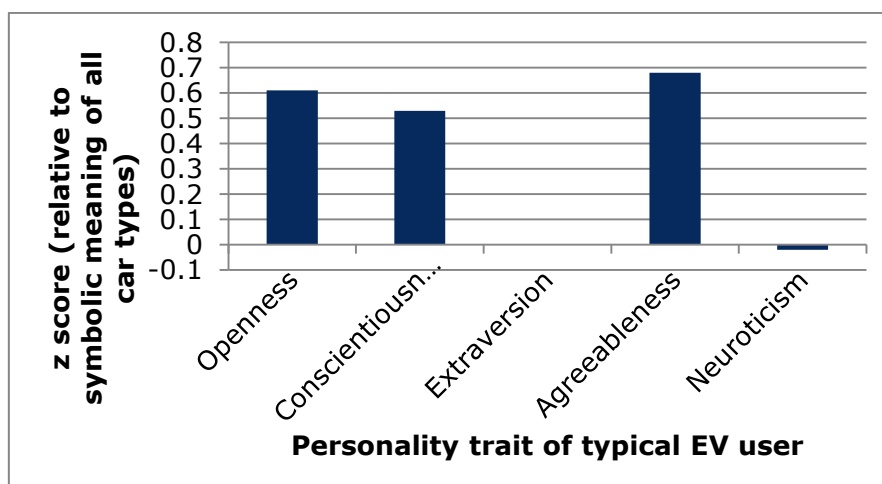


Figure 21: Symbolic meaning of a BEV: personality traits attributed to a typical BEV user by experimental group participants after the experiment¹⁶

Very similar results were obtained from the control group, and from both groups before and after the usage experience, suggesting that these symbolic meanings are already established in the mainstream consumer driver population. The results were also consistent with those found by Skippon and Garwood (2011) using an early version of this method with a small, non-Innovator sample.

Self-congruity theory (Sirgy, 1982; 1985) predicts that people will tend to purchase consumer products whose symbolic meanings are congruent with their perceived self-identities. The study measured self-congruity and compared this with willingness to consider having a BEV with various ranges on a full battery. Those (few) participants who were willing to consider a BEV with a relatively short range (50 to 100 miles, equivalent to the ranges of vehicles currently on the market) had significantly higher self-congruity than those who were not, suggesting that for them, the symbolic meanings of BEVs were particularly important. The effect disappeared for longer ranges, suggesting that, as the overall functionality of BEVs increases, symbolic meanings specific to their nature as BEVs will have less impact on their overall appeal.

¹⁶ Results are expressed as z scores, which relate the score to the distribution of symbolic meanings across all car types. The z score reflects the distance between a specific symbolic meaning and the mean of that distribution, expressed in units equal to one standard deviation of that distribution. Thus a z score of 0.6 shows that a vehicle signals a substantially higher value of that trait than the mean of the values signalled by cars in general.

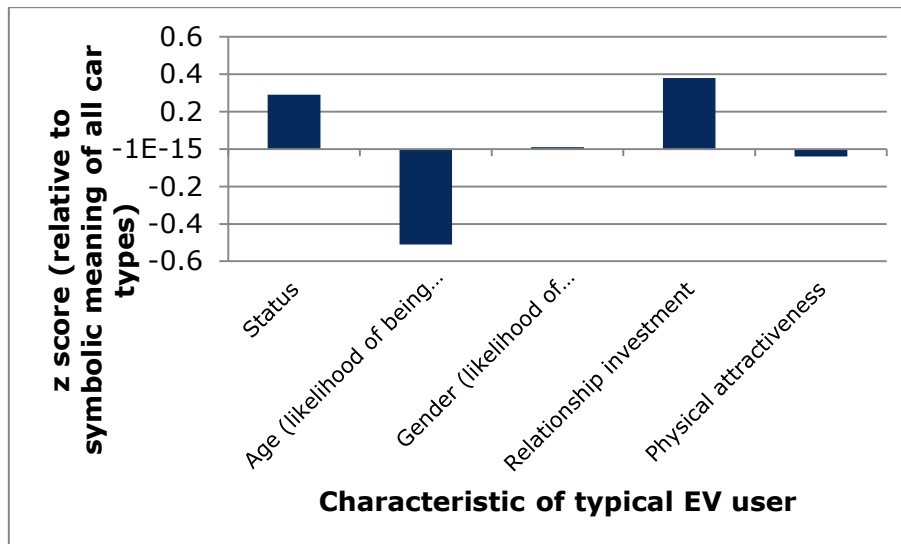


Figure 22: Symbolic meaning of a BEV: status, age, gender, relationship investment and physical attractiveness attributed to a typical BEV user by experimental group participants after the experiment

3.5.4 The TRL comparative user experience study

In a so-far unreported study at TRL, 15 mainstream car user participants were each given one week’s direct experience of a Nissan Leaf BEV, Vauxhall Ampera RE-EV (all electric range ~50-60km), Toyota Prius PHEV (all electric range ~20km), Toyota Prius gasoline HEV, and Peugeot 3004 diesel HEV, and then interviewed qualitatively about their experiences with each. The findings generally supported the picture above. After direct experience of using a BEV, participants were favourably impressed by the driving experience, but tended to conclude that the short all electric range (AER) meant the vehicles were unsuitable for their lifestyles and needs. On the other hand, user responses to the RE-EV were much more favourable as this class of vehicle, combining 50-60km of AER with the ability to make longer journeys under ICE power, was seen as fully compatible with their lifestyles and needs (subject to purchase price being affordable). Shorter AER PHEVs were not well received.

This study also investigated how far into the week’s experience participants thought their responses had settled. The majority of participants reported that they formed their evaluations within the first 1-2 days and that subsequent days of use confirmed them but did little to change them. This finding has implications for the Stage 2 trial design.

4 Lessons learned review

4.1 Aim

The aim of the lessons learned review was to establish practical lessons that can be learned from relevant PiV and/or energy management trials that have been undertaken to date. The purpose of this task was to ensure that the design of the trial mitigates or minimises known risks, reduces the number of assumptions and improves the accuracy of time, data and cost predictions.

4.2 Method

The approach to this task first sought to identify relevant published literature. Literature identified for the reviews detailed in section 3.2 was filtered for relevance to this task. It was identified early in the process that the published literature generally reports findings from trials and while some limitations may be noted, it is unusual to see practical difficulties openly discussed. To account for this limitation the method was adapted to include discursive interviews with those known to have been previously involved in running PiV or managed charging trials with consumer or fleet drivers.

All members of the project team were consulted and requested to highlight published and unpublished trials that they considered to be relevant for this project. Where possible, known literature or a known contact was also provided. Where literature were available (and had not been already sourced for the reviews) these were added to the literature for review. Contacts provided were considered for either providing unpublished feedback or qualitative input via a telephone interview based on relevance to the current project.

Seven discursive interviews were undertaken with contacts that had direct experience of planning, running and/or analysing data from live PiV trials. Potential interviewees were informally approached by email or telephone and asked if they would volunteer to take part in a discussion of their experiences for up to one hour. An overview of the current study and the purpose of the interview were provided to participants. All participants contacted agreed to take part and verbally consented to the interview at the beginning of the call.

The interviewees included representatives from commercial, research, academic and public organisations. Due to commercial sensitivities (for example some studies were unpublished) interviews were not recorded and notes were only taken with permission. To further encourage openness, interviewees were informed that their input would be anonymous. The identity of the interviewees, their organisation or the trials they were discussing is not reported.

Interviews were semi-structured. Discussion was allowed to flow and areas of interest were explored by the interviewer. Nevertheless, the following topics were used as a guide for the discussion:

- Studies the interviewee was involved with
- Study design
- Recruitment
- Vehicle choice
- Vehicles (general)

- Technology and communications
- Infrastructure
- Managing the trial (e.g. accidents, fires, cleaning, home charge inspections, cables)
- Data
- Analysis
- Reporting
- Other (e.g. general advice or topics not covered)

Interviewees were not asked to report on the results of the studies, but instead to report on practical matters, unexpected events or advice based on experience. Typical questions included:

- If you were to run the trial again, what would you do differently?
- How could the trial have been improved?
- Based on your experience, what would your advice be to someone who was designing a trial now?

4.3 Results

Based on feedback from project partners and a review of literature, limitations and lessons to be learned were explored for trials detailed in Table 10. Literature relating to these trials was interrogated along with any relevant additional online reporting; links to reports or study websites can be seen in Appendix A. The studies covered include trials relating to the uptake of PiVs and/or trials of charging or vehicle use.

The study references in the left-hand column of Table 10 relate to the study reference in the left-hand column of Table 11, which summarises limitations and lessons to be learned from the literature or online reporting of these trials. Reported and observed limitations and lessons learned were coded under the following headings:

- Study design
- Participants and recruitment
- Vehicles
- Technology and communications
- Infrastructure
- Managing risks and practicalities
- Data and analysis
- Reporting

The key finding from this task is immediately clear from the gaps that are evident in Table 11; there is a lack of reporting of limitations or practical lessons learned from published studies. The lack of information reported is in itself a significant weakness given the number of trials conducted and the lessons that could be learned to improve the accuracy of data collected in future. The following interpretation and themes emerging from observations in the literature is therefore supplemented and enriched by the learnings from the discursive interviews.

4.3.1 Study design

With respect to study design a prominent theme arising from a critique of the literature and reported in interviews is a lack of control over confounding variables. Confounding variables have two main effects on the validity of the findings of trials and their use. First, they can adversely affect the relationship between the independent variable and dependent variable leading to the researcher drawing incorrect conclusions. Second, there can be subsequent difficulty in applying the data or results to a wider population without significant uncertainty. Such methodological restrictions lead to the data collected having limited scope and future value.

Such weaknesses relate to either control over the study design or control over participant recruitment. These factors can be complicated by the nature of vehicle ownership or organisational involvement in trials. For example, in some studies private consumer participants chose to invest in ownership of the vehicle (usually through a lease scheme) or were already PiV adopters. This process biases the participant sample towards those with a current willingness and affordability to pay for such a novel vehicle and new technology; a sample known not to be representative of the mass-market population (Anable et al., 2014).

It is apparent that the purpose of many studies utilising the deployment of vehicles was focused on the demonstration of technology or possibly to gather early learnings of user behaviour and response. While successful demonstration may have met the aims of particular trials, the application of such data to inform public policy would not be considered scientifically valid (Haynes, Goldacre & Torgerson, 2012). Methodological weaknesses in study design therefore leave significant gaps in knowledge relating to the understanding of the PiV and energy market and the wider mainstream consumer population.

Similarly, in fleet studies, control over conditions is reported to be problematic and difficult to manage. Fleets have ongoing working requirements and by their nature vary in size and purpose (see deliverable D2.2). Trials with fleets also suffer from a lack of control of confounding variables and a lack of applicability of the data they collect to the wider population.

4.3.2 Participants

There is a close relationship between quality of the study design and appropriateness of the participant sample; one without the other will devalue the quality of the data collected. As noted, there is some acknowledgement within the literature and wider industry of weaknesses in the sampling of trials to date. Some unpublished studies have sought to employ more robust study designs and use representative participant samples. While this is a step in the right direction the publication of studies with valid data is necessary to inform future public policy decisions.

From a practical perspective, the interaction with participants during the study was highlighted as being crucial. Interviewees noted that there was a need for participants to be well informed and supported throughout the trial. It was reported that due to the novel nature of the technology and the concepts being demonstrated (vehicles and charging), participants required more support than anticipated. In some cases, simply being recruited to the trial developed expectations that had to be managed. Ongoing participant support was also noted and provided challenges to project teams.

4.3.3 Vehicles

There was very little reported other than battery performance degradation in winter months regarding vehicles used in the trials. There was nothing regarding how their procurement or use could have been improved. Lessons to be learned regarding vehicles largely came from the discursive interviews and varied by experience. Many of the challenges faced by previous trials relate to the immaturity of the market at the time, particularly a lack of vehicle options or a need to use retrofitted models. Specific challenges were noted in the fleet domain where the availability of electric powered vans trails that of cars. Some vehicle reliability issues were mentioned for one or two models but on the whole reliability was not reported as a general issue.

4.3.4 Technology and communications

Specific technology and communications problems were reported by some trials. Such challenges were usually specific to the trial in question, for example the 'Espirit' technology in the My Electric Avenue trial. Nevertheless, the emerging theme generally related to the use of bespoke technologies or communications systems, such as those between the user and the charge point or telematics products for data collection. A consistent message throughout discussions with interviewees was that establishing and maintaining the technical solutions can be time-consuming. Advice given regarded the use of suppliers with previous experience where possible, a general allocation of contingency (time and cost) for unforeseen development or maintenance and to keep things as simple as possible.

One example given was the consideration of charge points in areas with weak mobile communications signals where the system is reliant on the real-time signal from the charge point. Such technology and communication systems require on-going consideration even where a system has been tested and piloted. A further example included the collection of data from vehicles. While after-market telematics systems were largely reported to be successful in obtaining the data necessary for the trials discussed, some vehicle data, such as state of charge, often required bespoke interrogation.

4.3.5 Infrastructure

Infrastructure was both reported in the literature and noted in interviews as necessitating careful consideration. The key matters relating to infrastructure included:

- Land ownership permissions (particularly in shared ownership and leased properties)
- Physical installation challenges in some locations (e.g. running cables)
- Vehicle connectors
- Health and safety (e.g. installation standards)

Practical challenges caused by installation and land ownership permissions, in addition to meeting installation standards, impacts on participant recruitment and participant sampling. Due to these factors, the participant sample in trials with private consumers almost always consists of those with off-street parking who own their own property. This has created a knowledge gap with regard to those living in shared ownership properties, such as apartments. However, it might be argued that until infrastructure can support

those living in shared ownership properties, then the likely real-world adopters of PiVs are those where home charging can be supported.

Physical installation challenges and vehicle connectors meanwhile are likely to be the result of unknown factors in an early market. For example, charge point installers are now aware of common barriers to installation and commonly apply telephone home checks with owners to identify known barriers and ensure the correct equipment is taken to the site, or to establish whether the sight is unsuitable. Such mitigation strategies have improved the level of successful first-time visit installations.

Installation standards, such as the Electric Vehicle Homecharge Scheme guidelines and The Institution of Engineering and Technology (IET) installation standards¹⁷, have been developed and have established guidelines where charge points are installed. A variety of views were expressed with regard to the need to install a dedicated charge point for trial participants. In general this was done where the trial had suitable access but in some cases it was the decision of the vehicle owner. Nevertheless, in light of the updated guidelines it was assessed as most appropriate for a dedicated charge point to be installed where participants are recruited for a trial with a PiV. With this comes the necessary consideration of associated costs, time delays and recruitment challenges.

4.3.6 Managing risks and practicalities

There was almost no reference made in the literature regarding either how risks and practicalities were managed or of unexpected events. Some unexpected events (e.g. vehicle breakdowns) were noted within the discussions but there were very few.

Practical challenges generally related to vehicle handovers between participants. These included issues such as the storage of participants' existing vehicles, where they swapped their own vehicle for a trial vehicle, and vehicle cleaning and preparation. Such practicalities are study specific but were noted as space and time consuming and therefore necessary for planning into trials where this is a consideration. Another consideration was the need for additional charge cables. Either through damage or loss, a vehicle handed back without a charge cable cannot be re-utilised and this can therefore cause delays to the trial.

4.3.7 Data

There was little detail reported in publications with respect to the preparation and analysis of data (much less than might be expected in other scientific domains). This may be due to the format of studies and reporting, again with a focus on demonstration rather than scientific endeavour. It may also be because of the reported complexities and size of the data collected in such trials. With data being collected from vehicle telematics, charge points and participants, the quantity of data was often described as overwhelming. It was regularly noted within discussions that data cleaning and processing took a considerable amount of time, usually significantly more than anticipated. For example, data timing needs to be clearly defined to allow the extraction of participant data from data collected during vehicle handovers (i.e. when the vehicle is with researchers). Following this, data analysis needs to be clearly defined and focused in order to avoid scope creep.

¹⁷ https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/497619/electric-vehicle-homecharge-scheme-guidance-for-customers-2015.pdf
<http://www.theiet.org/resources/standards/ev-cop.cfm>

Data communications were noted to require regular checks and maintenance to ensure they were working, particularly where complex information technology systems were being used. To meet studies' needs several data collection and communications suppliers were often required and it was recommended to use suppliers who have experience of working together.

4.3.8 Reporting

Limitations of the reporting of studies appear to stem from weaknesses in the study design (see section 4.3.1). For example, there is often little detail that would enable replication of the study (a basic requirement in peer-reviewed publications), or discussion of how the results can be reliably applied to a wider population or future scenarios. Again, this is somewhat symptomatic of the nature of the trials whereby demonstration of the technology or initial exploration were the aims. Where this is the case only limited conclusions can be made; a lack of control over confounding variables prevents valid conclusions being drawn. A lack of valid and reliable conclusions hinders the development of future research and decision making; in the worst case scenario it can lead to erroneous decisions being made.

Interviewees noted that dissemination of material is important. It was suggested that reports should be disseminated as early as possible due to the fast moving nature of the domain and industry. Short summary reports for industry were suggested¹⁸, as were academic publications demonstrating the scientific rigour of the work.

¹⁸ The publication of influential non-peer-reviewed publications highlights the importance that the conclusions are based on valid findings from a strong methodology so as not to mislead or encourage industry opinion or activities that may in fact be erroneous.

Table 10: Summary of PiV trial literature reviewed

Study ref	Trial	Uptake	Charging and use	Summary of trial
1	Assessing the viability of EVs in daily life (Cenex/ Oxford Brookes University)	✓		349 Low Carbon Vehicles (>90% of which were PiVs, remainder PHEV and FCEV) deployed to a mix of corporate and private users for 1-12m each. Study looked at drivers' perceptions/attitudes towards the [pure] EVs and their real-world performance.
2	My Electric Avenue (EA Tech Ltd.)		✓	Clusters of neighbours were given Leafs to drive for 18 months. Purpose of trial was to test the new technology 'Espirit', which monitored/controlled electricity used during car charging, whilst avoiding potential power outages/damage to network infrastructure.
3	Green eMotion	✓		Using a hybrid choice model, this study investigated the effect of experience on individual preferences for specific PiV characteristics, attitudes towards the environment and attitudes on the choice between PiVs and ICE vehicles. Preferences were found to change significantly after experience with a PiV.
4	Berlin Mini E trial (Chemnitz University of Technology/BMW)	✓		Study aimed to investigate the extent to which PiVs are useable/ satisfying in their present form. Also aimed to define valid evaluation criteria for the assessment of impact of PiVs on user behaviour, the environment and the mobility system.
5	LCV Procurement Programme (Cenex)	✓	✓	This programme placed 200 hybrid + electric panel vans within 21 public sector fleets – the data from the vehicles was analysed.
6	Smart Move (Cenex)	✓	✓	This programme incorporated PiVs into twelve vehicle fleets.
7	Crome (EDF)		✓	The CROME project (CROss-border Mobility for Electric vehicles) is a cross-border charging network on both sides of the Rhine (with chargers in both France and Germany).
8	PI-FI (Energy Savings Trust, EDF, Route Monkey)	✓		The Plugged-in Fleets Initiative (PI-FI) offers fleets tailored analysis/review in order to show the potential benefits of plug-in vehicles.
9	Kleber Toyota trial (Toyota, EDF)		✓	Toyota/EDF leased 70 PHEVs in Strasbourg to partner company employees. The aim of the project was to trial an innovative charging infrastructure.
10	SAVE project (Renault)		✓	PiVs were loaned to 40 participants, and 130 charging stations were installed in the Seine Aval region (anybody within Seine Aval was within 15km of a charging point). Aims of project included contributing to knowledge on PiV use and charging infrastructure.
11	Grid for Vehicles project		✓	Grid for Vehicles (G4V) aimed to develop an analytical method to assess the effect of a sharp increase in PiVs on the grid.
12	Sacramento Municipal Utility District (SMUD)'s SmartSacramento project		✓	Project aimed to deliver an advanced metering infrastructure, as part of building future smart grid functionality. Included 80 PiV charging stations.
13	Evaluating EV Charging Impacts and Customer Charging Behaviours (US Dept. of Energy)		✓	Project (across six utilities providers) aimed to evaluate the technical performance of charging systems/impact on the grid of the rising uptake of PiVs.

Table 11: Summary of lessons learned or limitations reported in or observed from trial publications

Study ref	Study design	Participants and recruitment	Vehicles	Technology and comms	Infrastructure	Managing risks & practicalities	Data and analysis	Reporting
1	Information collected between December 2009 – March 2012 Potential for charging infrastructure to change a lot in this time period. May have affected perceptions of charging during study. Vehicles loaned to participants for inconsistent periods of time.	“The vehicle drivers and their usage types were selected by the consortia for the purpose of their individual projects. It is not proposed that the usage experienced in this trial is representative of expected UK average vehicle performance or demographics.” (page 8) Sample was 76% male, most had higher than average income (82% >£41k, 25% >£101k)	Limited information regarding vehicle types and experience of types used.	N/A	N/A	N/A	Some vehicle data collected manually on driver log sheets. “Data submissions between consortia [8 consortium partners] were not fully compatible therefore, where appropriate, the data analysed in this report used different data populations dependent on subject of the analysis.” (page 8)	Limited conclusions probably due to lack of control over confounding variables. Comparability of results difficult due to lack of control over study variables.
2	N/A	In the early stages there was difficulty in recruiting the minimum of 100 participants (in clusters of neighbours).	N/A	Issues with the ‘Espirit’ technologies – initially there was failure to curtail PIV charging. Some Intelligent Control Boxes were not wired in accordance with installation instructions.	Some residents (who were not participating in the trial) halted the installation of a cabinet to house ‘repeaters’ above ground Delays to cluster installations due to lack of available equipment/ delays in acquiring PIVs.	N/A	N/A	Report highlighted the importance of future projects using independent project reviewers
3	N/A	Participants had to fulfil certain criteria e.g. having their own private parking space	N/A	N/A	N/A	N/A	N/A	Bühler, Cocron, Neumann, Franke, and Krems (2014, p.46) commented that this study “investigated selected EV attributes that are potential

Study ref	Study design	Participants and recruitment	Vehicles	Technology and comms	Infrastructure	Managing risks & practicalities	Data and analysis	Reporting
								<p>disadvantages when using EVs (e.g. purchase price, range). Many potential advantages and barriers were not included in these analyses.”</p> <p>Also disagrees with one key result of the trial: “our data does not support the findings of Jensen et al. (2013), which showed that the importance of range increases after testing an EV, as our data suggest that it remains stable. (p.46)</p>
4	N/A	Study sample might not be representative of the whole population due to self-selecting processes and other limiting factors (e.g. environmental consciousness, income and education)	Air cooled batteries reduced cold weather performance.	No remote access to vehicle information.	Lack of direct connection to the charging system gave rise to post-installation servicing and troubleshooting challenges.	N/A	N/A	N/A

Study ref	Study design	Participants and recruitment	Vehicles	Technology and comms	Infrastructure	Managing risks & practicalities	Data and analysis	Reporting
5	N/A	N/A	By the end of Stage 1 (2011), one of the four electric van suppliers had ceased trading, and a second was being used by too few fleets to provide sufficient data for a thorough study of its performance. Therefore only two vehicles were carried through to the second stage of analysis.	N/A	N/A	N/A	N/A	Limited discussion of the value of findings.
6	N/A	N/A	The trial took place during the winter of 2010/2011 and the performance of the PiVs was affected by the low ambient temperatures.	N/A	N/A	N/A	N/A	Virtually no discussion on methodology/ lessons learned etc.
7	N/A	N/A	N/A	Challenge of having to serve all users, whatever their operating system (e.g. CROME allowed users to use either their smartphones or contactless access cards)	Challenge of having to install stations that met the different French and German standards, enabling them to charge any model by any car manufacturer.	N/A	N/A	N/A
8	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Inconsistent reporting of data does not allow direct comparison.

Study ref	Study design	Participants and recruitment	Vehicles	Technology and comms	Infrastructure	Managing risks & practicalities	Data and analysis	Reporting
9	Very little explanation of study design. Did not make explicit what would be measured.	Employees/ partner company employees used. Not representative of mainstream markets.	N/A	N/A	N/A	N/A	N/A	Some headline figures given, otherwise few details given about results.
10	N/A	Virtually no info given about the 40 participants.	N/A	N/A	N/A	N/A	N/A	Whilst the rationale of the study was very clear, little was said concerning the charging infrastructure and the extent to which issues were avoided. Many other results/ numbers were given, which, whilst interesting, were unrelated to the originally stated aims of the study.
11	N/A	Report points out that survey results are from a small sample per country – which would need verification on a larger scale	N/A	N/A	N/A	N/A	N/A	Little discussion of strengths/ limitations of the simulations of energy usage

Study ref	Study design	Participants and recruitment	Vehicles	Technology and comms	Infrastructure	Managing risks & practicalities	Data and analysis	Reporting
12	N/A	N/A	Report highlighted importance of communication between employees (especially inter-departmental) when implementing projects. Also important to communicate well with customers when implementing meters (e.g. training utility staff to make presentations/ answer questions)	Many PiV charging station technologies were 'immature' and ended up failing. Charging equipment communication modules successfully connected to Sacramento Municipal Utility District meters approximately 50% of the time. Lesson learned: robust design/testing of metering network important. Important to ensure that meter readings come through, especially in dense urban areas with many obstacles to signals.	Vendors of PiV charging stations allegedly over-promised and under-delivered.	Issues with PiV charging station vendors failing to deliver on promises resulting in failure of meters.	N/A	N/A
13	N/A	Stated that it is important to consider the needs of various target markets, and evaluate use cases for each (in terms of charging patterns etc.)	N/A	N/A	Begin by installing a small number of changers as demonstrators, and evaluate use before larger deployments.	Allocate sufficient resources for customer support – a high level typically required. Develop process maps to streamline operating procedures.	N/A	N/A

4.4 Summary and impact on WP1b Stage 2 trial design

It was evident from the review of the literature that reports rarely openly detail limitations or challenges encountered during the trial. From a methodological perspective, this is surprising given that none of these studies reported the use of either a control group or random sampling; both of these approaches are considered important when establishing a valid scientific methodology (Haynes et al., 2012)¹⁹. The inherent methodological limitations of such trials reflect a primary motivation of demonstration rather than experimental scientific research. The result of this is that while studies have demonstrated the concept of PiVs or charging technology, significant knowledge gaps remain with regard to valid and reliable data that can be used to inform future research, decision making and/or future policy decisions. This situation has been evidenced previously (e.g. Anable et al., 2015 and see sections 3.3 and 3.4). The CVEI project aims to both demonstrate and test possible future systems solutions, including the collection of data from real-world trials with consumers. Application of a randomised and controlled trial methodology with mainstream consumers will address limitations of previous trials.

Some of the inherent weaknesses and limitations of earlier trials have been overcome simply through market maturation. It is no longer necessary, for example, to rely on retro-fit vehicles, and OEM support overcomes certain technological challenges. Nevertheless, a number of lessons can be learned from previous trials to inform the Stage 2 trial design. Emerging themes and mitigation strategies for the trial design are summarised in Table 12.

Table 12: Table of emerging themes of lessons to be learned with suggested mitigation strategies

Theme	Suggested mitigation strategy
<p>Methodological weakness</p> <ul style="list-style-type: none"> • Lack of control over confounding variables • Self-selecting samples or lack of control over sampling characteristics • Poor comparability of data • Inability to apply data and results to future scenarios 	<ul style="list-style-type: none"> • Employ scientifically robust study design with control for confounding variables • Sample mainstream car consumers stratifying for potential confounding variables
<p>Technological challenges</p> <ul style="list-style-type: none"> • Vehicles • Charge point installation • Communication technology 	<ul style="list-style-type: none"> • Maturing market presents more vehicle options. Choose popular comparable mid-range OEM vehicles • Work with experienced suppliers to provide charge point installation and

¹⁹ Note that unpublished studies that have included the use of control groups and random sampling were covered during interviews.

	<p>communication network</p> <ul style="list-style-type: none"> • Adhere to established installation guidelines
Participant information and support	<ul style="list-style-type: none"> • Ensure all materials are well designed and piloted. Ensure processes for participant follow-up and support
<p>Practical challenges</p> <ul style="list-style-type: none"> • Day-to-day handovers • Staffing • Vehicle cleaning and maintenance between handovers • Vehicle charging between handovers 	<ul style="list-style-type: none"> • Careful planning and piloting of the handover process • Utilise a dedicated and trained trials team • Plan for vehicle maintenance checks and cleaning between handovers
Volume of data	<ul style="list-style-type: none"> • Ensure the collection of only data necessary to answer and explore findings related to the defined research questions and aims of the project. • Plan data management and data cleaning
<p>Time</p> <ul style="list-style-type: none"> • Set-up • Administration • Analysis 	<ul style="list-style-type: none"> • Ensure adequate resourcing of staffing • Establish and test administrative processes for efficiency and accuracy • Develop an analysis plan pre-trial
Simplicity	<ul style="list-style-type: none"> • Ensure the development of a challenging trial with a focus on the primary aims of the project without the inclusion of unnecessary complications

5 Consumer interviews

5.1 Aim

Little is known as yet about how consumer drivers will experience engagement with charging options that provide for some degree of energy system integration, such as time of use tariffs or managed charging, or to what extent they will be willing to engage with such options.

For widespread energy system integration in the next few decades, it would be necessary for there to be wide engagement among mass-market consumer segments that use PiVs. The exploration of mass-market consumer responses to different charging options is the purpose of the proposed Stage 2 managed charging field trial. However the opportunity has also been taken to acquire some initial knowledge from the responses of EV “innovators”, those early-market consumer drivers who have already acquired a PiV themselves. It may be, for example, that BEV and PHEV users respond differently (given the different battery storage capacities of their vehicles, and their different degrees of dependency on electric charging) and such differences among PiV Innovators might be reflected in later differences among mass-market consumer drivers. Further, responses of those PiV Innovators who have only recently acquired a PiV may be more similar to those of mass market consumers, compared to the responses of PiV Innovators who acquired their EVs at an even earlier stage in the development of the market. Differences between very early innovators and more recent innovators may therefore be directionally indicative of the ways mass-market consumer drivers might respond. This type of information is potentially valuable in framing assumptions behind the modelling framework, and sensitivity analyses using it.

Accordingly, qualitative interviews with several groups of PiV Innovators were conducted to:

- inform understanding of consumers’ attitudes towards PiV uptake and managed charging; and
- contribute to the effective design of the Stage 2 managed charging field trial by providing consumer perspectives on managed charging.

A qualitative methodology was employed as interviews are ideally suited to experience-type research questions, including exploration of understanding, perceptions and constructions of things that people have a personal stake in (Braun and Clarke, 2013).

Interviews were also conducted with a comparison group who were not PiV Innovators, but had some direct experience of using a BEV, for instance as a participant in another PiV research project. These were assumed to be closer to the mass-market than the EV pioneer groups (though their experience may still indicate an above-average interest in EVs, perhaps putting the comparison group in the “early majority” of diffusion theory (Rogers, 2003)).

This chapter describes how the interviews were conducted and analysed (section 5.2) and the demographics of the 60 participants (section 5.3). Current charging routines described by the interviewees are discussed in section 5.4. Perceptions of PiVs are examined in sections 5.5, 5.6 and 5.7; section 5.8 describes whether interviewees intend to purchase another PiV. In section 5.9, the two charging options are discussed, including perceived advantages and disadvantages of each and overall preference for

either tariff. Questions posed by participants about the two tariffs are also presented. Section 5.10 contains case studies describing the experiences and attitudes of six interviewees. Finally, section 5.11 provides a summary and implications for the trial design.

5.2 Method

5.2.1 Sample

Sixty interviews were conducted with four groups of participants:

- 15 consumers who have owned or leased a BEV for 18 months or longer ('BEV18').
- 15 consumers who have owned or leased a BEV for six months or less ('BEV6').
- 15 consumers who have owned or leased a PHEV for any length of time ('PHEV').
- 15 non-EV owners who have had previous experience of driving and charging a PiV ('ICE'), e.g. as a participant in a previous PiV trial.

Participants were recruited via EV forums, Twitter and TRL's database of previous participants (to contact participants of previous PiV trials).

Interested individuals were asked to complete a short pre-registration survey to provide basic information on their experience with EVs (see Appendix B). Suitable candidates were invited by email to take part in an interview.

All participants were offered a £30 shopping voucher or equivalent charity donation in recognition of their contribution, and to facilitate recruitment.

Some participants owned more than one PiV; in this case they were asked about the vehicle that they personally used most frequently, but they were also able to offer insight into owning both a BEV and PHEV.

5.2.2 Topic guides

The topic guides were developed to address the research questions.

Two structured topic guides using open, non-leading questions (one for the three PiV pioneer groups and one for the ICE group) were developed to capture data in an objective, consistent and non-biased way. Interviewers probed particularly relevant or interesting topics that emerged when appropriate opportunities arose during the interview.

It was important to ensure that the topic guides were tested and refined. A pilot interview was conducted to ensure that interviewees understood the purpose of the interview, and the questions. Modifications were made to the topic guide where appropriate, based on the pilot interview.

5.2.3 Interviews

Participants were sent an information sheet to read in advance of the interview, which outlined the main features of BEVs and PHEVs, and described the time of use (ToU) and managed charging (MC) tariffs (see Appendix C). The tariff descriptions were developed specifically for use in this project and were deliberately high level to enable participants

to read them prior to interview. The tariff descriptions were developed specifically for use in this project and were intentionally generalised and high-level, as Construal Level Theory suggests that this is the most effective approach to communication with people who are psychologically distant from a concept. The descriptions were however informed from tariff outlines used in previous consumer engagement research (Fell et al., 2015). Participants were asked to have the information sheet with them during the interview to aid with the discussion of the charging options.

The qualitative data collection was undertaken by a team of experienced researchers, who were fully briefed to ensure that a consistent approach was applied to all of the interviews. Telephone interviews typically lasted around 45-60 minutes.

All interviews were recorded with participants' consent using Digital Voice Recorders. The interviews were transcribed verbatim into a Microsoft Word document.

5.2.4 Analysis

Transcribing the interviews provided a rich data source for a full thematic content analysis to identify themes emerging from the interviews (e.g. Braun & Clarke, 2013).

Two workshops were undertaken with all of the interviewees, during which a thematic structure was identified using the interview data. The content of these workshops was structured so that the interviewees consolidated the emerging themes and negotiated their boundaries and meanings. The first of these workshops was conducted approximately half way through the data collection period; the second was conducted towards the end of data collection. Interviewees also liaised with each other while the interviews were being undertaken to share emerging themes.

The interview data were entered into a framework in Microsoft Excel, to aid with organising the data according to the emerging themes. The themes identified are presented throughout this report and are accompanied by verbatim quotes from interview participants.

5.3 Participants

The participants were not intended to be representative of the PiV-owning population in the UK, as qualitative research does not seek to be statistically representative, but rather aims to reflect sufficient diversity to capture all the main themes. The sixty participants in this study represent a 'large scale' qualitative sample (Sandelowski, 1995).

As shown in Figure 25 and Figure 26, there was a range of ages and annual mileages included in the final sample. Appendix D presents further information relating to each participant, including the type of car they own, whether they also own an internal combustion engine (ICE) vehicle, the number of cars in their household, and whether they currently have a time of use tariff for their electricity. Some participants owned more than one PiV; in this case they were asked about the vehicle that they personally used most frequently, but they were also able to own insight into owning both a BEV and PHEV. In terms of length of vehicle ownership, some participants had owned more than one PiV. In this case, the total length of vehicle ownership was taken into account.

Participants tended to be male, with 10 female participants across all groups, as shown in Figure 23.

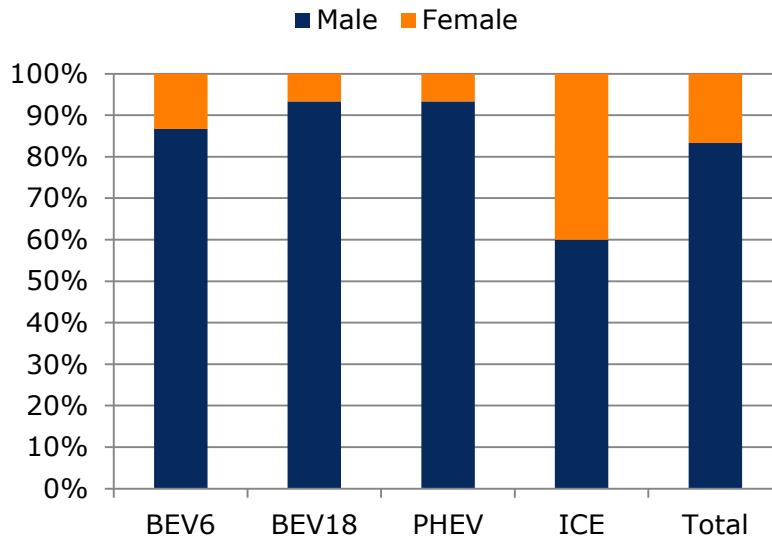


Figure 23: Participant gender

None of the participants were aged 25 or under, as shown in Figure 24; the group with the youngest demographic was BEV6, with nine of the 15 participants aged 45 or under. The PHEV group was the most likely to contain participants in the older age categories, with seven of the 15 participants aged 56 or older. Overall, the most common age category represented was 46-55, with just over a third of participants in this group.

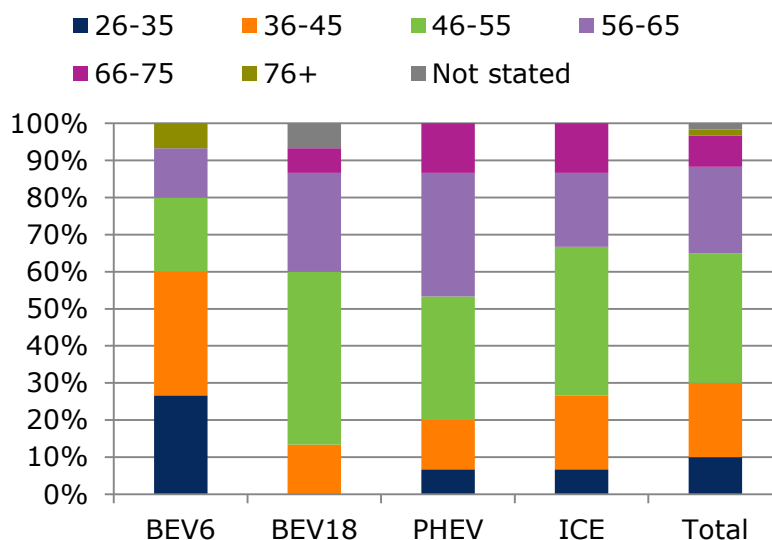


Figure 24: Participant age

The geographical location of participants is displayed in Figure 25, based on the postcodes provided in the registration survey (not all participants provided usable postcodes). There is a good geographical spread of participants. The ICE vehicle owners were drawn from participants of a previous TRL trial, therefore are clustered together.

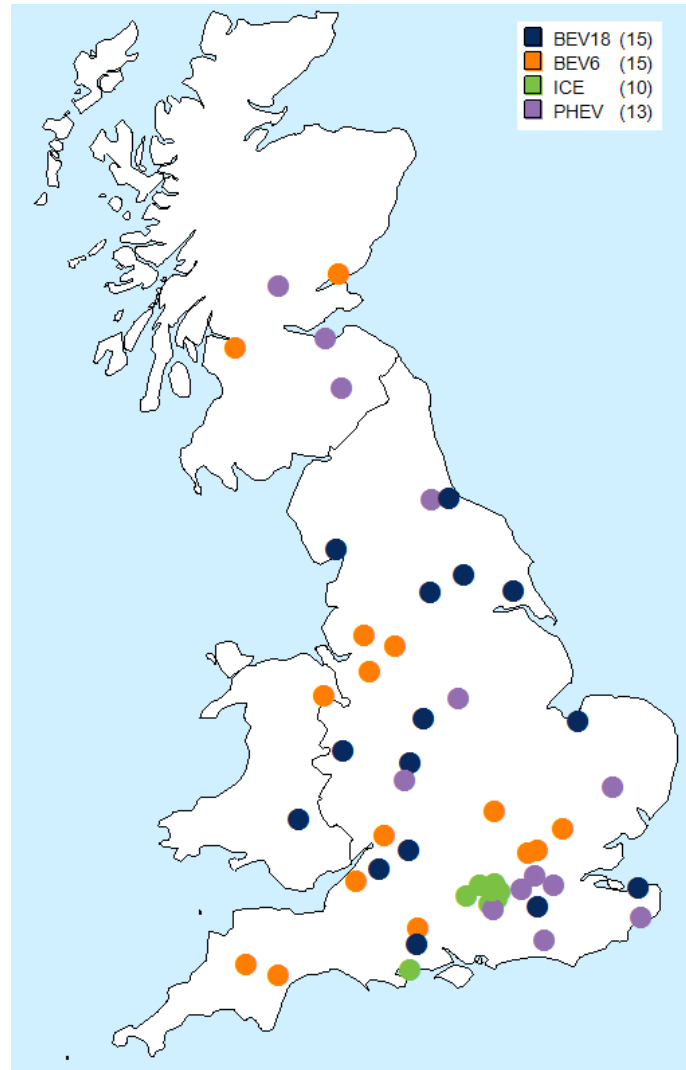


Figure 25: Location of participants

The annual mileage of participants was generally between 5,001 and 15,000 miles (45 out of 60 participants), as shown in Figure 26. The group with the most varied annual mileage was ICE vehicle owners, which was the only group containing participants in all mileage categories. Amongst the PiV Innovators, one BEV pioneer and two PHEV Innovators reported driving over 20,001 miles a year. Five BEV Innovators and two PHEV Innovators reported driving between 15,000 and 20,000 miles a year. The estimated average annual mileage in England in 2014 was 7,900²⁰, therefore the majority of the sample comprises of individuals with an above average mileage.

²⁰ https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/457752/nts2014-01.pdf

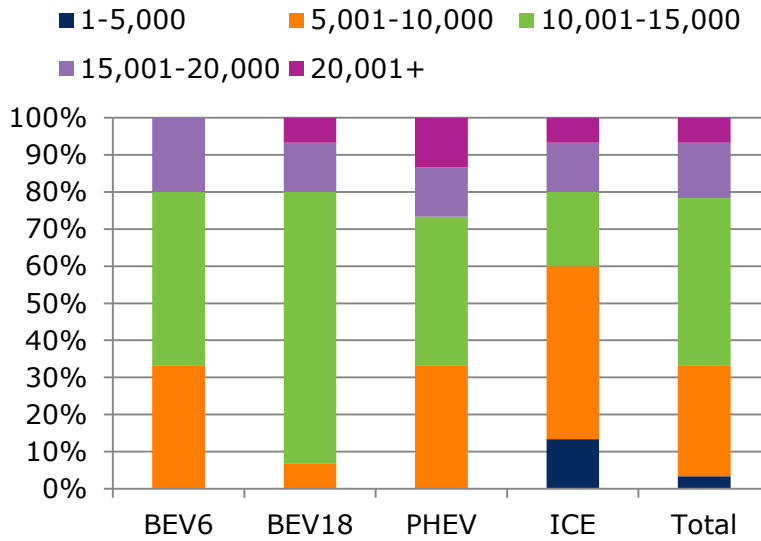


Figure 26: Participant annual mileage

The total number of household cars is shown in Figure 26. Over half of all participants had two household cars, and 49 of the 60 had two or more cars. Of the 15 BEV Innovators who had owned their BEV for 18 months or more, all had at least two household cars. However four of the more recent BEV Innovators reported that it was the only household car, along with five of the PHEV Innovators.

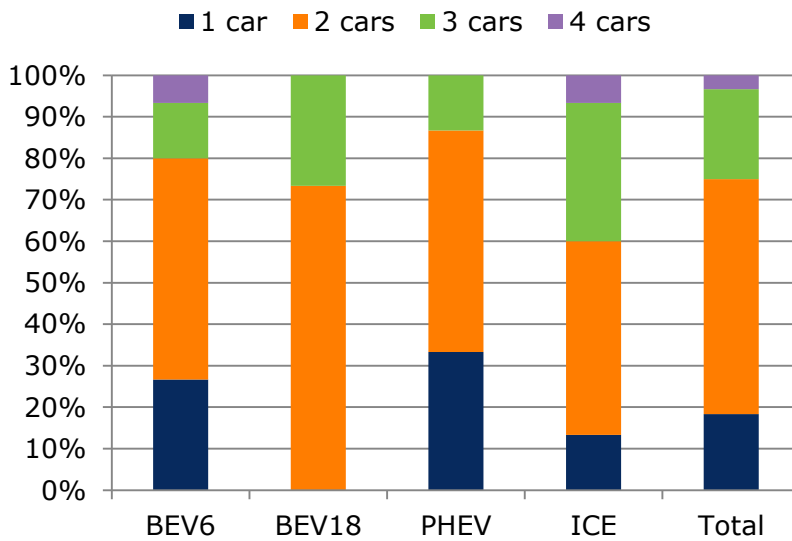


Figure 27: Number of household cars

Figure 28 shows whether participants reported that they also own an ICE vehicle. PHEV Innovators were least likely to also own an ICE vehicle.

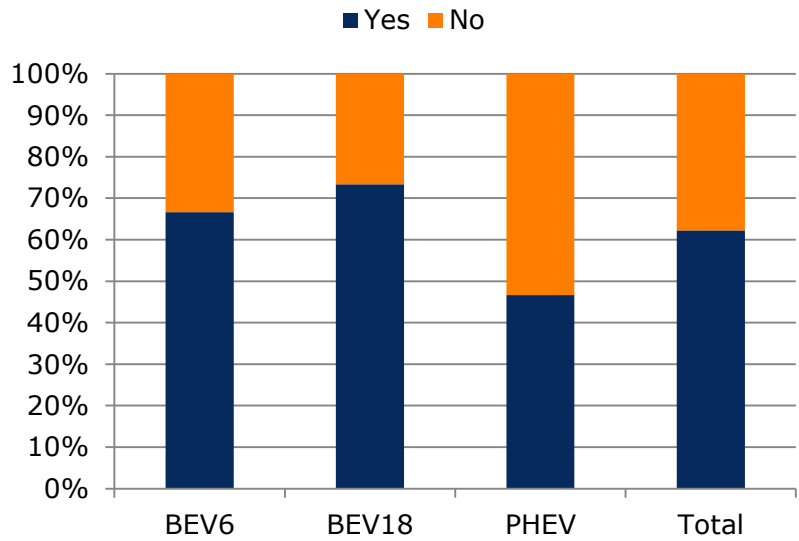


Figure 28: ICE vehicle ownership

Most participants did not currently have a time of use tariff, as shown in Figure 29. None of the ICE vehicle owner participants reported having a time of use tariff.

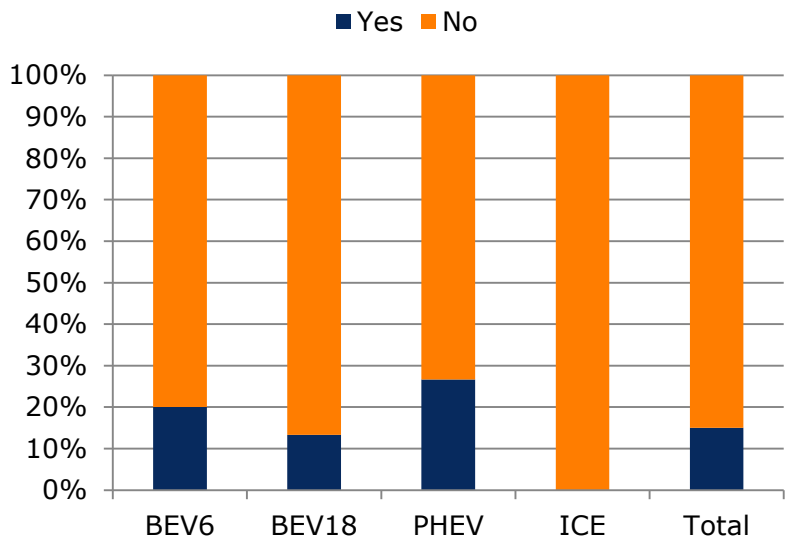


Figure 29: Time of use tariff

The type of residence of the participants is shown in Figure 30. The majority of participants in all vehicle groups have a detached house, particularly those who have owned a PiV for more than 18 months.

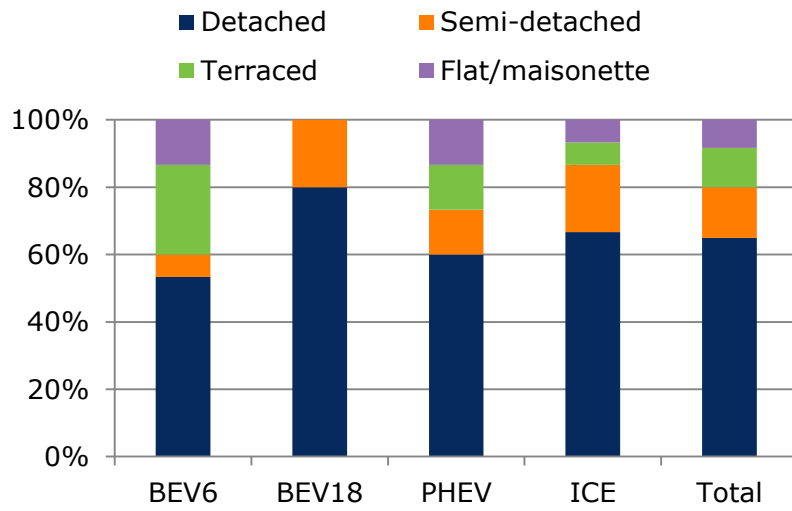


Figure 30: Residence type

No.	Group	Gender	Age group	Annual mileage	No.	Group	Gender	Age group	Annual mileage
1	BEV < 6 months	F	26-35	10,001-15,000	31	PHEV	F	56-65	10,001-15,000
2		F	36-45	10,001-15,000	32		M	46-55	5,001-10,000
3		M	36-45	10,001-15,000	33		M	46-55	10,001-15,000
4		M	46-55	15,001-20,000	34		M	56-65	10,001-15,000
5		M	56-65	10,001-15,000	35		M	56-65	20,001+
6		M	46-55	15,001-20,000	36		M	26-35	10,001-15,000
7		M	26-35	5,001-10,000	37		M	56-65	10,001-15,000
8		M	76-85	5,001-10,000	38		M	56-65	15,001-20,000
9		M	36-45	10,001-15,000	39		M	66-75	5,001-10,000
10		M	36-45	5,001-10,000	40		M	46-55	20,001+
11		M	26-35	5,001-10,000	41		M	46-55	5,001-10,000
12		M	46-55	10,001-15,000	42		M	36-45	10,001-15,000
13		M	26-35	10,001-15,000	43		M	46-55	15,001-20,000
14		M	56-65	15,001-20,000	44		M	36-45	5,001-10,000
15		M	36-45	5,001-10,000	45		M	66-75	5,001-10,000
16	BEV > 18 months	F	56-65	10,001-15,000	46	ICE Vehicle	F	46-55	10,001-15,000
17		M	*	10,001-15,000	47		F	46-55	5,001-10,000
18		M	46-55	10,001-15,000	48		F	46-55	5,001-10,000
19		M	46-55	10,001-15,000	49		F	46-55	15,001-20,000
20		M	46-55	10,001-15,000	50		F	36-45	10,001-15,000
21		M	66-75	10,001-15,000	51		F	36-45	1-5,000
22		M	56-65	10,001-15,000	52		M	46-55	20,001+
23		M	36-45	15,001-20,000	53		M	66-75	5,001-10,000
24		M	36-45	10,001-15,000	54		M	26-35	5,001-10,000
25		M	46-55	15,001-20,000	55		M	56-65	5,001-10,000
26		M	46-55	20,001+	56		M	66-75	1-5,000
27		M	56-65	10,001-15,000	57		M	56-65	5,001-10,000
28		M	46-55	10,001-15,000	58		M	56-65	10,001-15,000
29		M	46-55	5,001-10,000	59		M	46-55	5,001-10,000
30		M	56-65	10,001-15,000	60		M	36-45	15,001-20,000

* Participant did not provide their age

Figure 31: Summary participant demographics

5.4 Current charging routines

In this section, the current charging routines of participants are discussed. These can be summarised as follows:

- Charging typically takes place at home
- Routine charging is common, with many reporting a preference to keep the battery fully charged whenever possible
- Solar panel ownership is common amongst those who had owned a PiV for at least 18 months; those with solar panels prefer to charge their PiV when the panels are generating electricity
- Few participants currently had time of use tariffs, such as Economy 7, but where they did charging was often controlled using socket timers or apps to maximise charging at the lower rate.
- Timers and apps are used to charge when grid demand is lower and/or to take advantage of cheaper electricity
- Some participants had comprehensive knowledge of their electricity usage and cost, others had little awareness

5.4.1 Charging location

Amongst the participants, charging typically took place at their home. However, not all participants were able to do this. One participant was completely reliant on public charging infrastructure and charging at work:

At the moment I stay in a flat, so I'm reliant on a public charging point. I'm very lucky that our local infrastructure is excellent, and I charge at work, so it's not been a problem. (P1, BEV6)

A number of participants stated that they charge their car at work as well as at their home, and in some cases rarely charged at home.

I charge in the office, I just leave it plugged in charge to 100%, drive home. I could get back to the office the next day without needing to charge at home. (P6, BEV6)

When I told my boss that I was getting a plug in hybrid car he kindly agreed to install a charge station in the office for me. So I'm able to charge at work. (P36, PHEV)

However, charging at work could be unreliable, as could using public charging points (also see section 5.5.2.2).

At home, easy. Plug it in, it just charges, that is great. At work, frustrating. We have moved to a new office where the charge posts are...completely unreliable. We have four charging points. If more than two are working, it is a bonanza day. (P6, BEV6)

Others went out of their way to use public charge points; one participant described spending over an hour per week travelling to public charge points, but expected that in the future this situation would improve.

Public charging probably costs me about an hour and a half a week. Purely because of the detour I have to make because it's not available at my destination. That's obviously due to lack of infrastructure at the moment, but hopefully that will be coming...I accept it at the moment because I'm an early adopter. (P10, BEV6)

5.4.2 Routine

Some participants described a strict charging routine, which in a few cases resulted in the car owner going out of their way to charge at public charge points.

A total routine for charging the car...it's a case of 12 o'clock lunch time comes, into the car, drive around to the charging point, out with the bike, cycle back to work, have my lunch, back to work. And then four o'clock comes, cycle back to collect the car and then head home. (P35, PHEV)

We've just got into the habit now, it doesn't matter how far we've driven, every time it's put on the drive we plug it in, and we're used to the car having 100 mile range every time we get in it. (P26, BEV18)

I have a set routine which is just to drive into work, plug it in, drive home and I tend not to really use the fast charger at home unless I really need it...typically it's just sort of an automatic reaction now, just get out of the car in the morning, plug it in and by the time I go home it's fully charged again...I really do the same thing day in day out, it is very much a routine. (P11, BEV6)

However, in other cases, participants stated that they do not have a routine, and will charge their PiV when it is convenient or necessary to do so (or in the case of those with solar panels, when the sun is out; see section 5.4.1).

I don't really [have a routine] because it depends on how and what the car's been doing on previous days. Temperature obviously has a big impact on the roads, so when it was really cold two weeks ago I probably charged it I think three times during the week. This week I'll probably just charge it twice. (P10, BEV6)

At home I'm more likely to charge if I need it. At work I'm more likely to charge if it's worth it. If that makes any sense. When I'm at home I tend to plug it in and charge if I'm 25 percent charge. I suppose at work I might plug it in if there's 75 percent remaining, I may as well just top it up. (P36, PHEV)

5.4.2.1 'Just in case' charging

For some ICE vehicle owners with experience of a BEV, there was the expectation that, if they owned a BEV, they would keep the battery topped up regardless of their planned journeys. Others reported that they did this during their BEV trial, but would expect to become less anxious over time. Amongst current PiV Innovators, there was also some desire to keep the battery topped up whenever possible.

My view is that I'd probably be overcautious and make sure it was always topped up. (P50, ICE)

We used to charge it every night. Just in case. (P49, ICE)

Every time I came home [I would charge the BEV], so I didn't leave it sort of half, a third charge and then go out again, I always made sure I had enough. I think if

you had the car for longer you would be more relaxed about it and you would know it would be fine to pop to wherever. (P47, ICE)

We actually tend to just recharge all the time, leave it plugged in all the time...the routine is basically whenever we get out of the car you plug it in. (P43, PHEV)

I tend to keep it topped up. So the analogy that somebody gave me, and I use, is treat it more like a mobile phone than like a car. So with a petrol or diesel car you would basically let it run near empty and then fill it up, with an electric car if you see charging, use it. Plug in, charge up...anywhere below 70% of battery and there is a charger free, I will plug in. (P6, BEV6)

5.4.2.2 *Desire not to charge to 100%*

However, at the other end of the spectrum, some participants described that they would avoid topping up the battery to 100%, due to a belief that this may damage the battery.

It's not particularly good to have a car that's permanently filled up to 100%...the manufacturers say keeping it somewhere between 20 and 80% is quite adequate. (P21, BEV18)

I could just plug it in every night, but I don't like the idea of actually, maybe you come back and you've only used 25% charge – I don't think it's appropriate to recharge the vehicle from that stage, because there are some impacts upon the battery. (P22, BEV18)

Another participant explained that they prefer to completely discharge the battery before charging, when possible.

What I try and do is I look at all that we have got on for the next day, and if I think there is enough left in it to do that on electric then I will try and discharge the battery completely. (P39, PHEV)

5.4.3 *Solar panels*

A number of participants who own PiVs have solar panels at home, and stated that they will charge their vehicle when the panels are generating energy to take advantage of the 'free electricity'. Solar panel ownership was more frequently reported amongst those in the BEV18 group (ten of the 15 participants) than the BE6, PHEV or ICE groups (three, five and two participants respectively).

If it's a sunny day, I'll try and do it during the day so that I'm using solar cells. (P27, BEV18)

I've also got solar panels, so during the day I'm not even paying to charge it up. (P40, PHEV)

In some cases the use of solar panels was motivated by monetary savings, while for others the environmental benefits were the key motivation.

I charge it using solar energy during the day time, so it's free driving for me pretty much. (P28, BEV18)

I've not done it for financial gain in truth, I've done it because I just like the idea of getting electric from the sun. (P10, BEV6)

Some participants described altering their routine to enable them to charge the car from the solar panels, while others did not.

If I need to charge it in the middle of the day, which we will be doing when it's sunny, because all the power from the solar panels will go straight into the car then. (P3, BEV6)

I had solar panels installed in September, so my plan is, once we start getting longer days and more sunlight, my plan is to occasionally cycle to work and plug in the car and charge off the solar panels during the day. (P41, PHEV)

We just charge it up as and when. We don't really plan charging the car to coincide with the solar...I don't not charge it overnight because I've got solar. (P12, BEV6)

In some cases, the participants had solar panels prior to considering purchasing a PiV. For others, owning a PiV and installing solar panels went hand in hand.

No, we got them first...it is part of a general desire to try and reduce our carbon footprint – we insulated the house very well first, and so on, and then we got the PV panels. (P21, BEV18)

If I didn't have an electric car, I'd probably still have the solar panels. (P35, PHEV)

[At] the same time as we got the car we decided we were going to get solar PV, so I've had solar installed at the same time as well. (P12, BEV6)

I purchased some solar panels for my house and as I was reading about them it led me into electric vehicles, and how you could charge them off of the solar panels, which made me then start researching what was available. (P24, BEV18)

One participant expected that there would be a correlation between PiV ownership and solar panel ownership:

There will be a higher proportion of people that have got electric vehicles or plug in hybrids, that will be inclined – the propensity to have solar panels will be higher than the general public, won't it? (P41, PHEV)

The use of apps alongside solar panels was discussed, both in terms of current available apps for use alongside the solar panels, and future apps; in particular, a desire was expressed for an app to be made available which would begin charging the PiV once enough energy to do so was available through the solar panels.

She [the participant's wife] would wait until the skies have brightened up, she would then look at her phone, another app for the solar panels, once they are producing a better amount of power she will plug the car in...it is costing you less and it is also saving the environment. (P32, PHEV)

I think you'll find that there're certainly people who...have the same concern as I have, which is, they would like a smart controller to actually charge the car when the solar was generating, because then they can get it for free, and from a renewable source. (P16, BEV18)

Participants who used solar panels were not always certain of the proportion of their electricity bill that was attributable to charging their vehicle.

Well, it's hard to say whether it [having solar panels] actually affects our bill, but we get the feed in tariff, which is probably about £700 a year, so not far short of what we actually spend. (P19, BEV18)

I'll have to go and find out. The trouble is, it doesn't reflect how much we use, because the solar, we use quite a lot of the solar. (P16, BEV18)

I know it [the proportion of electricity used to charge the PiV] is 18% because our electric costs have risen by 18%. Maybe even slightly higher because the solar panels have got a contributing factor there. (P32, PHEV)

5.4.4 Time of use tariffs

Most participants did not have a time of use tariff (according to the registration survey responses, nine participants had a time of use tariff; all were BEV or PHEV Innovators). Some stated that they were aware of or had considered a time of use tariff, but had decided it was not suitable for their needs, or that they tried to use electricity at off-peak times despite not benefitting financially.

[Do you have a time of use tariff for your electricity supply at home?] I don't, no, my supplier doesn't offer it. [If they did, would you be tempted do you think?] No. Again going back to my sort of slightly unusual charging profile, I don't necessarily charge at night...yes it might make me charge at night, but I am not doing that much. (P6, BEV6)

I'm not on any sort of split rate tariff. When I'm at home, it's easy enough for me to look, to walk out late in the evening and think, right, the peak demand of the evening has now gone, I'll just go in and plug the car in now. (P22, BEV18)

Some participants described that they do currently have a time of use tariff, which can be used alongside a timer to make use of the lower rates.

I charge it overnight because we have Economy 7 in the property...normally if I didn't think that I would need to use it again later on in the day I would just wait until the night time top up. (P34, PHEV)

We have Economy 7, so we specifically put in Economy 7 to do that, and we're on such a low night rate that it's literally about 80p if we fully charged either car. (P20, BEV18)

I've got it set on a timer. The car can actually...you can set a time from the time the car starts to charge, and I have it set to use off-peak electricity and be charged just before departing in the morning. (P35, PHEV)

I'm on quite good rates, and now that I've got solar panels, I think I did right to stay on Economy 7 because hopefully, especially as the days get longer and brighter, I'll be using even less electricity during the day. (P41, PHEV)

5.4.5 Use of timers and apps

The use of technology such as timers and apps to control PiV charging was described. In some cases, this was motivated by a desire to charge the vehicle while electricity demand was lower, and while energy production may be cleaner:

The car rather nicely has a timer built in...the charger will switch on at 2am, and will then take as long as it takes, as I say, anything from two to four hours to

charge it back up, and then it will switch off. The timer's set to switch off at six. [What's your motivation for charging it at 2am?] Purely because I understand it's better for the grid. I don't have Economy 7, I don't have any financial incentive for charging overnight, but I just feel it is more convenient for the electric grid, for the planet in general. I think that there's fewer coal fired stations working at that time in the morning as well, so the electricity I'd be getting would be a bit cleaner. (P5, BEV6)

A timer is set, so it's charged by the time we leave, so it uses the base load electricity, generally...so I say I want it to be charged by, say, 7am or 8am, it's generally charged by roughly an hour before that. (P18, BEV18)

In other cases, it was motivated by a desire to minimise charging costs:

The car itself has got timers in it so it decides when to top itself up, so I set that during the Economy 7 period. (P34, PHEV)

Currently I'm actually using the off-peak system, because I'm telling it to charge it for 4.45 in the morning, so it's actually using the off-peak part of the meter. (P14, BEV6)

However, some participants indicated that they do not use timers and, in one case, deliberately avoided a time of use tariff, because they prefer the simplicity of knowing that when the car is plugged in, it is charging.

I haven't yet used a charge timer, mainly because I'm not on any sort of split rate tariff. When I'm at home, it's easy enough for me to look, to walk out late in the evening and think, right, the peak demand of the evening has now gone, I'll just go in and plug the car in now. That's not an issue for me. (P22, BEV18)

I never use it for the charge timer. If I want to charge it, I'll plug it in. If I bring it home and I plug it in, I expect it to charge, which is another reason why I didn't actually go for an Economy 7, overnight type tariff. If I want it charged up...if it's plugged in, I expect it to be charged up. (P38, PHEV)

5.4.6 Knowledge of electricity costs

Some participants were not aware of how much they pay per month for their household electricity or to charge their car:

No, not off the top of my head. I think I pay something like one monthly fee, I can't remember what the tariff is...I just pay a certain amount every month, so I've just been paying that and I've not even looked at it. (P46, ICE)

[The cost of charging the car] is something I don't track. (P44, PHEV)

I would probably guess my electricity bill is about £150 a month. I would reckon that the car has probably...probably, I don't know, maybe a tenner...I've got no real idea. It's so insignificant I don't really think about it to be honest. (P28, BEV18)

I haven't estimated it because for me it's not a factor. (P27, BEV18)

Others were able to state the precise amount, and also to define what proportion of that went towards charging their car. Twenty participants had solar panels, which made it more difficult for them to state their electricity bill, as described in section 5.4.1.

I'm giving them about £60 a month...until we got the car, we were around 1,800 units per year, and the car's taken it up to 3,600, and it will possibly be higher this year. (P21, BEV18)

I would say probably only about 5% [of electricity is used to charge the car] at the moment. I think that's primarily because I don't charge it all that much at home...per year it's about £550. (P11, BEV6)

5.4.7 Energy suppliers

The selection of energy suppliers was discussed with some participants, with ethical considerations guiding the choice for a number of PiV Innovators, in particular BEV Innovators more so than PHEV Innovators.

We pay a premium to get green energy, so the whole thing is about zero emissions for me more than the cost. (P17, BEV18)

I changed to Ecotricity not long after I moved into this flat, so a couple of years ago. I changed to them because of their green policies. (P1, BEV6)

It was mainly because Ecotricity was a green supplier really. (P28, BEV18)

We are, by choice, with Good Energy, because they provide 100% green electricity, which is generated in the UK. (P14, BEV6)

They are effectively running the electric highway for free, they're not charging electric vehicle owners, and I think that's absolutely utterly fantastic, and I wanted to support them in that. (P20, BEV18)

Similarly to solar panels (see section 5.4.1), some had chosen a 'green' energy supplier prior to owning a PiV, while other switched energy supplier because of purchasing a PiV.

Before I even knew I had an electric car, I had, for a period of probably about three or four years, been with green energy suppliers anyway. (P22, BEV18)

For environmental reasons...I switched, about a year before getting the car. I chose Ecotricity...because I was preparing to get an electric vehicle, and I thought to myself, well, Ecotricity have gone out there and they've created this infrastructure, so I should support them. (P5, BEV6)

[How much did owning an electric car influence that decision?] Greatly, because I'd changed from one of the big six to Ecotricity...All their energy is derived from renewable sources. (P10, BEV6)

5.5 Perceptions of PiVs

5.5.1 Advantages of PiVs

Advantages which can apply both BEVs and PHEVs are described in this section. These can be summarised as follows:

- PiVs have financial benefits including reduced running costs and tax benefits. These were mentioned by the vast majority of participants.
- PiVs remove or reduce the need to visit petrol stations.

- PiVs are pleasant to drive, often exceeding expectations.
- PiVs have environmental benefits. This can be a deciding factor in PiV purchase, or a pleasant consequence of PiV ownership.

5.5.1.1 'A lot cheaper'

A key advantage of both BEVs and PHEVs that was reported amongst participants in all groups was the financial benefits. These benefits can be associated with running costs, fuel costs, tax, congestion charge and maintenance.

Many participants referred to the fact that overall running costs are lower.

It feels like it's almost once you've sort of made that investment and got the car it feels like it pretty much doesn't cost much to use on a day to day basis. (P11, BEV6)

Hopefully it [a BEV] would be cheaper to run in the long run, particularly if you've got solar power. (P48, ICE)

I save a fortune – I think I've had it 18 months, and I'd estimate I've probably saved a few grand in petrol in that time. (P41, PHEV)

The electric consumption bill has gone up 18%, but I'm only on my fourth tank of petrol. So in real terms I am saving considerable sums of money. (P32, PHEV)

In many cases the reduced running costs would be an important factor in deciding to purchase a PiV, but for some PHEV Innovators it was an unexpected benefit, or was not an important consideration.

I didn't realise the savings I'd make, but it's certainly saving me a lot of money in running costs as well, refuelling and everything else. It's certainly a lot cheaper that way as well. (P42, PHEV)

When it comes to what you call the running costs of the vehicle, I consider it to be effectively neutral. It's not costing me any more to run this vehicle than it would to drive a more conventional vehicle. But it does come with the advantages of being electric. (P36, PHEV)

Other specific aspects of the running costs mentioned by participants included:

- Tax savings: this appeared to be a greater consideration amongst PHEV Innovators, but was also mentioned by a few BEV Innovators. These related to both Vehicle Excise Duty, and – more commonly – to company car tax.

The saving on the fact that the vehicle excise duty is zero. (P8, BEV6)

To be honest with you, it was the tax benefits were the main reason, the savings and benefit in kind were a big driver for it. (P42, PHEV)

I got it through our company car scheme...when I looked at the costs, it was just really significantly cheaper, and as my commute to and from work is not something I can claim back from the company, something I have to pay out my pocket, the fuel cost savings are just huge. (P23, BEV18)

It's a company car so we have the tax incentives...it's a leased car, so we get the tax incentives from the monthly lease payments. There is also the benefit in kind incentives as driving it as a company car. (P31, PHEV)

- Fuel savings: this was a key factor for both BEV and PHEV Innovators, including those who are able to 'refuel' using solar panels.

A lot cheaper than running a petrol or diesel car. (P55, ICE)

Fuel costs are obviously minimal, even though petrol and diesel has almost halved in price since I bought it, it's still nearly half the cost to fuel up with electricity than fuel up with diesel. (BH, BEV18)

When I'm charging on solar panels at home, pretty much free mileage. (P40, PHEV)

- The city congestion charge exemption: this was a driving factor for one BEV pioneer, and was recognised as a benefit by a couple of other PiV Innovators.

It was really just getting a vehicle that was going to be congestion charge exempt. That was really the main reason, it wasn't really the cost of running that was the main reason for going for it, it was something that was congestion charge exempt primarily. (P11, BEV6)

If I lived or worked in London as I did when I was working, and the congestion charge was there, that would be another big bonus. (P39, PHEV)

- Maintenance costs: these were considered to be lower than for ICE vehicles or PHEVs by some BEV Innovators, whilst one PHEV pioneer felt that there was no reduction in servicing costs for a PHEV compared to an equivalent ICE vehicle.

At the moment, it's much cheaper to run than an internal combustion engine because the servicing is less. (P5, BEV6)

It's much better technology; there's virtually no servicing to be done on it. (P27, BEV18)

I'll bet you the costs [for a PHEV] of servicing are greater, because there's a lot of extra stuff involved in it. (P21, BEV18)

I wouldn't quite say reduced servicing costs because ours was the same servicing costs as all the other Golfs. (P32, PHEV)

5.5.1.2 'A fuel station at home'

A few participants mentioned that they valued not needing to visit a petrol station to fill up their vehicle with petrol or diesel.

You don't have to go to a petrol station and queue and go and fill up when you're out and about, you can just do it at home. (P51, ICE)

The fact you don't have to go to the garage to fill it up, so again, living in a rural location, our nearest fuel station is about five miles away, and not en route to where we're normally going. So, it's a special trip, just go and fill a car up with fuel, and it's nice not having to do that. (P16, BEV18)

Based on the way the vehicle is used, we're not filling up or putting petrol in the car for on average about four months at a time...I hate going to the petrol station

and wasting ten minutes of my life...it's nice to move to an environment where you don't have to do that so often. (P44, PHEV)

I know I'm going to, straight away just by plugging it in overnight, get an extra 40 miles, and you do that every day. So, in a way, you've almost got a fuel station at home. (P41, PHEV)

5.5.1.3 'Really like the way it drives'

The performance of BEVs and PHEVs was largely described in positive terms, particularly in relation to the vehicles' quietness and responsiveness which tended to exceed expectations amongst the ICE group.

It was quite responsive, much more responsive than I would've expected from an electric car; very comfortable, had quite a few nice features. (P48, ICE)

It's very quiet. So it's a very peaceful, relaxing drive. You don't have the roar of the engine. (P55, ICE)

The electric vehicle has one compromise, range – everything else, the car drives better, it's smoother, it's more engaging, it's got more power at low speeds, it really pulls well at low speeds; you're not having to fight a gearbox all the time. It just is much easier to drive, much more relaxing to drive than a conventional car. (P5, BEV6)

The concept and the response of the car, there is no delay between switching from electricity to fuel. It's instant and the power is there as well when you need it. (P37, PHEV)

5.5.1.4 'Better for the environment'

Another key advantage reported by BEV and PHEV users is the environmental benefit of using PiVs instead of an ICE vehicle, in terms of emissions and using renewable energy. For some, this was a deciding factor in purchasing the vehicle, while for others it is a positive by-product of owning a PiV.

I've always been very environmentally aware, so that was a big consideration as well. (P10, BEV6)

It's better for the environment, particularly the local environment, no emissions as you're driving into the city centre, busy places like that. (P41, PHEV)

If you're just putting dinosaur juice in your car, there is no option to run it from a renewable source. So that means the uptake of electrical vehicles has effectively the ability to use those renewable sources. (P36, PHEV)

Low impact on the immediate environment in terms of noise. (P60, ICE)

People say they bought it to be green, I guess, in our case, it's nice, but it wasn't an overriding factor us...it was more to do with cost and having something a bit different. (P20, BEV18)

Whilst the green element of all of this is all well and good I wouldn't say that it was the driving motivator from my perspective. (P44, PHEV)

5.5.1.5 'It changes the way that you drive'

Participants reported that driving a PiV had changed their driving style and behaviour so that they maximise the efficiency of their vehicle.

You anticipate what's ahead far more because you're constantly aware that you need to regenerate the battery if you're going to come on to a junction...you drive a lot more smoothly when you've got this. (P10, BEV6)

If you drive smoothly, you find that you get regeneration on the battery anyway. It's quite remarkable, so I think it changes the way that you drive, the way that you think about driving. (P8, BEV6)

You tend to find now that you have got something that is giving you great economy, you are always trying to get that goal of getting that bit more economy out of it. So you are changing your driving standards. (P32, PHEV)

5.5.1.6 'Getting into a warm vehicle'

Another advantage of both BEVs and PHEVs mentioned by a couple of participants was the ability to pre-warm the vehicle prior to getting in.

If it's cold which it has been I can programme the car to heat up when we actually get into the car, so I can programme it half an hour beforehand before I'm getting ready to leave rather than getting into a cold car. (P2, BEV6)

I pre-heat the car so the car is warmed up beautifully when you go into it. (P35, PHEV)

Certain features of an electric car that an internal combustion engine car doesn't have, such as, when it is winter, the ability to, on a cold morning, just get the car to heat itself up, so you're getting into a warm vehicle. (P41, PHEV)

5.5.2 Disadvantages of PiVs

A number of disadvantages of both PHEVs and BEVs were also reported. The key reported disadvantages are summarised below.

Section summary

- Unreliable electric range as displayed on the dashboard.
- Poor public charging infrastructure, in terms of availability and reliability.
- Inconvenience of plugging vehicles in to charge.
- Uncertainty about the long term future of PiVs.
- High initial purchase cost and uncertainty over residual value.

5.5.2.1 'I find the range calculations quite strange'

The electric range of PiVs was reported to be unreliable, both in terms of the range advertised by the manufacturers, and the range displayed in the vehicle. This may contribute to range anxiety amongst BEV Innovators. Unreliability extended to fuel consumption figures for PHEVs.

I don't think you're ever getting the battery life that it says. (P46, ICE)

I find the range calculations of the Outlander quite strange. I think it tries to second guess too much...I would almost describe it as not giving me a straight answer. (P39, PHEV)

It's got a range of 26 miles on the battery, and then once you go any further than that, the miles per gallon, the manufacturer is claiming 144 miles per gallon; you're really pushed to get 40...I was warned by the salesman at the garages, actually. (P40, PHEV)

I don't think you get anything like the miles per gallon that they really say, especially if it won't run on electric. (P33, PHEV)

You don't really get the official range that the official figures state. (P36, PHEV)

The range variations between summer and winter driving were also reported to be an issue.

In the winter, when it's using the petrol engine more, it [fuel consumption] is probably worse than you'd get if you were running the equivalent diesel car. (P33, PHEV)

When it gets cold, during the middle of the winter, the battery doesn't hold quite as much charge, or it doesn't seem to. (P43, PHEV)

It does vary, winter to summer. Summertime, it's maximum of about 90 miles, but you get uncomfortable around about the 75 to 90 miles. In the winter, that can drop as low as about 50 miles. (P30, BEV18)

Related to the range issue is the issue of charging using public infrastructure (see section 5.5.2.1). This issue will generally affect BEV Innovators more than PHEV Innovators.

5.5.2.2 *'The infrastructure needs to become more reliable'*

Most accounts from BEV and PHEV Innovators of using public infrastructure were negative. Issues included experience of charging points being unreliable or permanently broken.

You go to the chargers and they're decommissioned, they're just not working. I don't know whether it's a permanent fault. But in the last two times I've been there they've not been working. (P44, PHEV)

I don't risk going to places that I don't know beyond its range. Probably a crucial thing really, I do find it frightening going to charging points. I find they don't work. (P28, BEV18)

If we are doing a long distance theoretically I could use the Leaf, but most of the time we will simply just take my wife's car, because you just can't rely on the charging infrastructure, which is very disappointing. (P6, BEV6)

I was checking on the internet last weekend for a trip to the Lake District, and ended up having to take the Toyota, because on that route, all three of the available chargers were broken, and they weren't anticipating repairs until Monday. (P26, BEV18)

Another commonly-reported issue was that of ICE vehicles parking in charging bays.

It's the abuse of the charging spots by cars that are petrol and diesel that are constantly parking in these bays...there's no governance in place in the public areas around people who abuse these spaces. (P44, PHEV)

Somebody had parked a car, a four-wheeled drive, in the electric bay. I lifted the bonnet up and thought this car isn't a plug in at all. (P29, BEV18)

You get a lot of people who just park in them, because they think they're parking spaces, so you turn up and it's really annoying when it's a non-electric car, that's just nicked the electric parking space. (P26, BEV18)

As uptake of PiVs increases, PiV Innovators may need to wait to use chargers.

As they get more popular, the charging facilities are becoming busier as well, so again, you have to be prepared that your journey may take longer than you're expecting. (P23, BEV18)

Recently, occasionally I have pulled up and had to wait for someone to finish using it. (P19, BEV18)

There is an issue now of demand; a number of these chargers are very much in demand, and I have had experience of going to Newcastle and not being able to find an available charger. (P22, BEV18)

A lack of local infrastructure was reported by some participants, and this may be a deterring factor in PiV uptake, or may encourage people to use their ICE vehicle instead of their BEV.

There are certain areas of East Yorkshire, say, the coast, where we can't go, because there isn't a charging infrastructure. (P20, BEV18)

One of the reasons why I actually didn't go any further with the electric vehicle that I was looking at, although it had a range of, effectively, 250 miles²¹, I was looking at an area of the country where we normally go on holiday that had no fast charging facilities whatsoever, and a full charge, to be able to do a day's driving, would actually be ten to 12 hours, off a normal household supply, or longer. So, at the moment, that just doesn't add up. (P38, PHEV)

So, the infrastructure needs to become more reliable, and it needs to be much, much bigger, I think, before I'll be using it [in my BEV rather than using my ICE vehicle]. (P18, BEV18)

The varying charging networks were also a point of dissatisfaction amongst PiV Innovators.

There are so many different networks operating with so many different tariffs and so many different charging structures and so many different owners that the government has made a right hash of this. They've allowed it to be a completely unregulated, free market. (P36, PHEV)

I've got many cards for many different charging networks, many apps, and perhaps one of the problems is, there's no joined up infrastructure today. (P23, BEV18)

²¹ The vehicle under discussion was a Tesla Model S, which has a greater range than other BEVs, but at a greater capital cost.

I occasionally use charge points... of course, then you have to carry lots of different cards, and belong to half a dozen different schemes, which is really tedious. (P16, BEV18)

I would sooner use the petrol alternative, rather than having to mess about and pay a subscription for a card to give me access to charging points. (P39, PHEV)

A few participants did not have any experience of using public infrastructure:

Well to date I actually haven't used one of them. (P11, BEV6)

I haven't charged it in any public chargers yet. I've only ever used my own one. (P31, PHEV)

One participant explained that the state of the current charging infrastructure was a key obstruction to buying a BEV, and another explained that it was preventing him from encouraging others to adopt a PiV.

I went for the plug-in hybrid because I didn't like the idea of range anxiety, as it is termed...you have always got that feeling of what if I can't find somewhere to charge. So from that point of view I don't think I would ever, unless the infrastructure got much better, go for a purely electric car. (P39, PHEV)

I think the biggest reason I wouldn't be going round everyone I know saying you should get one of these things immediately is the state of public charging. (P4, BEV6)

A desire was expressed for improvements to the infrastructure in order to increase uptake of PiVs.

It does need an investment by somebody into better public infrastructure for rapid charging. (P22, BEV18)

Unless people see the infrastructure around them they're not going to do it. (P20, BEV18)

I think that the current infrastructure, the way it's been rolled out and the way it's ad hoc, it's just not very good. I'd like to see the government get behind something much bigger, and I think that will hold back battery electric vehicles for a while, until the infrastructure is sorted out properly. Yes, I think it's a bit of an Achilles heel for battery electric vehicles at the moment. (P18, BEV18)

5.5.2.3 'The plug-in side of it is a pain'

The act of physically plugging in a PiV was considered to be an inconvenience by a couple of ICE vehicle owners:

It'd be fine for me, but I think a lot of people would find it a bore to have to plug it in. (P57, ICE)

The plug-in side of it is a pain. I think that process is annoying. Whereas you can just park up an ordinary petrol or diesel car and go away, this time you've got to get the plug out and so on. (P55, ICE)

It was also acknowledged to be a slight inconvenience by a couple of PHEV Innovators, but the benefits were perceived as outweighing this, and some PiV Innovators do not consider it to be an inconvenience at all.

Having to charge it every day when you get in from work. I know you have to fill a petrol car but it lasts for at least a week even if it's a cold, rainy day yes you've got five minutes out filling the car up, but to come in every day open the garage door, get the plug thing out and do it all, it's just a nuisance. (P47, ICE)

There is the inconvenience of having to plug it in. The cable is quite chunky, it takes a little concentration on rolling it up...but that is just a minor...it is no inconvenience for what it gives you back in bonuses. (P39, PHEV)

It is more hassle, in fairness, because you're having to charge and do things like that. There's a bit of hassle, but probably the savings outweigh the hassle. (P42, PHEV)

It takes me two minutes to do, I don't find it an inconvenience. (P1, BEV6)

You pull a lead out the front, and stick it in. It's like charging a mobile phone, so no, it's not something to think about at all. (P16, BEV18)

5.5.2.4 'I'm not convinced at the moment'

Particularly amongst the ICE vehicle and PHEV Innovators, there was concern about the technology and longevity of PiVs and battery technology. PiVs are still considered by many to be a 'new' concept, leading to anxiety over what the future holds for those who adopt PiVs now.

My personal opinion at the moment is, it's very new technology, so long term reliability. And, the potential cost of replacing the fuel cell, so how long is that car going to last me? Is it going to last me ten or 15 years like a reliable petrol or diesel car might do? They'd be my main concerns. (P54, ICE)

Long term reliability as well. We don't know what they're going to be like 10 years down the line. (P60, ICE)

Unless it's come a long way forward and from what I gather it hasn't that much from what I've read or seen, I'm not convinced at the moment, so I would say no [to buying an EV as next vehicle]...I know it's come a long way since I tested it, but I'm still not really impressed. (P59, ICE)

I don't know how...because these are relatively new cars, the reliability aspects haven't been really shown up to be yet, whether they're that reliable in terms of long lasting. (P33, PHEV)

5.5.2.5 'It's a lot of money'

The initial cost associated with purchasing a PiV was considered to be a disadvantage.

They're incredibly expensive. (P16, BEV18)

The only real drawback with them is the cost. They're expensive to buy. They're cheap to run, but they're expensive to buy. (P4, BEV6)

They tend to be significantly, for the same size car, they tend to be significantly more expensive. (P48, ICE)

The Leaf is a cracking good vehicle, but it's a lot of money for what you get. (P36, PHEV)

The biggest [disadvantage] would be cost, the outlay whether you are buying it outright, or whether you are buying it on finance. (P32, PHEV)

5.5.2.6 'Residual value is actually quite low'

There was concern and a general lack of knowledge over the residual value of PiVs, with a general expectation that the level of depreciation would be high.

Most people who have bought them are finding that the dealers don't want them back because they're being so heavily discounted, so the residual value after two or three years is actually quite low compared to a comparative petrol car or a diesel car. (P10, BEV6)

The only one that I can't answer, and no one seems to answer yet is the long term devaluation of the car. There's no real way yet of knowing, until my two or three years have elapsed and I come to see what somebody's willing to offer me to take this vehicle off my hands, I can't tell how much I will have lost in depreciation. (P5, BEV6)

It's a lease rental vehicle, so we didn't have any concern about residual value, because I'm not sure what that's going to be in the future...I think that with the warranty of the battery only being three years, and the warranty on the vehicle being more, I think that would have been a bit of a concern. (P43, PHEV)

5.5.2.7 'People don't know it's there'

Whilst the quietness of PiVs was seen as an advantage by some participants, it was also perceived to be a disadvantage in terms of potential safety issues.

A big disadvantage is the fact that it's silent. (P53, ICE)

It's silent, it's very silent and because it's so silent what we've done is we've added...you can actually switch it so it's a little bit noisy. Because it's so silent people don't know it's there, especially pedestrians. (P37, PHEV)

Although I do think they're very quiet...that's my only thing. If you're on a pushbike, if it's that quiet you're not going to be able to hear them coming. (P46, ICE)

5.5.2.8 Other disadvantages

Other disadvantages mentioned by individual participants were:

- 'No disabled electric bays'

No disabled electric bays. So that is something that we have noticed, that you can have a disabled space or an electric vehicle charging space, but you don't have both... we choose not to charge and go for the disabled bay. They are not usually near the doors as disabled bays are. That is more important. (P39, PHEV)

- 'Limited choice'

The choice of electric or plug-in hybrid are limited. So you are maybe limited with size of car, or options on the car. (P32, PHEV)

- Electricity production

The only thing I would question is, can electricity be produced as cheaply as fossil fuel? I don't know. (P53, ICE)

5.6 Perceptions of BEVs

5.6.1 Advantages of BEVs

This section describes the advantages of BEVs which do not apply to PHEVs. In most cases, the advantage was mentioned by participants from the BEV group and the PHEV and/or ICE vehicle groups. The key advantages of BEVs are summarised below.

- BEVs are seen as a practical vehicle for shorter journeys and as a second car
- The price of electricity is perceived to be more stable than that of petrol or diesel
- BEV Innovators may self-identify as a 'trailblazer' and feel that they are promoting a new technology to the general population

5.6.1.1 'Nipping round town'

Participants in all groups mentioned that BEV vehicles are practical for shorter trips and as a second vehicle.

It wasn't a big car but there's enough space for what I needed and again, nipping round town it's a nice cheap easy car to get on with. (P46, ICE)

I chose this quite specifically to fit the need, mainly for my commute. My work premises are 20 miles from home, and I make that journey every day there and back, five days' a week, which gives me a, sort of, 40-mile round trip every day. (P14, BEV6)

If you need the town driving, no A roads or dual carriageways or motorways it would be okay when driving locally where you're just covering five or 10 miles, then you know you've got fuel left. (P37, PHEV)

I think it is fine, with the caveat that it is a second car. If it was the only car in the family, I don't think it would be suitable with that range. (P5, BEV6)

5.6.1.2 'Petrol and diesel prices can be quite volatile'

A couple of participants stated that an advantage of BEVs was not being exposed to volatile petrol/diesel prices, therefore being better able to predict your fuel costs.

Because you have fixed tariffs for electric, you know how much you're going to pay for your mileage for the rest of the year, whereas the petrol and diesel prices can be quite volatile. (P50, ICE)

[An advantage of a BEV is] not having to be, I suppose, relying on the pricing and the up and down movement of petrol prices. Electric energy is a little bit more consistent in terms of its pricing. (P38, PHEV)

The use of a sustainable energy source in place of fossil fuels was also seen as an advantage, as fossil fuels can be seen as less reliable.

Assuming we get nuclear power, it's the only sustainable method of propulsion. Petrol is finite, and so long as we can generate sufficient electric power, then we can continue abusing power like we do with battery powered cars. (P57, ICE)

We're running out of fossil fuels, so we need to make a switch in the kind of energy that we use, and how much of it we use, and I need to be part of that. (P16, BEV18)

5.6.1.3 'Trailblazing'

Some PiV Innovators felt that it was important for some individuals to demonstrate to the general public that BEVs are a viable option, and were keen to be early adopters.

I had decided that, notwithstanding that my nerves would be easier to have the plug-in hybrid, there is a degree of wanting to encourage the promotion of purely electric vehicles here. (P21, BEV18)

It is very, very early days in terms of switching the whole infrastructure over for everybody, but it requires some trailblazers, if you like, some early adopters, to assist by purchasing these cars so that the manufacturers can improve them and make them more efficient, extend the range, and then make them more suitable for the masses to use. I don't think we're at the point yet whereby everybody could have an electric car. (P5, BEV6)

Ultimately, everybody will be driving round in a hybrid, or an electric car eventually, so we just feel we're in on it early, we've seen the benefits early, but most people will eventually come round to that's the way it will be in the future. (P20, BEV18)

5.6.1.4 Other advantages

A number of other advantages of BEVs were acknowledged by one or two participants:

- Perception that BEVs are cheaper than PHEVs

It's a little bit cheaper than a hybrid, so yes just decided to go straight for the full electric. (P11, BEV6)

- Ability to make use of existing solar panels

We also have solar panels on our house, so we were obviously keen to use that energy to support our travel, if we could, which it does to some extent. (P16, BEV18)

- Being 'greener' than PHEVs (see also section 5.7.3.5)

You have far more range than a plug in hybrid, so 100 miles in the smaller vehicles ...range is a major plus so you can do a lot more driving on them and never have to visit the petrol station and so obviously you're that much more green. (P44, PHEV)

The one advantage of BEVs that was only mentioned by ICE vehicle innovators who had experience of a BEV was that the vehicles often exceeded their expectations.

It was a smooth ride and it was, surprisingly, I thought an electric vehicle would be slow to response, but it did have a fair old accelerator on it, and yeah, it was enjoyable, it was an enjoyable car. (P49, ICE)

It was very quiet. It was quite responsive, much more responsive than I would've expected from an electric car; very comfortable. (P48, ICE)

I was pleasantly surprised by electric power...I like a car that's going to give me a good response, and I was very impressed with the Leaf for that very reason. It responded very quickly. It's virtually instant; the acceleration is virtually instant, being electric. (P53, ICE)

5.6.2 Disadvantages of BEVs

This section describes the disadvantages of BEVs which do not apply to PHEVs. Again, in most cases, the disadvantage was mentioned by participants from the BEV group and the PHEV and/or ICE vehicle groups. The key disadvantages of BEVs are summarised below.

- The limited range of the vehicle was by far the most frequently-mentioned disadvantage of BEVs
- Concerns over being able to charge during longer journeys were common
- The extra planning required to undertake journeys and ensure adequate charge was seen as a disadvantage
- The long-term reliability of PiV batteries was a concern to some

5.6.2.1 'You are completely limited by the battery range'

The key disadvantage of BEVs, mentioned by all participants in all groups, is the limited range.

The main concern that I would have with a purely electric vehicle would be the range. (P52, ICE)

With an electric vehicle you have got this sort of scare that you're suddenly going to be using more power than you anticipate and you're not going to make your destination. (P55, ICE)

You are completely limited by the battery range. So when you run out, you run out. You can't splash a bit of petrol or diesel in to get you somewhere. It makes it more difficult to do long distances. (P6, BEV6)

The only downside on it is the number of miles you can do on pure electric...I don't honestly think that the pure electric cars would meet our requirements. (P34, PHEV)

However, amongst those participants who own a BEV, there were reports of the limited range not being an issue.

Not a lack of [range], but not a great number of places that charge the vehicle. (P11, BEV6)

If I hadn't got one, I'd have probably said to you range anxiety but having now owned one, I don't have range anxiety any more. (P24, BEV18)

I've got used to [range anxiety], I do not suffer from range anxiety now, when I first had the van I definitely did. (P14, BEV6)

There is an expectation that the range on most BEVs will improve over the next few years, thus reducing the problem of range anxiety.

It's always going to be range until, again, probably the next Leaf in about a year's time when the new Leaf comes out, until you get a range of 200 miles plus, I think most people will need fairly heavy convincing. (P20, BEV18)

I would ideally like to stay all electric, and quite excited by the potential developments with the increased range. (P1, BEV6)

5.6.2.2 'I don't want to be stuck out somewhere'

Relating to range anxiety, the necessity to charge the car during longer journeys (or between shorter journeys during the day) is a key disadvantage, particularly reported by ICE vehicle owners and PHEV Innovators.

On long journeys you'll have to break up your journey into 100 mile chunks and go and find somewhere, come off the motorway and come and find somewhere to charge up which just makes your journey time longer. (P51, ICE)

The disadvantage for me would be how far I could travel outside my local area before I needed to charge, and how difficult that would be in areas where you're not going to regularly. I can only think of that as a disadvantage. (P50, ICE)

I would find it a bit stressful having...to worry about getting to a charger on time. (P31, PHEV)

You've only got to get to about half of your range capability and you start thinking, where am I going to have to be able to recharge, and how long is it going to take? I'm not under time pressures these days, but I don't want to be stuck out somewhere waiting for a four hour charge just to get home. (P38, PHEV)

However, a couple of BEV Innovators described how they had turned this perceived disadvantage into an advantage on longer journeys.

We've done longer journeys...when we got to the service station, while we were charging, we would play football with the kids...now it's become part of the journey, oh great, we get to play football, so actually, it's a positive thing, you get out of the car and get to do something we love, so it was a positive addition, rather than a negative, to stop. (P20, BEV18)

It just means that when we're having a long journey we've got these 20 minute, half an hour breaks in a journey, when we just sit together with a cup of tea. So, there's lots of conversations going on, it's a little bit more attentive than sitting next to each other and concentrating on the road, so we've got more time to sit and chat when we're out on a journey. (P26, BEV18)

5.6.2.3 'You have to do a lot more planning'

The planning associated with using a BEV on longer journeys was another key disadvantage, typically reported by PHEV Innovators, but also acknowledged by some BEV Innovators.

Some of my journeys do take me beyond it [the range], and I have to stop and charge, and occasionally that can be inconvenient, if I have to plan in advance, and plan the longer journey time to get there. (P23, BEV18)

You do have to...make sure you've got a plan A to charge it up and a plan B back up in case plan A doesn't work and to some extent plan C in case plan B and plan A don't work. So there is a bit more planning involved. (P12, BEV6)

The disadvantage is that...if you are planning on using it for a longer journey you have to do a lot more planning. Your journey is likely to take at least a third longer if you've got to stop and do a couple of charges. (P44, PHEV)

You're going to have to plan your journey more to get to the next electricity point so you can end up travelling further than you wanted to in the first place. So to me I think they're a non-starter. (P37, PHEV)

Other BEV Innovators recognised that more planning was required, but did not consider this to be a big disadvantage.

It's not stopped us from going anywhere, or doing anything, you just have to build in a bit more time for your journey, which I absolutely don't mind if I'm not paying for the charge en route. (P20, BEV18)

Having to plan a bit more for a longer journey, just takes a bit of forward planning and thinking. Knowing where your charging points are going to be. (P1, BEV6)

5.6.2.4 'The reliability of the battery'

Concerns were expressed, particularly amongst ICE vehicle owners with experience of a BEV, about BEV battery lifespan and costs of replacement.

I would probably have another look at the reliability of the battery because I know that those batteries are very expensive to replace. (P49, ICE)

I would think about reliability, and the cost of it going wrong...if [the warranty] was, sort of, a standard three year one, I might be concerned if something went wrong with it, and then you've suddenly got to find £3,000 or something to replace a battery which, something's gone wrong with it. (P54, ICE)

The lifespan of the batteries [is a disadvantage], which I understand is maybe around three years. (P11, BEV6)

A couple of ICE vehicle owners also expressed concerns regarding the safety of batteries.

It's a bit scary, having that amount of energy constrained in a battery. The energy density is alarmingly high, when you have high range. (P57, ICE)

Plugging it in at home and leaving it...we're told all the time don't leave anything on...my worry would be well will the battery overheat, will I do something in the garage will that cause a problem, electricity in the garage. I know it sounds stupid, but our garage is detached therefore can it get damp or wet in there, could that cause a problem? Those things would worry me. (P59, ICE)

5.6.2.5 Other disadvantages

A number of other disadvantages of BEVs were acknowledged by one or two participants:

- Size

The fully electric vehicles, most of the models are a little bit small, apart from one, which is quite expensive...they'd be okay round town, or whatever. (P40, PHEV)

Sometimes I have to carry large loads, and the Renault is not quite big enough, and it doesn't quite have the range at the moment, but it's not far short. (P19, BEV18)

- Requirement for driveway

If you don't have a driveway you're stuffed really. It seems very unfair actually because a lot of city dwellers would be ideal for short range clean vehicles and you know, cities that have got most of the problems with pollution. (P4, BEV6)

- Style

Some of them look a bit odd. That's not to everyone's liking. I don't like the looks of quite a few of them actually. [Is that something that would be important to you?] Yes. Well, I also imagine that's important to a lot of other people. (P4, BEV6)

It's a fairly bland vehicle, but it's unique in its zero emissions...it's not something that excites me from a shape point of view, but I do feel it's fairly special in other ways. (P14, BEV6)

- Extra energy generation required

Power stations would have to pump out more pollution, assuming they're coal fired or something like that, to generate the extra electricity required to charge all these electric cars. (P58, ICE)

The power that's generated for them has to come from somewhere, which may not be so environmentally friendly anyway. (P60, ICE)

Some of the concerns recently have been that we're going to need more power stations to power all the electric cars. (P19, BEV18)

A few disadvantages associated with BEVs were mentioned by ICE vehicle owners only, based on their experience of a BEV:

- Restricted car usage

If I owned it, it would really affect my life. I'd only feel I'm getting half the available usage time out of a car...that's why a hybrid would be so much more suitable. (P58, ICE)

- Too much information displayed

I found too much information being displayed [on the dashboard], I thought, than I needed. (P56, ICE)

- Not able to tow

That is a disadvantage, in that it can't tow something like a small trailer. (P14, BEV6)

The fact they can't tow really heavy loads at the moment. (P48, ICE)

5.7 Perceptions of PHEVs

5.7.1 Advantages of PHEVs

This section describes the advantages of PHEVs which do not apply to BEVs. In most cases, the advantage was mentioned by participants from the PHEV group and the BEV and/or ICE vehicle groups. The key advantages of PHEVs are summarised below.

- PHEVs are seen as a positive means of introducing PiVs into the car pool whilst avoiding range anxiety amongst drivers
- PHEV drivers do not need to plan their journeys as much as BEV drivers

5.7.1.1 'Introduces people to the concept'

Some BEV and PHEV Innovators described PHEVs as an effective means of encouraging consumers towards using PiVs.

It introduces people to the concept of a battery vehicle, so it might encourage more people to do it. (P24, BEV18)

Plug-in hybrids, I think are another good step, I think for a lot of people that is the bridge between petrol and diesel cars to full electric. (P20, BEV18)

They were also seen to be a useful step towards PiVs until the range on BEVs increases.

One day we might get to a stage where battery range is much higher, and charging stations are plentiful, and you just stop for a quarter of an hour, plug in, and you've got plenty of mileage. But, we're not there yet, and that's why a plug in hybrid is a great stopgap technology. (P41, PHEV)

I think, until you can get a reasonable range on an electric vehicle, I think a hybrid makes, if somebody needs to drive long distances, the hybrid makes a lot of sense, because then they're getting to do most of their everyday local journeys on electric, and just using the fuel when they need to go further. So, no, I think for the time being, they make a lot of sense. (P16, BEV18)

5.7.1.2 'Best of both worlds'

The key advantage of PHEVs over BEVs and ICE vehicles was reported to be the ability to use both electricity and conventional fuel to power the vehicle, thereby reducing 'range anxiety' (reported to be the key disadvantage of BEVs).

A hybrid electric car seems to be the best of both worlds. You've got a Plan B. So, I think that will be, if I was looking for a car it would probably be a hybrid electric. (P49, ICE)

A hybrid would give, by all reports, would give you the best of both worlds. It gives you range, and gives you power. (P53, ICE)

So a plug-in hybrid was the only way that we could make the biggest gain of moving over to zero emissions but equally give us the range when we need it on the lesser amount of journeys. (P32, PHEV)

It's handy having that backup so that if you do run out of battery, you've got the range still on your conventional power. (P49, ICE)

5.7.1.3 'Doesn't give you range anxiety'

The lack of (or reduction in) range anxiety associated with PHEVs was discussed as an advantage.

No range anxiety at all. (P35, PHEV)

It's definitely the fact that you haven't got to worry about running out of charge and then finding somewhere to charge it up. (P33, PHEV)

The hybrid doesn't give you range anxiety, other than the fact that it's got a relatively small tank, but I still get 340-odd miles per tankful. (P38, PHEV)

5.7.1.4 'I don't have to plan ahead'

Related to the reduction in range anxiety is the feeling that PHEV users are able to make a journey without planning it ahead, unlike some BEV Innovators.

I don't have to plan ahead, in terms of where am I going to charge it, or do I have to have it fully charged, which is slightly different from owning a full EV only...you can do a journey, basically, because you know you've got the ability to complete it. (P38, PHEV)

You simply don't have to plan unless you want to, you can just get in the thing and drive it wherever you want to go, assuming there is a petrol station somewhere you can fill it up and continue. (P24, BEV18)

5.7.1.5 'It's using less petrol'

The improved petrol consumption is seen to be a benefit of PHEVs, both in terms of using less petrol and having a higher mpg figure.

The fuel consumption [was the main factor] and at the time the petrol prices were going up and up and up and obviously they've dropped now, but it will go back up eventually. (P37, PHEV)

As opposed to a petrol car obviously it's using less petrol and less emissions so it's better for the environment. (P34, PHEV)

I'm assuming that you'd get potentially quite a high mileage per gallon anyway, you'd barely...if you drove it in such a way that you wouldn't need to fill it up much, I guess, you'd be getting hopefully 70 to 80 miles per gallon, potentially. (P54, ICE)

5.7.1.6 Other advantages

Other advantages of PHEVs mentioned by one or two participants were:

- 'Could run on electricity most of the time'

You get the opportunity to commute, i.e. pop around a few miles here, few miles there, and do local stuff, and yet still be able to use the same vehicle for long runs, where the battery power wouldn't be sufficient. So, it's sort of a halfway house. For a lot of people, I suspect, a plug in hybrid, if they were disciplined enough and plugged it in, they could run on electricity most of the time. (P57, ICE)

If you can go ten, 40 miles [on electric charge], then that would be great, for a large amount of the population, doing the school run and this, that and the other, other small runs, provided they'll take on board the inconvenience. [Would switch to] a hybrid perhaps, but not a purely electric (P58, ICE)

- 'Same on the road price as the equivalent diesel'

I wasn't paying a premium for buying the car, versus buying a diesel equivalent. (P36, PHEV)

it was the first vehicle that was the same on the road price as the equivalent diesel outlander. And, that was because of the 5K government electric vehicle grant. Every other electric vehicle...those are more expensive than their equivalent style, or equivalent body style vehicle. So, it was a good vehicle to get into, to keep the price more or less compatible with what I was expecting to pay for any other vehicle, but still experiment with how the hybrid worked. (P38, PHEV)

- 'Next step forward'

When I previously purchased the Prius that was more because I was interested in the technology and this is the next step forward. (P34, PHEV)

I just liked the idea of the upgrade from the basic hybrid to being able to charge the car and run around without burning any fuel at all. (P34, PHEV)

- 'It's your only alternative'

I think they've both got their place, and I think until fully electric technology catches up, it's your only alternative, really, isn't it? (P49, ICE)

when you take your foot off the accelerator and you coast the engine will shut down and it will use and it will actually put charge back into the battery when you're coasting. You don't get that with a combustion engine vehicle. (P44, PHEV)

- '4x4'

This car fitted very well because it's a good sized car for moving stuff around and met my four wheel drive requirement. (P34, PHEV)

We live in the, sort of, Scottish borders, and it's hilly, and you get bad weather in the winter, so a 4X4 is quite handy. (P33, PHEV)

- 'A lot of the hybrids are cheaper'

I've not done much market research recently, but you would probably pick one up at a more affordable price. (P54, ICE)

If you don't do a lot of miles, a lot of the hybrids are cheaper...if you're pottering around town or you know your commute is only ten miles a day or something, you're probably better off getting a plug-in hybrid because...you'd be running it on

electric 99 days out of 100. You'd get all the cost savings of having it but it would be cheaper to buy. Whereas a large battery electric car is going to be expensive because the battery's expensive. (P4, BEV6)

- 'Good size'

It was a good size family vehicle. What I was looking for was something a bit bigger than my previous car, but without going to a Range Rover or Land Rover bulk. It had some basic off road capability. It fitted nicely with my lifestyle and identify (P36, PHEV)

The hybrids would seem to be more of a nicer style of vehicle; they'd be bigger vehicles, and I get the impression that the fully electric would be smaller type vehicles. (P42, PHEV)

- 'Free parking'

It's just like using a normal car, plugging it in overnight, and occasionally, if we're out somewhere, we find a fast charger, we use that, which often has the benefit of a free parking space. That's a little bonus. (P33, PHEV)

- 'Economical'

even if you drive the car and you never actually plug it in, it's a far more, from a technology perspective, economical car to drive than any combustion engine vehicle. (P44, PHEV)

- 'Don't have to wait'

You don't have to come home, plug the car in and wait for it to get charged before you can head back out again. If some emergency cropped up, I can come home and just head straight back out again. (P35, PHEV)

- 'Stylish'

It's a very stylish looking car. (P37, PHEV)

It looks like any other mainstream Golf, so it is not like it is shouting out I'm different. (P32, PHEV)

5.7.2 Disadvantages of PHEVs (reported by PHEV Innovators only)

PHEV Innovators did not tend to report any disadvantages of their vehicles (over and above those related to PIVs in general).

I haven't actually found one that I would say is a disadvantage over a normal internal combustion engine. For me, it's been a delightful vehicle to own and drive, and live with. (P38, PHEV)

However one or two participants mentioned each of the following disadvantages.

- Changing routine to maximise use of electric power (note that this particular participant did not perceive this to be a disadvantage, but it is likely that others who were keen to maximise usage of the electric powertrain could see this as a disadvantage)

So I use that [public charge point], which is half a mile from work and I've got a folding bike which I take in the boot of the car just for the last wee bit of the commute. Drop the car off at the...take the car to the charging point at lunch

time, cycle back to work, and at night time cycle back to the car and then head home. (P35, PHEV)

- 'Number of miles you can do on pure electric'

The only downside on it is the number of miles you can do on pure electric but I don't honestly think that the pure electric cars would meet our requirements because of the hassle of having to get it charged when you're on longer journeys. (P34, PHEV)

- 'Boot space'

There's the space that's given up in the car to the batteries, so it removes quite a lot of space from an equivalent diesel Outlander. (P40, PHEV)

Boot space, because the capacity has been reduced to get the fuel tank in there where the fuel tank has been displaced by the battery pack. (P32, PHEV)

5.7.3 Disadvantages of PHEVs (reported by BEV and ICE vehicle owners)

There was a general trend for BEV Innovators to hold unique views about PHEVs, but not vice versa. This section describes the disadvantages of PHEVs which do not apply to BEVs, and which were only reported by BEV and ICE vehicle owners. The key disadvantages of PHEVs as perceived by BEV and ICE vehicle owners are summarised below.

- Some BEV and ICE vehicle owners expressed the view that PHEV Innovators are not willing to commit to BEVs.
- The idea that PHEVs (especially company cars) are purchased solely based on their tax benefits was asserted by some BEV Innovators.
- A disadvantage of PHEVs to BEV Innovators is that they are reported to 'block' public charging points; BEV Innovators tend to feel PHEV Innovators are not as reliant upon charging their vehicle to the same extent that as BEV Innovators.
- The merit of PHEVs in relation to emissions and reduced fuel consumption were also questioned by BEV Innovators.

5.7.3.1 'Worst of both worlds'

When discussing PHEVs, many BEV Innovators expressed negative perceptions, over and above the disadvantages described above. A couple of BEV participants felt that PHEVs are 'the worst of both worlds', and that there is little rationale for owning a vehicle which is neither ICE or fully electric.

I think they have the worst of both worlds. I honestly do not see the point of such vehicles at all...I mean, you've either got to plug in, or you have a vehicle which is almost all electric, but has got a tiny petrol availability - it doesn't make any sense to me at all. It's not even a halfway house, really. (P8, BEV6)

They feel like a stopgap...a stepping stone, they don't feel like the answer. (P4, BEV6)

For me, you've still got an engine, you're still carrying round an engine, so for me it's not the ideal situation. I'd rather go full electric. (P20, BEV18)

If you have a car that's a hybrid, granted there's that safety factor where you think, oh, well, at least I've got petrol there anyway, but in the longer term, that's not going to be viable as a solution anyway. So, why not just make the jump and build some nuclear power, and everybody go electric? (P57, ICE)

I would expect a lot of plug in hybrids to actually be petrol or diesel vehicles, with occasional electric use, rather than the other way round. (P14, BEV6)

5.7.3.2 'Transitional product'

A couple of ICE vehicle owners also expressed the opinion that PHEVs will not be a long-term presence in the car market, or that further development is required.

I think they're a bit of a transitional product. (P57, ICE)

I was quite impressed with the hybrid technology, but I think it's got a long way to go yet. (P53, ICE)

5.7.3.3 'They're a tax avoidance vehicle'

Whilst the tax benefits of PHEV ownership were seen as an advantage by some PHEV participants, some BEV Innovators viewed this critically. There was a sentiment that PHEV Innovators have only moved towards EV technology to benefit from the tax incentives, and may not use the electric mode.

I do know, from what I've anecdotally heard, is that a lot of people who have seen the business advantages of PHEVs have just jumped on the bandwagon to have the tax benefits, they're not utilising the technology, so it's actually not benefitting the environment as much as it could do, because they're just not bothering to charge, and they just bung the fuel in and drive it as an ordinary petrol or diesel car. (P30, BEV18)

Basically they're a tax avoidance vehicle as far as I can see. I'm not a fan of plug in hybrids. (P10, BEV6)

[On the difference between a PHEV and BEV] Yes, one is an electric car, and the other is a tax dodge. (P3, BEV6)

a lot of the plug in hybrids are bought for tax purposes rather than because of any kind of real environmental advantage. I know at least a couple of people who have bought them in order to get into London and out of London and they run them on petrol which is utterly defeating the object. (P6, BEV6)

One PHEV participant also reported being aware of other PHEV Innovators who did not use the electric mode, but purchased the car purely for tax benefits:

I also know people who have got plug in hybrids that never actually plug them in, they've just done it to get the benefit taxation wise because it's a company car. Now in those instances they are getting some economy but they're obviously not using the car for its potential. (P44, PHEV)

5.7.3.4 'Hog charging points'

Several BEV Innovators reported that PHEVs can often be found 'hogging' public charging spots, preventing BEV Innovators from being able to charge their car, despite the perception that PHEVs are not in as much need of charging compared to BEVs.

Four times probably I see somebody putting hybrid on a charger. I mean there will be three or four other vehicles, full electric vehicles waiting to get on to that charger. (P10, BEV6)

They tend to hog charging points when you go anywhere because the battery is so small. It doesn't take long to charge, but they'll leave it sitting on a charger for three/four hours because they know they're parking for free. (P2, BEV6)

A pure electric vehicle ought to have priority when in desperate need of a charge rather than first come, first served as it is today. Whether that is ever likely to happen or not is another story. But in my utopian world, that is the way it should be. (P6, BEV6)

You can imagine you turn up to charge somewhere and there's one of them sitting there, it does frustrate me. I don't kick them off the charger, but it is frustrating. (P3, BEV6)

One PHEV pioneer recognised that BEV Innovators may be frustrated by PHEVs using public charging points.

Pure electric drivers consider themselves to be a superior need or a superior worthiness that they should have priority at charging stations and all this kind of jazz. (P36, PHEV)

5.7.3.5 'Not that much less polluting'

The credentials of PHEVs as 'green' vehicles were also questioned by a number of BEV Innovators. It was felt that PHEV Innovators tend to use the petrol mode more than electric, and therefore do little to reduce emissions.

I think the impact on the environment is worse, because you're using two methods of propulsion instead of one. Yes, they're tending to use the combustion engines routinely, which obviously is causing greater pollution. (P19, BEV18)

It certainly still has advantages in terms of air quality, but not the advantages in terms of, I suppose, overall environmental benefits or running costs. (P23, BEV18)

One PHEV pioneer agreed with this viewpoint.

The current generation of hybrids might be good on paper. The reality is they're not that much less polluting than conventional combustion technologies. (P36, PHEV)

5.7.3.6 'More things to go wrong'

Some BEV Innovators believed that PHEVs would be difficult or costly to maintain due to the combination of both electric and liquid fuel engines.

You've got a combination of two things in one car so more things to go wrong, you've still got an engine to maintain and service. (P12, BEV6)

I do worry about the long-term maintenance costs on them because they're going to be at least as complicated as a petrol engine plus more. (P4, BEV6)

The charging mechanism, the switching mechanism – all of these things could go wrong, potentially. (P27, BEV18)

Instead of having reduced complexity, and reduced maintenance, you've actually got more. Because, you've still got all the conventional problems of a petrol/diesel engine, oil changes, air filters, all those sorts of things, plus the additional overhead of having an electric engine and a battery system. (P14, BEV6)

5.7.3.7 'Dreadful fuel consumption'

The fuel consumption of PHEVs was considered to be inferior to some ICE vehicles by a couple of participants.

The battery range is normally appalling, and most of the time, their total, overall economy is less than buying a smaller diesel or petrol, because you're carrying around the weight of the batteries. Long term, I don't think they're the solution at all. (P19, BEV18)

Certainly, the main plug in hybrids that you see...[have] got dreadful fuel consumption, so if you do run it beyond the electric range, and you then start to use petrol, you're going to see a combined of about 35 miles to the gallon, which is outrageously bad in this day in age. (P5, BEV6)

5.8 Next car purchase

Participants were asked whether they would consider purchasing a BEV or PHEV as their next vehicle. Their responses are described in this section, and are summarised below.

- The vast majority of participants who currently own a BEV, and a small proportion who own a PHEV or ICE vehicle, stated that they would purchase a BEV as their next car, particularly if it was a second car or had a higher range than currently available on most BEVs.
- The vast majority of participants who currently own an ICE vehicle but had experience of a BEV reported that they would not consider buying a BEV as their next vehicle, largely due to initial cost and range anxiety.
- Most current PHEV Innovators said that they would purchase another PHEV, as did a number of ICE vehicle owners, who stipulated that they would consider a PHEV but not a BEV.
- A handful of participants ruled out buying a PiV as their next vehicle.
- There was a general expectation amongst participants that PiV technology will improve in the future, making them more attractive to buyers.

5.8.1 BEV as next car

5.8.1.1 BEV Innovators

Nearly all current BEV participants stated that they would purchase another BEV. Reasons for this included:

- Not wanting to take a 'backwards step'

Definitely. Because having driven one now, the thought of putting petrol in, I don't like the idea. (P24, BEV18)

Absolutely. I will never go back to combustion engines. (P17, BEV18)

I wouldn't consider a plug in hybrid. I would certainly buy another electric. (P8, BEV6)

I cannot see it's not going to happen. I don't want a car with an engine in; I just want electric. I absolutely love electric vehicles. (P29, BEV18)

- Environmental considerations

I don't think I'd go back to a combustion engine vehicle again. The main reasons are not having to muck around with dirty fuel and oils, knowing that it's always going to be full and ready in the morning, knowing that I'm not causing any local pollution at street level and I charge 100 per cent on renewables. (P10, BEV6)

I just think it is a good experience... I really like the environmental impact, or the non-impact of an electric car in comparison to other cars...and bluntly I think electric cars are and should be the future. (P6, BEV6)

- Nicer to drive

Definitely. They are nicer to drive and cheaper to run. (P4, BEV6)

Yes. it's just my experience so far is, it's a nicer way to drive and it's much better for the environment, so hopefully the next model out will fulfil all my needs. (P19, BEV18)

- Expected improvements in technology

I can't see myself going back to a diesel ever again, having been in...I think as the plug in hybrids evolve – I've got my car for another 2.5 years before the contract runs out, so I expect the market will change again. My next car could be a plug-in hybrid maybe, but I think I'm more likely to stick with battery only. (P23, BEV18)

I would ideally like to stay all electric, and quite excited by the potential developments with the increased range. Hopefully with the technology improving, definitely stay electric. (P1, BEV6)

Oh, yes. Yes, almost certainly...I like, on the horizon, the potential for having extended range batteries as technology improves, and battery pack size increase, and I thought it would be...as time passes, I think in the next five years or so, the range of electric vehicles available will be broadened quite significantly with more manufacturers coming online. (P30, BEV18)

5.8.1.2 PHEV Innovators

A few of the PHEV Innovators would consider purchasing a BEV as their next car, particularly if the range was higher, or the purchase cost lower.

I would probably say I would definitely have a plug-in hybrid as a minimum. If the battery performance range is increased by 30% I could be then converted to full electric. (P39, PHEV)

I have been considering, actually, changing it for a full electric, but the price on the full electrics at the moment is still far too high...there is one that would suit what my expectations of a full electric would be, but at the moment, the price is about 15% too high. (P38, PHEV)

I don't know how far the technology is going to go in the next three years, if there was a bigger range on a full electric vehicle, then I would consider a full one. But it would have to be with a much bigger range than currently exists. Otherwise then it would be another hybrid. (P31, PHEV)

5.8.1.3 ICE vehicle owners

One participant stated that they would "be very tempted" to buy a BEV (P46, ICE). Another stated that they would like to purchase a TESLA because of the high range:

I don't think I would get a plug in hybrid, because it's neither one thing nor t'other. I would very seriously consider a pure battery one. (P57, ICE)

Another who had a diesel vehicle as a second car said "Yes, so I mean, as I said, we have a diesel car as well. Would we replace that with a...? Yes, at some point we might do" (P16, BEV18).

However, when asked whether they would be likely to purchase a BEV as their next car, most of the ICE vehicle owners with some experience of a BEV stated that they would not. Factors contributing to this included:

- Cost

It would have to seriously come down in price, but the last time I did look at the Nissan Leaf it was quite expensive. (P49, ICE)

They're still quite expensive at the moment, so it wouldn't be something I'd consider at this time. (P54, ICE)

- Range anxiety

I don't think I'd go for the battery, unless the range could be really improved to maybe 250/300 miles, which I understand some electric cars will do, so I'm not quite sure what the electric range is. (P56, ICE)

I don't like the idea of just electric. I would worry that it would break down a bit like a lawnmower, I just don't feel if there's a power cut I felt, you know, I know it wouldn't be a power cut, but it's a similar feel. (P59, ICE)

- Desire for further development of technology

Unless it's come a long way forward and from what I gather it hasn't that much from what I've read or seen, I'm not convinced at the moment, so I would say no. But I wouldn't say I wouldn't be averse against it in the future I just don't think at the moment ... I think it's still in its progress making sort of thing if you know what I mean. (P59, ICE)

I don't think I'd have a total battery car. Unless the technology had improved such a lot.... I think there's still more technology to be developed on the battery cars, the pure battery-operated cars. I think the hybrid is probably more of an option for me and I would certainly look at a hybrid car. (P55, ICE)

- Inability to tow

We've got a fairly large caravan, which is another reason for having the Range Rover. So, I might buy it as a second car, but not as a primary car. (P48, ICE)

5.8.2 PHEV as next car

5.8.2.1 PHEV Innovators

Similarly, most, PHEV Innovators stated that they expect to purchase another PHEV as their next car.

There was a range of deciding factors underlying this.

- Not wanting to take a 'backwards step'

If I had the choice, yes, I think I would, yes. It just seems wrong, now, to go back to something else, particularly...it just seems wrong to go backwards, now. It seems like I've taken this step now, and let's move forward with it. (P40, PHEV)

Quite possibly, yes. Because I think it's the way forward really. (P34, PHEV)

- Tax benefits

I get taxed on a company vehicle, so it's a significant benefit there. (P40, PHEV)

- Money saving

Yes absolutely. From the fuel economy point of view. (P39, PHEV)

I've got the charger in my house, and I've also got solar panels, so during the day I'm not even paying to charge it up. (P40, PHEV)

- Not fully relying on battery power

Certainly, because our experiences so far have all been positive. [Do you think that you would consider a BEV?] No, because I think they're quite limited on the battery, when the power is gone it's gone. So with the multi-fuel system you can rely on something else. (P37, PHEV)

One PHEV participant commented that their two-car household would ideally consist of a hybrid vehicle and a BEV:

Yes I'd definitely consider another hybrid vehicle...in terms of our family, I think the best fit for us is one hybrid and one electric...I think that for me personally I'd replace my current hybrid with another plug in hybrid. I think my wife would seriously consider replacing her combustion engine car with an EV as a next vehicle. (P36, PHEV)

Two BEV participants whose second household vehicles were a hybrid and an ICE vehicle respectively stated that they would like to purchase a PHEV:

I would certainly seriously consider a plug in hybrid to replace our existing non-plug in hybrid. So, when that comes for replacement, I will certainly be looking around to try and find a plug in hybrid to replace that car. (P5, BEV6)

I'd be a lot more keen to have a plug-in hybrid for the main car and electric one for the second one, if I can afford it. (P7, BEV6)

5.8.2.2 ICE vehicle owners

Some ICE vehicle owners expressed an interest in purchasing a PHEV, but typically ruled out purchasing a BEV as their next vehicle.

I think that's probably the way they're going to be going soon. I can imagine they're cheaper to run so I would think that's probably the way we're going to go with the future. For me, I'd be quite happy having one I think. (P46, ICE)

I would consider a plug in hybrid, I would not choose the battery electric car on its own. (P51, ICE)

I might consider yeah a plug in hybrid. At the moment I wouldn't consider a pure electric vehicle. (P60, ICE)

A hybrid, definitely. Electric solely in its current...yes, current technology, if you like, no way. Absolutely no way, but hybrid, yes, could consider it. (P53, ICE)

5.8.3 ICE vehicle as next car

5.8.3.1 PHEV Innovators

One PHEV pioneer, who purchased their PHEV as a company car, stated that they would purchase an ICE vehicle as their next car if it was not a company car.

It would depend on the tax situation, if it's a company car. If it was my own car, probably not, because I think I'd get better miles per gallon with a diesel car, or even a smaller petrol car, than what this one is. And, I'd be worried about the reliability of the batteries, and things like that. (P33, PHEV)

5.8.3.2 ICE vehicle owners

Two participants clearly stated that they would not purchase a PHEV or BEV at this stage; one of these expressed an interest in a (non-plug-in) hybrid vehicle.

Not over an economical petrol or diesel. It would have to be a big...there'd have to be something about it to make me be swayed because I'm still not convinced that it's the right way forward. (P60, ICE)

I'm not sure about the plug-in hybrid. I think I would probably be looking initially, unless there were very good reasons, to have a hybrid which had a separate sort of diesel or whatever, or petrol engine, which was then recharging the battery as you go along. (P55, ICE)

5.8.4 Expected improvements

There was a generally high expectation that the technology associated with PiVs and their range will improve in the future, as will charging infrastructure and vehicle-to-grid technology, making PiVs the cars of the future.

The lease that I've got it on will come to an end in 2017 or so, and by that time I anticipate there'll be a completely different generation of electric cars on the road, with at least a 200 mile range, and things like that, and it will be a lot better. (P21, BEV18)

It's definitely the future once things like the range improves more. (P11, BEV6)

I'm an early adopter and the infrastructure is not there, but I expect it to improve greatly in the next couple of years. (P10, BEV6)

I think, ultimately, everybody will be driving round in a hybrid, or an electric car eventually...we've seen the benefits early, but most people will eventually come round to that's the way it will be in the future. (P20, BEV18)

Already the next generation Leaf has 20% more battery power, and all of the journals, and the magazines reckon that, by the time we've got a three-year-old Leaf, and we're looking to replace it, the battery power will have increased again. So, that will take the range up to at least 150 miles, I should think, which would make day trips easier. (P26, BEV18)

5.9 Time of use and managed charging

5.9.1 Lack of understanding among some participants

Some participants indicated a lower level of understanding of the two tariffs than others. The key areas of misunderstanding are summarised below.

- Difficulty comprehending the information provided was apparent amongst a number of participants.
- The two tariffs were not easily differentiated by all participants.
- In a few cases, participants thought that MC was primarily a tool to allow charging to stop before reaching 100%.

As described in section 5.2.3, participants were provided with an information sheet (see Appendix C) describing the MC and ToU tariffs prior to the interview. The tariffs were described again during the interview. Many participants appeared to grasp the concepts well, however during some interviews, it emerged that the participant's comprehension of the two tariffs was limited. This is likely to be a result of the fairly high level of informational distance and the abstract thinking required to fully comprehend the two charging options in the short time available. The finding replicates similar challenges reported in undertaking consumer interviews on this issue (Bailey & Axsen, 2015; in personal communication). Limited comprehension of the tariff information might be attributed either to the design of the information sheet or to mismatch of construal level for some participants (e.g. those finding it easier to rapidly comprehend a more concrete, less abstract concept). The apparent level of understanding was taken into account during the analysis, with greater emphasis placed on the responses of those with a good understanding, where necessary.

Examples of confusion include:

- General difficulty understanding the information provided

Didn't quite understand it, so had to read it through a few times, but I think I've got it now. (P12, BEV6)

I'm not sure what the difference is, frankly, except that in each case you're telling the supplier what you need, and your supplier works out how to do it. (P21, BEV18)

Maybe I'm getting confused on what I've got written down here. (P49, ICE)

I'm getting a bit confused here. (P58, ICE)

It sounds complicated. I do quite a complicated job. So if it took me quite a while to get my head around reading this, I don't know how you'd explain that to the general public. (P7, BEV6)

- Difficulty differentiating between the two tariffs

They're similar in many respects. But I think is the main difference that in number two the energy supplier basically may toggle when you get the charge? (P44, PHEV)

I've got to say they look very, the tariffs look very similar. (P49, ICE)

I didn't realise they were two approaches to the same problem. I thought they were just one solution, now you're telling me there's two sections there, that I didn't differentiate. (P57, ICE)

Between them both I think it's just swings and roundabouts to be honest. (P47, ICE)

- The belief that the key function of MC was to enable PiV Innovators to charge their vehicle to a pre-determined percentage less than 100%

I do not want to be fiddling about saying I'd like 70%...I don't understand why anybody would want to have their car charged only to 70% for example. I couldn't quite grasp that at all. (P28, BEV18)

Some people, if you say you only need 70% then instead of most people just leave the car plugged in, it will go to 100%, they might save a bit more because they can get the electricity company to, effectively, stop it for them, if they only needed 70%. (P20, BEV18)

- Concern over whether others would understand complicated concepts

I can see that the managed one there might be a way that it works...because you're just setting the time you need the car, it does it as a lower rate, it would be cheaper. But it sounds complicated. I do quite a complicated job. So if it took me quite a while to get my head around reading this, I don't know how you'd explain that to the general public. (P7, BEV6)

5.9.2 Advantages of time of use tariff

A number of advantages of the ToU tariff were observed by participants in all ownership groups. The key advantages are summarised below.

- The ToU tariff was considered to be simple, particularly compared to the MC tariff; participants generally felt that they understood how the tariff would work.
- Again, compared to the MC tariff, the ToU tariff was perceived to offer the consumer a greater degree of control over the charging of their vehicle.

5.9.2.1 'Simpler'

Participants commonly felt that the ToU tariff was simple to understand, in terms of how the tariff system would work, and what the user would be charged.

It's quite clear what you would be charged, at what time. (P1, BEV6)

It seems to indicate almost a similar charging system to public transport almost. Where you have peak charges at rush hour times, standard charges during the day and cheaper outside of normal hours. So yeah, it makes a lot of sense. (P52, ICE)

I think option one [ToU] is a less complicated way of setting it up and you're getting the cheapest. (P47, ICE)

That makes sense, it's kind of what we're doing now, really. (P25, BEV18)

You know how much your bill's going to be because you know what you're going to get charged, at what point in the day...you are in control more of how much you spend because it's very clear what your pricing brackets are, and you're in control of it, really. (P50, ICE)

5.9.2.2 'More control'

Compared to the MC tariff, a few participants felt that ToU offered a greater degree of control (see also section 5.9.6.2).

You know when you're charging, and you're not reliant on the company turning your car on and charging on and off. You'd be more in control yourself. (P1, BEV6)

It seems to be you have a bit more control over it [than MC]. (P60, ICE)

You just have a bit more flexibility with that one, you're in control of it more and you're not reliant on someone else... it seems more simple and there's less to go wrong. (P11, BEV6)

Option one [ToU] is more in your control when you can save and when you can use things. (P33, PHEV)

5.9.2.3 'Avoid the peak times'

Another perceived advantage of the ToU tariff was that it would encourage people to avoid using electricity at peak times, thereby reducing the strain on the grid.

There would be a greater load in the off-peak times, and it would spread out the demand on the grid. People would avoid the peak times, and so therefore, that would enable the kettle and the cookers to work at six o' clock, and all that kind of thing, without tripping any power stations. (P5, BEV6)

It is then putting less strain on the National Grid to try and balance out the peaks and troughs. (P32, PHEV)

5.9.2.4 'More reliable'

One participant expected that they would expect the ToU tariff to be reliable as it is similar to existing tariffs.

The advantage of the time of use tariff is that that technology we've had for many, many years, basically, on the Economy 7 meters and different times a day charging, I would expect that to be more reliable. (P19, BEV18)

5.9.3 Advantages of managed charging tariff

A number of advantages of the MC tariff were observed by participants, particularly those who currently own a BEV. These advantages are summarised below.

- The MC system was recognised as optimising the available energy, and was principally seen as offering an advantage to the energy supplier rather than to consumers.
- Some BEV Innovators felt that MC did offer wider benefits to society.
- The idea of allowing the supplier to manage their vehicle's charging was seen as an advantage by a number of BEV Innovators.

5.9.3.1 'Intelligent'

A key advantage of the MC tariff, mentioned by the majority of participants, was optimising the use of the energy supply.

It's not taking more from the grid when there's high usage. (P2, BEV6)

The managed charging is intelligent, because when the grid has more capacity than it knows what to do with, we are just dumping electricity, we don't have enough capacity to store. (P6, BEV6)

This improved management of the energy supply peaks and troughs was seen to benefit the energy suppliers, society, individuals and the environment, as described below.

5.9.3.2 'More advantageous to the supplier'

A commonly held view was that the energy suppliers would receive the most benefit from a MC scheme.

I think the managed ones are the ones that are potentially more advantageous to the supplier. (P27, BEV18)

I think the advantages are good for the suppliers, and I think there will have to be some kind of managed tariff. (P25, BEV18)

The second option [MC] is a lot more flexible for them, yes, as to evening out demand on the grid. (P19, BEV18)

A few participants stated that they did not believe that there were any advantages to society associated with MC.

It would even out the draw on the supply. I can't think that we would, as consumers, a society experience a massive benefit from that. (P51, ICE)

I don't know about society, but I think the electricity supplier would like it. (P56, ICE)

It would provide an advantage to the electricity generators...but, you know, it is very much a case of the tail wagging the dog, it's a utility telling people how to behave to suit the utility, and that's not how it should work. So, I can't see the advantages for society. (P26, BEV18)

Likewise, the benefits to consumers were questioned by a couple of participants.

Okay, it's using it efficiently, but it's not using it in a way that suits the users. (P26, BEV18)

Well, it seems to be more beneficial to them, from what's written here about using the grid when it's working at a more efficient rate for them, so I think it's suits the provider better than the consumer. (P54, ICE)

5.9.3.3 'A benefit to society'

Some participants did believe that a system of MC would have wider societal benefits.

It would help with smoothing out the grid, and require fewer power stations to be put up...for society, then that is the better option, in ten years, 15 years' time, when there are more electric vehicles, then that is going to be the only way to manage the demand on the grid, without having to drastically change the infrastructure. (P5, BEV6)

Some of the concerns recently have been that we're going to need more power stations to power all the electric cars, and hopefully this could even out that demand. (P19, BEV18)

What you are doing is you are helping the grid, which I guess is the logic behind it, help us offload energy when we have got too much...on a societal level, that one is much more attractive to me than it is on a personal level. (P6, BEV6)

Anything that helps even up the supply would be better, and if it had better prediction, and more use of renewable energy for mainstream electricity production, that would be a benefit to society. (P30, BEV18)

5.9.3.4 'Morally more appealing'

Benefits on an individual level were mentioned by a couple of PiV Innovators, in terms of how MC may make them feel about their use of electricity.

I'd feel that I was contributing towards using less electricity, or using it more efficiently. (P54, ICE)

I suppose, knowing the restrictions or the limitations on energy supply, having the power companies supply the energy at a time that's most appropriate to them is morally more appealing. (P30, BEV18)

Getting an electric car and then saying, 'okay I'm going to be charging up on the peak rate constantly', sort of defeats the object of the whole ethos behind it. (P45, PHEV)

5.9.3.5 'A more sustainable way'

One participant felt that MC provided a more sustainable means of using energy.

It's actually using the electricity when it's being generated, if you like, and, as a result of that, it's a more sustainable way of using that electricity. (P3, BEV6)

5.9.3.6 'Managed by someone else'

A number of participants, particularly BEV users, believed that a MC tariff would make the process of charging their PiV simpler and would take some of the decision making process away from them.

That would take the thought out of it...somebody else can decide when it's going to be charged and make the best of it...I'll just plug it in when I get in, and the car itself won't be charging until much later when, effectively, there is excess electricity. But, since I don't personally know when the demand is higher or low within the network, I'll leave that to the supplier. I'm comfortable with that. (P22, BEV18)

As long as it worked and it was seamless and you really didn't have to think about it at all and you could just say I need a full battery by 6am and that was managed by someone else, and again you get the cheapest rate to do that, I can see that working really well actually. It seems quite a clever option. (P11, BEV6)

They will not have to think about getting the best rate; they'll just simply put it in, and leave it to do its own thing. So, they will get a better rate without having to think about it, which for some users, they would be happier to do that. It takes the decision making off them. (P5, BEV6)

I have absolutely no trouble with that at all. I would say, if you can do that, Sunny Jim, I'm dead easy with that. (P21, BEV18)

5.9.3.7 'Seems like the future'

MC was seen by some as bringing the future of charging a step closer.

To me something like that it just seems like the future. (P11, BEV6)

If it got to the stage where everybody had an electric vehicle, without having to rewire the whole national grid, I can appreciate, we'd all have to go to something like the option two [MC]. (P5, BEV6)

It brings the concept of a smarter grid a bit closer. (P24, BEV18)

5.9.4 Disadvantages related to both tariffs

A number of concerns and disadvantages were applicable to both the MC and ToU tariffs, as summarised below.

- Participants regularly expressed concern over any requirement to use a smartphone app to operate the tariff.
- The potential for emergency situations to arise when the PiV did not have adequate charge was another key concern.
- The additional time and effort associated with the MC and ToU tariffs was expected to be an inconvenience to some participants.

5.9.4.1 'I do not want to use a smartphone app'

The most frequently-mentioned disadvantage of the MC and ToU tariffs was the requirement to use a smartphone. In some cases this related to concerns about coverage.

I'm in a very poor reception area for mobile phones, so a smartphone only works intermittently here. (P21, BEV18)

It seems a bit of a pain in the proverbial really...trying to communicate with your smart phone for a start off, especially if you're in an area where you've got very poor coverage as we have. (P34, PHEV)

My initial reaction is how it would actually be controlled and managed, and the reason for that is that where we live we've hardly got any mobile phone signal. (P3, BEV6)

Other concerns included not being able to use their smartphone in particular situations.

If your phone has lost a charge or is on charge or you forgot to take your phone with you or something, oh, I've got to go and get my smartphone. Okay, right. I've got to now go online or whatever it is and tell the supplier that you need the car by a particular time. That's another hassle, I suppose. (P55, ICE)

If you don't have a smartphone on you, or the smartphone's battery's run out, or...no mobile reception...does that mean I wouldn't be able to charge at all? That would be a concern. (P23, BEV18)

In other cases, participants did not feel confident or happy to use a smartphone to control their car's charging.

I haven't got a smartphone, and have no use for a smartphone, so I don't know how easy or difficult that would be to do. (P56, ICE)

I just probably would have an issue with the texting them, or whatever the procedure is. (P20, BEV18)

I am not a huge of technology and smartphones...I think anything by smartphone is not everybody's cup of tea. (P49, ICE)

I think using your smartphone to tell the supplier the minimum charge you need the next day, and the time you need it, is probably a bit complicated. I think you need to be able to plug it in, tell it when you want it to be charged on the vehicle, but I wouldn't want to have to use my smartphone as well. (P14, BEV6)

I'd have to find out how to use a smartphone app, but I'm sure I could do that. (P33, PHEV)

Some participants had a general dislike of using smartphones, and felt that the requirement to do so in order to charge a vehicle would be a disincentive to PiV uptake.

I am sick of people looking at their phones for every damn thing. Actually now I can't charge my car or use electricity without pressing an app...I don't want to have to get involved with an app. That would be the stopping point for me doing any of it. (P28, BEV18)

Having to use a smartphone each time you park up and connect is possibly going to be a disincentive to a lot of users. (P30, BEV18)

It was suggested that, rather than using smartphones to operate the tariffs, the system should be integrated into the PiVs.

The smartphone thing really puts me off, because apps don't always work, phones don't always work, so I'd like to see something more integrated into the car, perhaps. (P18, BEV18)

If it was built into the car, then it would work, but having it on a smartphone as a separate app, it's just too disjointed (P38, PHEV)

A few participants had a more positive view of smartphone use, and felt that it was a useful element of the tariffs.

Using a smart phone, that's a really good idea, that would be quite useful to be able to do that. (P25, BEV18)

Also you use a smart phone with it or iPad or whatever system you use, that's quite useful. (P37, PHEV)

Well I guess I liked integrating the idea of the smart phones kind of thing. I think it's quite good that you can...not have to do it all via the car or over the web, on a computer or tablet or whatever. I think the smart phone is quite convenient. (P60, ICE)

5.9.4.2 'An emergency situation'

A frequently-expressed concern relating to both tariffs was related to unforeseen circumstances which may require the use of the PiV before it is charged.

If we had an emergency call in the middle of the night, and we had to use the car, but for one reason or another, it hadn't charged up because of that, that could be a problem. (P48, ICE)

I might get a phone call at 1 o'clock in the morning saying you need to be somewhere. Now, my mind-set is that I have to be ready for that. So I would always want to be charging straightaway. (P9, BEV6)

I don't know how often it would happen, but I don't like the idea of [me] deciding would I need it by tomorrow at 8am and it's there plugged in but not charging until they decide to charge it and I find suddenly I need to go and do something later on that night and I've got no range because it's not been charging. That would be my concern. (P12, BEV6)

Some participants recognised that this issue would be present for all PiV users, regardless of their tariff type.

That could happen, of course, at the moment anyway, if you hadn't charged your car, so it's not particularly as part of that tariff, but it's something that needs bearing in mind...saying that, I don't think it would put me off. (P19, BEV18)

If somebody had an emergency, and they suddenly need to run out to the car, and it hadn't charged because the supplier was managing demand, that could be it. But then those kind of emergencies could happen anyway. (P6, BEV6)

It's a fairly minor [issue] – I would say, it's not that important an issue, although there may be some people who don't like it, and they won't sign up for it [MC]. (P21, BEV18)

However, others felt that they would prefer to charge their vehicle as soon as possible, to minimise the risk of such a situation arising.

It would be a disadvantage if you held off charging until a cheaper rate time, and then something unexpected cropped up where you needed to use the vehicle, you could suddenly find yourself with insufficient charge there. (P30, BEV18)

5.9.4.3 'A burden'

There was a perception that using either tariff would involve additional time and consideration, with concerns expressed over forgetting to charge the vehicle.

I really like things where you don't have to think about them too much and you don't have to worry about them...I think it sort of spoils what an electric vehicle ownership is about when you start having to think too much about the charging of it. (P11, BEV6)

I come home after a long day and I just want to plug the car in and forget about it. I don't want to be up thinking about letting the energy company know where I'm going tomorrow, how many miles I'm driving. (P17, BEV18)

There's already certain jobs that I forget to do in the day...it'll just be one of those extra things...I'd end up forgetting to charge the car and it would make me less likely to want to choose an electric car if I had to do all of that extra. (P51, ICE)

It would be probably remembering to do that, you need to come home and we now just plug in and forget about it, if we had to plug in, come in and send a text, or whatever, it's that side of it that probably would become a burden. (P20, BEV18)

The drawback is, when you pull up at home, it's then having to use your smartphone to supply information, and it's another little activity that has to be done. (P30, BEV18)

5.9.4.4 'Can't be bothered to change tariff'

A few participants expressed the opinion that PiV Innovators would not change tariffs unless it was mandatory to do so, or unless there was a significant financial incentive, due to the perceived amount of effort involved.

It would mean a lot of effort overall to make the savings and I'm not sure we'd do it. (P12, BEV6)

Loads of people stay on the tariff that's not good for them because they can't be bothered to change, you know, so it needs to be quite a lot of money otherwise just inertia will make loads of people just carry on doing what they're already doing. (P4, BEV6)

Part of the reason I don't have a time of use tariff at the moment is it's just not worth it. The costs involved in installing and getting those tariffs far outweighs the cost benefit of doing so. (P36, PHEV)

It's superbly sensible, I'm just not sure that enough people would go to the trouble. Wish they would. (P57, ICE)

I've spent far too much of my life fussing over details, and certainly I would rather stick with what we have, than go through an enormous performance just to get something slightly cheaper. (P26, BEV18)

5.9.4.5 'Setting up the equipment'

A handful of participants were apprehensive about equipment being required for either tariff, and associated costs.

The disadvantage would be setting up the equipment...they've got to set these things up, haven't they? (P27, BEV18)

Presumably, you would have to have some additional hardware involved, probably at some cost, to manage that. (P43, PHEV)

I would need to look into it, I mean, if it's one of these things where it's all complicated and there's paperwork flying backwards and forwards, and there's stuff being installed in the house, I'm not particularly interested in that. (P26, BEV18)

5.9.4.6 Other concerns and disadvantages

Other concerns were expressed by one or two individuals:

- May dis-incentivise PiV uptake (amongst those unable to take advantage of cheaper electricity on either of the tariffs)

There was quite a strong economic argument for having an electric vehicle or a plug in hybrid. That has been somewhat lessened by the fact that petrol is now cheaper...if you now said, actually, we're even going to take away, we're going to make that gap even less, because in essence, we're charging you more now, for your electric, I think you'll get less people wanting to uptake it, and I don't think that's good for the country. (P41, PHEV)

- Aimed more at BEV Innovators than PHEV Innovators

These tariffs are definitely geared towards a vehicle that has got a large range where, for example, you might get away with selecting a block of time and as long as you get your full charge in you've got 100 miles by the time you wake up and go out or whatever. But I think for hybrids where you've got a small level of range it doesn't work, is my opinion. (P44, PHEV)

- Don't want to be first to adopt

I'd have to be convinced of its resilience, I wouldn't be an early adopter of these. (P18, BEV18)

- Would not bother to charge at particular times

To be fair I'm not the world's most economical user of energy...well actually that's unfair. I don't tend to think about how much stuff is going to cost like that. If I need to do something I'll just switch it on and do it and then turn it off when I'm finished. It doesn't really occur to me should I wait for an hour? [Would that be the same for the managed charging one as well?] Yes. (P60, ICE)

5.9.5 Disadvantages related to Time of use tariff

The disadvantages associated with the ToU tariff are described in this section, and summarised below.

- Participants felt that the ToU tariff was best suited to those with a charging routine who would be able to take advantage of the cheaper charging periods, and would therefore disadvantage those who are not able to regularly charge at these times.
- Similarities between the ToU tariff and the existing Economy 7 tariff were identified by many participants, who felt that ToU did not offer any additional advantages.
- The potential negative effect on the grid of encouraging many people to charge in off-peak periods (if PiV uptake increased) was another disadvantage discussed by participants.

5.9.5.1 'I don't think people stick to a routine'

The most frequently expressed concern regarding the ToU tariff is that it would only be of benefit to individuals with a regular charging routine.

If I had a day where I need to use it a bit more, I have no option but to charge it during the day...that's clearly not going to be at the low peak time. (P14, BEV6)

It's a nice idea if you've got lots of time to do it, and you don't have that variability of pattern. (P43, PHEV)

If you've got a very consistent pattern, then I could see that working, but if you've got any sort of flexibility in that pattern, I think that could be a potential issue. (P43, PHEV)

[With MC] I would have to think about it every day what I wanted to do. Option one [ToU] is fixed so you can get into a routine that falls in line with it. (P34, PHEV)

Several participants felt that it would not be suitable to people who work shift patterns or have different routines on different days.

If they work shifts or whatnot, they might need to charge during the day when it's expensive and lose out on potential discounts. (P1, BEV6)

There are two or three times a week when I need to top the car up in the early evening when I get home from work. If that's going to cost significantly more, then that would dissuade me from adopting that tariff. (P23, BEV18)

Because we need to charge during the day, in between journeys, and also then in the evening, I'm not sure how well that would work. Because, we're at least two charge a day use, it's a slightly unusual use, when I guess most people would just do one set of charging. (P43, PHEV)

The modern lifestyle was felt by a handful of participants to reduce the benefit of a ToU tariff.

We have all got lifestyles that are not as dictated as you do the same thing on a diary or on a calendar every day. It is trying to be practical with that. We don't

have crystal balls unfortunately, so we don't all know what we are going to be doing tomorrow. (P32, PHEV)

I don't think people stick to necessarily a routine in this day and age and if their partners are working or if people in the family are working...I think you need to have that flexibility of when you use different things. (P59, ICE)

However there was also the opinion that having a routine for charging could be an advantage:

I like the convenience of the time of use tariff, where you've got that routine there, you know you can plug it in and just forget about it. (P54, ICE)

5.9.5.2 'You'd just use Economy 7'

Participants regularly compare the ToU tariff to the existing Economy 7 tariff, and felt that the former offered no advantage over the latter, especially when used in conjunction with timers.

I think the system I use at the moment is actually effectively using that, because I'm trying to use off-peak electricity. (P14, BEV6)

It doesn't offer me any advantages of what I've got at the moment [Economy 7]. (P10, BEV6)

I probably would think the Economy 7 was better, because you only pay a fraction more for Economy 7. (P28, BEV18)

I can set timers and all that sort of thing on the car in any case, both directly inside the car or remotely from the app or from a browser. So that really didn't seem to me to provide any value that isn't already existent...people who have cheaper night time tariffs are already setting their timers to charge overnight. (P6, BEV6)

Why would you bother? You'd just use Economy 7. (P57, ICE)

5.9.5.3 'Putting quite a lot of strain on the grid'

Another concern expressed by a handful of PiV Innovators was that widespread use of the ToU tariff would increase the strain on the electric grid.

Well if the car starts charging at the immediate time when cheap electricity starts that's not so good because obviously at that time that's when everybody is home from work...so the car drawing more energy as well won't help because it's putting quite a lot of strain on the grid at that point in time. (P2, BEV6)

If everybody is plugging in their electric car at the same time when it's cheap, to maximise it, it might have an impact on the grid itself. (P1, BEV6)

If everybody in my town had an electric vehicle...everybody would be charging at the same time, and I think that would put too much strain on the infrastructure. (P5, BEV6)

If you had too many users, then you could create a reverse effect, so that actually would become the peak demand time. (P14, BEV6)

5.9.6 *Disadvantages related to managed charging tariff*

The disadvantages associated with the MC tariff are described in this section, and summarised below.

- The requirement to place trust in energy suppliers and relinquish some aspects of control to them when charging a PiV was a key issue.
- Concern was also expressed about the potential for fragmented charging to damage the PiV battery.

5.9.6.1 *'Do you trust your energy supplier?'*

Participants regularly expressed concern that the MC tariff would require them to place their trust in the energy supplier to charge their PiV. Some expressed a general mistrust in the supplier to ensure that they managed the charging.

You're relying on the provider to actually manage that aren't you? So, it depends whether you trust the provider to actually switch it at the right times. (P43, PHEV)

I think it sounds like a good idea, but it wouldn't be for me...I don't trust them to get my electricity bill right. So I certainly wouldn't trust them to make sure my car is charged in the morning. (P60, ICE)

I'd maybe be a little bit cautious initially, you worry that if you did it with a journey to do the next day and there'd be an error at all, that your charging hadn't been turned back on for any reason, if there was a glitch in the system. (P1, BEV6)

A lack of trust in the supplier to pass on any cost savings was also expressed by certain participants.

I believe the energy companies will distribute [their cost savings] to line the pockets of their CEOs and senior management...they're saving a lot of money, I just don't think the consumer is going to see the benefit of that...the issue for me is that it's in the energy companies' interests to make a small mistake in the way that that's implemented. So I'm always a bit suspicious of anything that involves somebody who would profit from it, getting it right. (P36, PHEV)

I suppose there's another issue there, which is, do you trust your energy supplier? I can imagine people wondering about that. How can I be sure that you won't decide to charge me 30 pence a unit because you can? That probably will be, actually, an issue, I would say. (P21, BEV18)

Another concern related to the idea of the energy supplier having knowledge of their schedule.

I also don't like the idea about the supplier knows my schedule. Why do I want someone that knows what time I'm going to do something in my own house? No, I don't like that, no. (P59, ICE)

5.9.6.2 'Losing some control'

Relating to the issue of placing trust in the energy supplier is the issue of passing over control of the charging. Many participants expressed apprehension at this.

The supplier is deciding when and why we can have stuff turned on and off. I don't like the sound of that at all. (P26, BEV18)

I would be losing some control. My perception is that I could be losing some control over how and when I charge the car. So, I have a minor worry. (P5, BEV6)

I suppose the fear of Big Brother having control as well, that could be a lot of people's concern over it. (P12, BEV6)

I don't like the fact that my supplier will turn the electricity off and on...because I'm not in control...it's a bit like Big Brother. Big Brother watching you or Big Brother is not going to allow you to watch this or do that between certain times. I think it's a bit too controlling. (P37, PHEV)

Wouldn't that feel like you were being very controlled? You would feel very detached from it, and I'm not overly sure that's a great thing...you see all these science fiction films about computers taking over, ruling the world and killing everybody, and that seems like a very good first step. (P9, BEV6)

A couple of participants felt that the MC tariff would take away elements of their freedom and choice over when to charge their PiV.

I wouldn't want the supplier to have any demands over me. It's my lifestyle, my choice of what I want to do, when I want to do it and I wouldn't want an electricity or a gas supplier to tell me or be able to have charge of it and turn it on or off. No, I don't like it all to be honest. (P55, ICE)

They're putting constraints on what you can do and when you can do it, and I like to live my life; I don't like being told what I have to do with it. (P53, ICE)

In particular for PiV Innovators who charge through solar power, this tariff was felt to be a hindrance.

I think for solar panel users, that option two [MC] is kind of unfair, because it will cut your power off, and you're generating your own anyway. (P40, PHEV)

One participant described that, during the winter, they will set the timer so that the car is warm at the time they get into the vehicle – a feature which they considered to be 'a really serious advantage'. They felt that the MC tariff would prevent this.

I've got mine programmed so that it finishes charging just as I want to use it the next day. And, at that point, while it's charging it will turn on the heater and warm the vehicle up...if the supplier has control of the charging, and can turn it on and off as it suited them, it wouldn't necessarily finish at the right time, and it wouldn't necessarily have the vehicle prepared with the windows defrosted. (P14, BEV6)

Another concern was a lack of knowledge relating to the car's level of charge at any particular point in time.

You are reliant on them charging your vehicle and you don't know whether it's charged, half charged, not charged at a particular time of the day. (P55, ICE)

If I wanted 60% charge and I wanted it by 2.30 in the morning, for the sake of example, and I got up and I went to get in my car at 2.30 in the morning and it only had 40% because there'd been a drain on the system. I suppose, it's a bit like range anxiety, in a way, range anxiety in your own home, where at the moment you've got complete control. (P3, BEV6)

5.9.6.3 'Damaged batteries'

A few participants were uneasy with the concept of the energy supply to their PiV's battery potentially turning on and off throughout the charging period, with the belief that this may damage the battery.

They [batteries] don't like being stopped and started. So that was a technical thing that sort of worried me. I guess that whoever is designing this sort of concept has probably thought of that, but for me I've got a bit of a background in batteries as well and I've always been told never to top it up a bit and then top it up again. (P28, BEV18)

I don't like the idea of the supplier switching the charging on and off remotely, to suit them. Firstly, that's well known to damage batteries when you recharge them, if you're messing about charging, stop charging, recharging, stop charging, that will destroy your battery life quite quickly. (P26, BEV18)

It's going to be tripping the car on and off. That makes me nervous because the charging unit...I don't think it particularly likes it going off and on within the same plug. (P7, BEV6)

I don't know if that would be particularly good for the vehicle if it was constantly getting interrupted...I think it even says that within the manuals and stuff, you shouldn't do that. (P42, PHEV)

5.9.7 Expected and required savings of each tariff

The savings that the participants would expect to make or require in order to move to each tariff were discussed. These are summarised below.

- The general consensus was that neither tariff would result in substantial savings for consumers.
- In order to move to either tariff, some participants suggested that they would require a bill reduction of between 25% and 60%.
- A commonly-held opinion was that financial savings are not important, as the current cost of charging a PiV is generally very low.
- Some participants reported that they value flexibility of charging above financial savings.

5.9.7.1 *Expected savings – Time of use*

Some participants discussed the amount of savings they would expect as a result of using the ToU tariff²². A couple of PiV Innovators expected that they would make a financial saving, particularly if the tariff applied to other household appliances.

We could potentially save as much as maybe 30%, because so much of that power is used on things like the washing machine and tumble drier and things that could probably be done during off-peak that are currently done during the day, those kind of appliances that really use the power. So I think it could probably save quite a lot generally speaking on that kind of tariff. (P11, BEV6)

Because it is only a plug in hybrid and a small battery...it might save me maybe two or three pounds a month...I've bought a 30 grand car that's depreciating at £4000 a year, a pound saving a month isn't significant. You know £20 a year, it's still not significant. (P36, PHEV)

However the general consensus was that the tariff would not result in a noticeable saving, particularly compared to the existing Economy 7 time of use tariff.

I think the tariff isn't very generous for the overnight to be honest, 20% off whereas Economy 7 is 50% off. (P28, BEV18)

Financially, it probably wouldn't make any difference to my bill, we probably use quite a lot of electricity during peak times, so there wouldn't be any financial advantage, I don't think. (P18, BEV18)

A couple of participants felt that the tariff, as described in the example provided to participants, would actually result in an increase to their energy bill.

The most you'd ever save by charging at a time that suits the power company is 20%, and then at other times, you'd be penalised...well, for me at the moment, I'm saving way more than 20% by charging on Economy 7. (P41, PHEV)

If we end up spending a lot more on the electricity we're using during the daytime, that may outweigh the charging benefits, when I can do a lot of my charging at work anyway. So, I think it'd probably work out about the same, maybe even slightly worse off. (P23, BEV18)

A number of participants did not feel able to comment on the expected savings (or otherwise) associated with this tariff – and with the MC tariff – either due to not being aware of their current electricity bill, or not being able to calculate the effect of the tariffs, during the interview.

5.9.7.2 *Required savings – Time of use*

When asked how much savings would be required in order to move to a ToU tariff, responses ranged from a third to 60%.

It would have to be substantially, substantially cheaper than the standard rate tariff to attract me...it would need to be about 30% [cheaper] I think. (P49, ICE)

You could probably bring it down by a third or so...that would be very acceptable if we could manage it. (P31, PHEV)

²² Responses were based on the information provided to participants prior to the interview – see Appendix C

Well I have already got a tariff advantage by being able to charge at night. At the moment that suits my needs adequately. It would have to be probably half again, say three pence a kilowatt hour, but then I don't suppose they can produce it for that. (P39, PHEV)

I guess the rate would have to be half what I'm paying now, so it'd have to be, we're paying 10p, so it'd have to be 5p or less before I'd even consider it, I think. (P9, BEV6)

I think the lower rate should be 60% lower overnight. (P10, BEV6)

Some participants felt that a PiV user on the ToU tariff would be penalised for charging their car during the day (as the information sheet indicated the weekday peak rate would be 20% higher than the standard rate):

I don't think you need to penalise them during the day because anybody who wants to save the money is going to go for the overnight option anyway...it would be better to give them 50% off overnight and not penalise the daytime use...psychologically I instantly went 'well I don't want to pay more'. (P28, BEV18)

I wouldn't want to pay 20% more than the standard rate at peak times...effectively I'd be being penalised for carrying out my normal daily life. (P3, BEV6)

You would be being penalised for charging at peak time and it depends on what people's own circumstances are. (P1, BEV6)

If you plug it in before 8 o'clock in the evening, well, we're going to charge you a penalty...you may be forced to do it earlier. And people would be upset about that. (P55, ICE)

One PHEV pioneer acknowledged that savings are likely to be less significant for them compared to for BEV Innovators.

Say I was saving £20 a month, yeah I'd be interested. But if it's less than a tenner a month, it hardly seems worth it. I think that would be a very different answer for a pure electric driver. I think it's because I'm a hybrid driver that the savings are relatively minimal. (P36, PHEV)

5.9.7.3 *Expected savings – Managed Charging*

The general opinion amongst participants was that, based on the information provided, the MC tariff would not result in substantial savings, with a couple of BEV Innovators estimating annual savings of £30 or less.

Financially, 12% incentive that's £30 a year from my current rate costs, to go through quite a lot of fuff, if you like, so unless I had to do it because the grid locally wasn't up to it, I wouldn't do it, initially. (P18, BEV18)

It's not going to save me, personally, that much... I probably really paid about 150 quid [on electricity for the car in the past 12 months]. 12% of 150 quid, well, it's okay, but it's not going to be a major driver. (P22, BEV18)

The figure of 12% was largely felt to be too small, resulting in little or no financial benefit.

I was slightly disappointed to find that charging rate would be a standard rate minus only 12%, so that wasn't enough incentive, given that you were giving almost total control to the electricity company as to when they charged it or not, so they ought to reward you with a better discount. [What kind of incentive do you think you would be looking for then?] Well, at least the same as the time of use tariff, 20%; 12% seemed a bit mean. (P56, ICE)

If it was just the car charging was the standard rate minus 12%, as an example, that wouldn't be a massive financial advantage to me. (P30, BEV18)

I think that from a user's perspective, they're not going to get such a financial advantage of using it, so they're not going to benefit as much initially. (P5, BEV6)

5.9.7.4 Required savings – managed charging

The level of savings which would incentivise PiV Innovators to move to a MC tariff was generally similar to those required for the ToU tariff.

I would be looking for 25%, because somebody else is controlling your life. (P38, PHEV)

To put up with the restrictions, and to sort of try and work my life round it, I would be looking for at least, sort of, 50%. (P48, ICE)

One participant suggested that the reduction should apply to the whole electricity bill, and not just the MC elements of it.

I think 12% off £2 or whatever it costs to charge, it's too little. It should be if you let us only charge your vehicle for this we will reward you by giving you 12 per cent, 10 per cent off of your total bill. (P37, PHEV)

5.9.7.5 'It wouldn't matter so much'

A number of participants stated that financial savings are not important to them or to other PiV users.

Our main concern isn't economic, so making marginal savings on energy costs versus the convenience, you know. I'm not convinced. I kind of find, you know, it costs maybe a pound or two pounds to charge the car. (P17, BEV18)

The cost saving would not be of much importance to me - of secondary importance, anyway, in comparison with having a car that I can use. (P58, ICE)

I don't personally see [the cost of energy] as being the barrier to adoption of electric vehicles...I don't think that the cost of electricity is at the forefront of the lifestyle change that they make. In fact, the cost of electricity arguably is the least important thing in the overall mix. (P44, PHEV)

To me, it wouldn't matter so much, as I say, even the cheaper rate, I mean, I'd be happy to be involved with something that sees the whole system running more efficiently, they wouldn't need to offer a discount to get me on it. (P25, BEV18)

Several participants recognised that they could make a cost saving, but did not consider the current costs to be substantial, and so any saving would be insignificant to them – particularly if a proportion of their charging took place at work or using public infrastructure.

The costs of charging, unless the costs change dramatically, are not very great. I mean, to me, it's a remarkably cheap thing. (P8, BEV6)

If I was paying for every bit of the electricity that goes into my car, I think I would be spending all of about £25 a month, you know? And coming from a time when I was spending £150/£160 a month on diesel, that is...not huge. So I don't know, I see it more as a thing to encourage electric vehicles on a societal scale than something I would personally be taken by. (P6, BEV6)

I might be charging up once a week. So it's a couple of pounds a week...obviously I'm not paying for petrol, so I don't think about it. (P7, BEV6)

However some also held the view that people would be keen to make any savings wherever possible.

If it is something which saves people money, they'll do it...if there was a cost advantage of one over the other, I would choose the cheaper one. (P55, ICE)

As long as the off-peak was less than the current rate I'm paying now, that would be all it would need to be. So, I don't have a figure in mind, but if there was a saving to do it overnight, I'd be happy to look at it. (P42, PHEV)

To me it's all about the financial side of things being...a one salaried household, it's all about saving the money. (P50, ICE)

As long as you maintain flexibility in some shape or form it just then comes down to price. (P44, PHEV)

5.9.7.6 'I'd rather have the flexibility'

A number of participants stated that they would value flexibility of charging above cost savings.

Anything that allows us to have increased flexibility in terms of when we charge to gain the maximum benefit from it, works for us. (P31, PHEV)

I think the whole idea of personal transport is that you have the ultimate flexibility of getting in it and going when you want to, and if any of this removes that or reduces that flexibility, it would be a disadvantage. (P30, BEV18)

You'd have to look at the costs. I mean, there are times when, perhaps, you would have to look at the inconvenience, if it's going to be considerably cheaper. But, if it worked out that there really wasn't very much in it, then I'd probably stick with the more flexible system. (P48, ICE)

5.9.7.7 'Knowing what it's costing'

A few participants stated a desire to know the precise savings, including the savings that they would make per charge.

I think people need to see actually how much savings they're going to make, people like it in pounds and pence. (P49, ICE)

Maybe just knowing what it's costing. Today it's cost £3.75 to charge and yesterday it only cost £2.05; just knowing exactly would be nice because when you fill a car up at a petrol station you know roughly what it's cost you. (P29, BEV18)

5.9.8 Overall preference for Time of use or managed charging

Participants were asked whether they prefer the ToU or MC tariff. Their responses are summarised below.

- In our sample, some participants preferred the ToU tariff and some preferred the MC tariff. The ToU tariff was the most popular option, with a statistically significant difference in preference ($p < 0.05$, one-sample chi squared test, 46 participants stated a preference).
- The MC tariff was slightly more popular amongst BEV Innovators than PHEV or ICE vehicle owners. This was particularly true for those who had owned a BEV for more than 18 months.
- Some participants did not state a preference, either because they were not able to decide between the two options, or because they could not envisage either option fitting their lifestyle.

There were mixed responses when asked which option would be preferred, should participants have a PiV in the future. Some stated that they would choose whichever option was the cheapest for them.

I'd have a look at the tariff, see if it worked for me and if it did, I'd go with it. I tend to look at the cheapest. (P46, ICE)

My ideal tariff is the cheapest tariff available. (P6, BEV6)

I am perfectly happy to change the tariff every year if need be, to go for the one which is cheapest for the amount that we use at the time. (P8, BEV6)

Overall, the ToU tariff was the more popular option, but a large proportion also stated that they would use the MC tariff.

Amongst participants who own an ICE vehicle, there was a tendency towards opting for the ToU tariff, although a few said they would choose the MC tariff, and others stated that they would have either or neither of the two options.

Amongst BEV pioneer participants, there was a fairly even split between preference for the ToU and MC tariff, but again there were participants in all categories, with a fairly large proportion choosing either or neither tariff. Among those with less than 6 months' experience of owning a BEV, there was an even split between ToU, MC and neither tariff, whereas those with more than 18 months' experience had a slight tendency to prefer the MC tariff.

Amongst PHEV participants, the ToU tariff was more likely to be chosen, with only a small proportion stating that they would adopt the MC tariff.

Reasons for choosing the ToU or MC tariff are described below. Many have already been discussed in this section, but the following summarises the factors mentioned when participants were asked which of the two tariffs they would choose.

5.9.8.1 Reasons for tariff choice

Participants were asked to explain why they chose the ToU or MC tariff. Most of the reasons aligned with the advantages assigned to each tariff, i.e.:

ToU:

- Easier to understand
- Fitting in with charging routine
- Perception of more control

MC:

- Benefits the energy supplier/spreads the load
- Being 'the future' of charging

For both tariffs, some participants chose the tariff as they felt it would offer greater savings to them.

The certainty with which participants chose one of the two tariffs varied, with some having a very strong opinion, and others less so. For example, two of these participants offered a range of motivations for choosing the MC tariff, while the other two were less certain of their choice:

It would be cheaper and it would be more socially responsible and I could control it all with the phone which I already do for my charging, so. I mean it would just be a no brainer, why wouldn't you do it. (P4, BEV6)

It's a cleverer way to manage the grid load, and I can understand that's something that needs to be done if lots of people take up battery electric vehicles, so for the greater good, for the cause. (P18, BEV18)

Something like tariff two is probably quite close to something that could work. But, it would need to tie up with the vehicle as well, and I'm not quite sure how you would do that. (P43, PHEV)

I'd sign up to that...probably in preference to the first one, although to be honest, the first one, I don't mind either. (P21, BEV18)

Likewise, these participants illustrate varying levels of certainty in their choice of the ToU tariff, with some choosing it as they perceive it to be a more favourable choice than MC, but perhaps less favourable than their current tariff:

I think the time of use tariff, I think it's simpler, it would be cheaper, it would be more reliable, and I'd prefer that, I think. (P25, BEV18)

I like the convenience of the time of use tariff, where you've got that routine there, you know you can plug it in and just forget about it. So, probably more likely number one [ToU]. (P54, ICE)

If I had to choose between the two, I would not choose the one where the supplier controls it, absolutely not. (P26, BEV18)

Both of these tariffs would have to have a serious tariff advantage to what I've got now...I can't see option two [MC] being an option that I would contemplate. (P39, PHEV)

5.9.8.2 *Reasons for choosing neither tariff*

A number of participants stated that they could not envisage adopting either tariff in the future, or were not able to choose their preferred option. Reasons for this included:

- Lack of charging routine:

I would never be able to say, even on a weekly basis, that I know when I'm going to be around. (P59, ICE)

I think for me it would be whichever tariff...in a sense, it wouldn't really matter. For me, I'm relatively so flexible that whenever it was the most advantageous to charge, is when I could almost certainly do it...if either tariff became available, I would adopt it, yes. (P8, BEV6)

- Being happy with their current tariff:

I've got the perfect tariff for me now. Unless somebody else comes out with a green tariff option that allows me free access of network of chargers through the country. (P10, BEV6)

For us, there's such a vast period [on Economy7] from 12.30 until 7.30 or 1.30 to 8.30 during the summer, it's such a good range anyway, that we'd probably stick with that rather than switch to a special tariff. (P20, BEV18)

- Needing further information on the exact cost savings of both options:

I'm not fussy about either, frankly. I think it would probably be down to cost advantages. If there was a cost advantage of one over the other, I would choose the cheaper one. (P55, ICE)

- Not being in a position to choose a tariff based on savings:

I wouldn't. I really wouldn't [adopt either tariff]. No. No. I was just thinking, what about if it was like half the price. And no, I can definitely see that there's a saving to be had and a cost benefit. I'm just fortunate enough to not have to need that, if that makes sense. (P8, BEV6)

- Neither tariff being compatible with solar charging:

None of them, because my hope is that, for a good six months of the year, I will be charging my car up for free because I'll be doing it on solar, and then when I do have to charge it up, it really suits me at the moment because I'm on Economy 7. (P41, PHEV)

I don't think that either of them would make any difference because of the fact that we have solar panels. (P24, BEV18)

- Not being able to decide which would be the preferred option:

Could I leave a question mark on that? I'm on the fence. (P29, BEV18)

Neither of them make sense for my scenario, so I think you should say that they don't make sense for me at all. (P16, BEV18)

5.9.8.3 Stipulations

Some participants stated that they would only be willing to adopt either tariff if there was an option to 'override' the instructions on the tariff, so that they could revert to standard charging when required:

[So you'd still want to be able to override it?] Yes, so with that caveat then I would be happy with the time of use one. I think you could say that for both of them I suppose. (P60, ICE)

I would say option two [MC] but I would like some sort of manual override. (P22, BEV18)

I think that as long as I had override I would look at whatever one was more cost effective. Because as long as you maintain flexibility in some shape or form it just then comes down to price. (P44, PHEV)

You'd almost want to make sure there is an override [for MC], that you can take control back yourself to ensure, if you had a definite journey the next day, that you relied on having a full charge. (P1, BEV6)

As long as there were flexibility within these systems to say, I need to override any pre-set criteria and get something immediately, as long as that facility were in existence, I wouldn't anticipate it being a problem. (P30, BEV18)

I would rather have that facility where I can just manually override it and say, look, I need charging now, just to be on the safe side. (P22, BEV18)

Another participant would choose the ToU tariff only if "the installation of the smart meter and the communication infrastructure is going to be very low cost, a token cost of say 30 or 50 quid...if I'm expected to pay hundreds of pounds for the privilege of upgrading my system, then I just wouldn't do it" (P36, PHEV).

Being able to trial the tariff prior to committing was an important consideration to one participant.

I do like the idea of the managed charging tariff, if it spreads the load on the grid and potentially maximises your money saving. I'd want to be able to trial it first before committing. Check that it fits my personal circumstance. (P1, BEV6)

5.9.9 Questions posed by participants

As discussed in section 5.9.1, understanding of the two tariff options amongst the participants was varied, with some not demonstrating comprehension of either of both of the tariffs. The tariffs are currently abstract concepts and so a high level of understanding was not to be expected, and in many cases the participants discussed situations which were beyond the current level of available information.

During the interviews, participants were asked whether they thought the two tariffs would fit in with their general household energy consumption. However this was an area of great uncertainty, particularly in relation to the MC tariff, and so tended to be a topic about which questions were asked by the participants, rather than answers being given.

This section presents the questions asked during the interviews about the two tariffs.

5.9.9.1 Managed charging

- How would it work?

How's it going to know when you've got your car plugged in? (P48, ICE)

How will it cut the power? (P48, ICE)

Yes, how would it know it was charging the car? (P48, ICE)

You wonder, how do they decide when it's your turn. If you're the last one to get charged each time. I wonder if you would see a pattern of when you're getting charged. (P1, BEV6)

How does the supplier tell my infrastructure when to turn it on and turn it off? I would imagine that it would be over the mobile network, the same as the data is collected. Is that right? (P39, PHEV)

How would they control the power, would it be through smart meters? (P12, BEV6)

- Would it affect all household appliances?

When you say that the electricity gets switched off, does that mean switched off for the whole house? (P48, ICE)

I don't know if anybody's got any plans on the managed ones to provide separate circuits, because that would make a huge difference as well. I suppose that's how they're going to do it, isn't it?...What I mean is, you would connect the car and the dishwasher and the washing machine, like you used to with economy four, onto a separate meter that was only available between certain times. (P27, BEV18)

Well the managed charging tariff to me just seems unrealistic because why would I want to have my washing machine switched on by an outside source when it might not be ready to be switched on? I don't understand to be honest. (P59, ICE)

Presumably the tariff goes to the property and not just for car charging? (P39, PHEV)

I am not quite clear whether its talking about turning off the car charging meter or turning off my supply, on and off? I guess it must be just for the car supply. (P28, BEV18)

Does it switch all of my electricity all over or is it just that particular appliance? (P28, BEV18)

Would that tariff be the whole house that would be metered, how does it work? (P18, BEV18)

5.9.9.2 Time of use

- How would it work?

How are they going to know that you're using the electricity for your car and not everything else? (P48, ICE)

I'm assuming they would probably have to put in some kind of second meter. (P48, ICE)

There is obviously the variable rate, so you could, if you felt like it, charge your car at a specific time of day, or it could charge your car at a specific time of day to take advantage of that and I don't know how they're planning on measuring that it's your car? (P24, BEV18)

Would they just know that you'd plugged it into a normal socket, or would they provide you with some sort of jack...they'd know by your smartphone, and tell you when to plug it in and stuff, so they'd be closely monitoring the output of your meter, if that makes sense? (P54, ICE)

When you set it at that for every day until you change it?...would you programme for the Monday to Friday and then Saturday and Sunday would be different or do you have to change it every day? (P47, ICE)

I'm presuming that cheaper, off-peak tariff would apply to every other electrical appliance in your property, or would it just be for vehicle charging? (P30, BEV18)

- Would there be any long term effects on the grid?

Well, if everyone uses it at night, then the peak is going to be at night and then it's all going to change...down the line, isn't it? I mean, the managed charging tariff is the one that will be more sustainable, but if everyone got electric cars and everyone was on tariff one, the night rate would no longer be the cheapest, would it, because it'd be the most in demand? The question is, will the electric car take off that much? (P50, ICE)

5.10 Case studies

Six case studies are presented, illustrating the accounts of six participants by current vehicle type and preference for MC or ToU. These case studies should not be considered to reflect overall opinion, but provide an indication of the various perspectives encountered and how the various themes identified in the analyses were reflected in a selection of individual accounts.

5.10.1 Case Study 1: BEV pioneer with preference for ToU tariff (P5)

Experience with PiV	
PiV purchased as a second car	<i>The Nissan Leaf is a second car, which we chose primarily for...short journeys, and we would take the hybrid car for any longer journeys.</i>
Reason for purchasing PiV	
Motivated by environmental factors	<i>I've always tried to be as eco as I can, and I'm absolutely delighted that...I've got to drive a car with no emissions, and which, I believe, at least is doing something towards helping the environment.</i>
Initial cost of PiV was a barrier	<i>I had been interested in buying the Leaf probably more than 12 months prior to the purchase, but had not been able to afford it.</i>
Conducted thorough research	<i>I wanted to seriously investigate buying a battery electric car, I did do a lot of research...so, when I actually did buy the car, I already knew quite a bit about electric cars and the difference between plug in hybrid and pure electric, and the pros and cons of each.</i>
Current charging routine	
Uses the car timer to charge vehicle overnight for environmental, rather than financial, motivations	<p><i>The car rather nicely has a timer built in, so when I know I want it fully charged for the following day, then when I've finished using it for the day, I simply plug it in and forget about it. The charger will switch on at 2am, and will then take...anything from two to four hours...and then it will switch off. The timer's set to switch off at six.</i></p> <p><i>I generally do that overnight.</i></p> <p><i>Purely because I understand it's better for the grid.</i></p> <p><i>I don't have any financial incentive for charging overnight, but I just feel it is more convenient for the electric grid, for the planet in general. I think that there's fewer coal fired stations working at that time in the morning as well, so the electricity I'd be getting would be a bit cleaner.</i></p>
Considers availability of charging points when selecting leisure destinations	<p><i>If we want to go out at the weekend, I'm not just looking for what nice National Trust property there is to go and visit, I'm looking for National Trust property that has got charging facilities.</i></p> <p><i>I try to favour going to a shopping centre that I know has got some charging posts, so I can arrive and plug it in and have it charging whilst I'm shopping.</i></p>
Selected energy supplier due to environmental factors	<p><i>I changed the energy supplier...a couple of years ago, for environmental reasons.</i></p> <p><i>I heard about Ecotricity. There is another one called Good Energy, who, both of them promise to supply the national grid with 100% renewable electricity, and I felt, well, that sounds sensible.</i></p> <p><i>I'd like to think that part of the profit that they're getting out of me as one of their customers is then going to be ploughed back into improving the infrastructure for the electric highway, and also for putting up more wind turbines and other renewable sources of energy.</i></p>

Tariff payments are confusing	<i>I probably won't know until the end of the first year of owning the electric vehicle, by the time they've balanced out all of the payments. Hellishly confusing.</i>
Views on ToU tariff	
Would receive a financial benefit rewarding existing energy usage / charging behaviours	<i>It encourages me to do what I'm doing anyway, and would give me a financial bonus for doing that, whereas at the moment, I've been very happy to do it, if it doesn't affect me, but I know it's helping. If I could get some financial reward, I think it'd be brilliant. I just try to run things at night. It would be good if there was a financial incentive to do that, because others in the household would then do the same.</i>
Concerned that tariff would not be sustainable if PiV adoption increased dramatically	<i>If everybody in my town had an electric vehicle, then I don't think that [tariff] would actually work...I think that would put too much strain on the infrastructure. I can't see any disadvantages until such a time as ownership of EVs becomes so large a proportion that the demand for charging electric vehicles begins to outstrip the standard domestic demand...that is then just going to shift the problem to later on at night.</i>
Views on MC tariff	
Concerned about relinquishing control to energy supplier	<i>Because you don't have the control, there may be times when there's a change to what I've predicted, and the network may not have automatically charged the car sufficiently for what I need. I would be losing some control. My perception is that I could be losing some control over how and when I charge the car.</i>
Less financial benefit than ToU tariff	<i>I think that from a user's perspective, they're not going to get such a financial advantage of using it, so they're not going to benefit as much.</i>
Appreciates the societal benefits of MC to manage increasing energy demand	<i>For society, then that is the better option, in ten years, 15 years' time, when there are more electric vehicles, then that is going to be the only way to manage the demand on the grid, without having to drastically change the infrastructure. If it got to the stage where everybody had an electric vehicle, without having to rewire the whole national grid, I can appreciate, we'd all have to go to something like the option two [MC].</i>
Likelihood of adopting either ToU or MC tariff	
Benefits for both tariffs	<i>Yes, if I adopt either of these, it would save money, and I would save more money from option one [ToU tariff].</i>
Keen to adopt ToU tariff	<i>I'd do that tomorrow, if Ecotricity offered that, I'd do it tomorrow.</i>

5.10.2 Case Study 2: BEV pioneer with preference for MC tariff (P21)

Experience with PiV	
Owned a BEV before	<i>The initial Nissan Leaf that we bought was in November 2013, and in September 2015, we replaced it with another new Nissan Leaf...I was sufficiently pleased with the experience to buy another one.</i>
Reason for purchasing PiV	
Not originally interested in purchasing a PiV	<i>I got approached by Nissan saying, 'try this', and I was going to do a report on it for our website, the Stretton Climate Care website. It was only actually in the process of driving it – it's so quiet, it's so smooth – these things suddenly became really tremendously attractive. I mean, it is a very different experience from driving an ordinary car.</i>
Promotes energy efficiency through climate care charity	<i>Vice Chairman of Stretton Climate Care, which is a charity which is obviously doing low energy, energy efficiency things, and we have got the...well, we had the first, and until just recently, the only electric charging point in Shropshire.</i> <i>There is a degree of wanting to encourage the promotion of purely electric vehicles here.</i>
Believes PiVs are the cars of the future	<i>I have driven the future.</i> <i>I'm firmly of the opinion that these will eventually be the cars of the future.</i>
Expects that improvements in technology will increase range	<i>The lease that I've got it on will come to an end in 2017 or so, and by that time I anticipate there'll be a completely different generation of electric cars on the road, with at least a 200 mile range, and things like that, and it will be a lot better. But, I wouldn't want to go back to a diesel or a petrol car now</i>
Current charging routine	
Solar panels provide some electricity to the household	<i>I could plug in my car and basically charge it from the roof.</i> <i>The grid pays me about 3.3 to 4p a unit for every kilowatt hour they take from my roof, and I have to pay them about 16p for every kilowatt hour I take back from them. So, it's worth my while using as much as I can of the energy that the array, the PV array generates, for my own use, as possible.</i> <i>The sun comes out, we'll do the vacuuming</i>
Charging behaviours	<i>I would say about 90% of the charging I do is at home, and of that, perhaps half is overnight.</i> <i>When I get enough power from the roof, I will plug the car in on its slow charger.</i> <i>I look forward to, one day, there being some sort of software that will enable it to turn itself on and off, as the sun goes in and comes out again, but at the moment, that's not available.</i> <i>The general way in which I'm going to be charging the car is probably to use the slow charger, which is two kilowatts, and if the sun is shining</i>

	<i>during the day, that's fine, and if it's not then I'll just plug it in overnight and it will just top up...you don't often run it right down to flat; you come in, it's about 30%, and you just plug it in overnight, and then in the morning, it's done.</i>
Acutely aware of electricity costs	<i>Before I got the car, the usage that we had was about 1,800 kilowatt hours per year, and it pretty much doubled with the car. You do become very knowledgeable about the capacity of all electrical equipment...the dishwasher is three, the cooker is 2.5, the washing machine is three. So, you get to think, right, we can use three kilowatts now, so you turn it on. I have a monitor of my electricity usage, as well as the one that tells me how much I'm producing.</i>
Views on ToU tariff	
Charging behaviours could be altered to fit ToU tariff	<i>There are times in the day when it's going to be more expensive to charge your car, so you're going to be less likely to charge it at the expensive time unless you need to, I suppose.</i>
Views on MC tariff	
Impressed with concept of MC	<i>I have absolutely no trouble with that at all. I would say, if you can do that, Sunny Jim, I'm dead easy with that. I think that, really, if you move into the area where your supplier is able to switch charging on and off remotely to deliver your required charge on time.. I'd actually see that as a solution. It's quite exciting to think that might be capable of being delivered.</i>
Felt tariff could be applied to other household energy use	<i>I mean, the idea that you could have not just your car, but also your freezer and other things turn on and off as required to manage the peaks and troughs of electricity demand are really good ideas.</i>
Identified benefits for society	<i>I actually think that unless you have something of this sort, then you won't be able to have a substantial electric vehicle sector, because they're going to be drawing an awful lot at the wrong time. You've got to have something like this that manages it. The benefits to society in general of having a smoothed energy demand curve are immense, and actually really important in terms of our long term future.</i>
Likelihood of adopting either ToU or MC tariff	
Would adopt MC tariff	<i>I'd probably go for...the dynamic managed charging tariff...I don't think it makes that much difference, in terms of, I have to do the same thing; I just tell you when I want the car – but, I think from the point of view of the supplier it gives them more flexibility, and would therefore be well worth giving me a discount on my basic tariff, so that's pretty good.</i>

5.10.3 Case Study 3: PHEV pioneer with preference for ToU tariff (P42)

Experience with PiV	
Company lease car	<i>It's a company car, so it's handy – where I work has a plug, so I'm able to plug it in whenever I get into work so I'm able to charge it there as well.</i>
Suitable for short journeys	<i>If you were going to be doing hundreds of miles every day, it wouldn't be the vehicle for you; it really is suited for short term journeys.</i>
Reason for purchasing PiV	
Tax savings were the most significant factor	<i>To be honest with you, it was the tax benefits were the main reason, the savings and benefit in kind were a big driver for it.</i>
Likes the size and styling of the Outlander	<i>It's a nice car; it's a Jeep type vehicle, so that's what I've driven previously, so I suppose that's why I went for this model. The hybrids would seem to be more of a nicer style of vehicle; they'd be bigger vehicles, and I get the impression that the fully electric would be smaller type vehicles.</i>
Did not anticipate the savings on running costs	<i>It's cheaper to run as well...I didn't realise the savings I'd make, but it's certainly saving me a lot of money in running costs as well, refuelling and everything else.</i>
Current charging routine	
Charging is an inconvenience but cheaper than petrol	<i>It's the hassle of having to plug it in and make sure that's done before you do your journey. There's a bit of hassle, but probably the savings outweigh the hassle. I suppose you have to [recharge at home]...there's no point in driving this on the petrol, because it just is far more expensive.</i>
Home charging routine is dependent on upcoming journeys	<i>If I know I'm going to be doing 20, 30 miles, I'll make sure it's fully charged. If it's down to ten or 12 miles, and I know I'm only going to be doing a few miles, I wouldn't necessarily charge it then, but it's just putting a bit of thought into what your journeys are going to be.</i>
Charges at work if the charge point is available	<i>It's potluck if I arrive in work and there's someone else parked there, I don't get to do it, but if I get in and the plug's free, I'll plug the car in there.</i>
Favours rapid chargers and would like more to be available	<i>I would never use any of the longer charge stations when I'm out. I just think if it's going to take two or three hours, it's not worth it, but if I can stop somewhere and get a 20 minute charge, I would do that occasionally. There's not that many of them, in fairness. The closest one to me would be 18 miles away, so it's not readily available.</i>

	<i>I think that would influence me more when I'm changing the car again, if there was more rapid chargers available, that would certainly interest me more.</i>
Views on ToU tariff	
Liked the potential to save money if the time periods were clear	<i>I suppose anything that's going to save you money, and it doesn't really matter when you...if you know it's going to happen, I wouldn't have an issue with it. If I knew when the times were, I would certainly be looking to maximise that for the items in my house.</i>
Potential increase in cost for charging at peak times	<i>[If] you weren't able to use the off-peak facility...it would cost you more in reality than it may have cost you before.</i>
Views on MC tariff	
Concerns about the impact on the vehicle's charging capability	<i>In principle, [it] sounds okay, it just depends on that the system could follow through and make sure it happened, and it's not going to be constantly turning things on and off. I don't know if that would be particularly good for the vehicle if it was constantly getting interrupted. I think it even says that within the manuals and stuff, you shouldn't do that.</i>
Would not work with other household energy use	<i>It's not going to work, is it, if you have a dishwasher and all of a sudden it's turned off and on, and things like that – I don't think that's going to work.</i>
Lack of control over the charging rate	<i>I can understand the benefits of it, if it was a smooth block that you got, but I can't see it being something I'd want to use, knowing that you didn't have that much control. You've no control over when you know the tariff's going to be lower, so really, you're at the mercy of the power company. So, as long as you're happy with the rate you're going to be paying the rest of the time, you're really at their mercy as to when the best rates are going to be.</i>
Likelihood of adopting either ToU or MC tariff	
Would adopt ToU tariff if it was cheaper than the current tariff	<i>It'd have to be a good deal, better than the current tariff I'm on. So, if it was better than that, I'd have no issue with it. I think as long as it was less, so as long as the off-peak was less than the current rate I'm paying now, that would be all it would need to be. So, I don't have a figure in mind, but if there was a saving to do it overnight, I'd be happy to look at it.</i>

5.10.4 Case Study 4: PHEV pioneer with preference for MC tariff (P35)

Experience with PiV	
Previously had a low petroleum gas (LPG) vehicle	<i>I do quite a bit of mileage a year. Previous to this I had an LPG car, which helped cut down the costs, but when I saw the Vauxhall Ampera I was quite taken with it and actually came into some money, so I thought, well, a good way to spend it.</i>
Reason for purchasing PiV	
Lower running costs	<i>My running costs before would be maybe about £8 a week on the LPG. I've cut that down to like £2 or £3 on electricity.</i>
Battery electric vehicle range is not sufficient	<i>Electric-wise, there was no other car that could have done what the Ampera can do for what I need. The lighter range just wasn't enough on the Nissan Leaf.</i>
Lack of charge points near workplace at the time of purchase	<i>I work in Edinburgh and to begin with there was no charging facilities, so I had to use petrol on the way home.</i>
Current charging routine	
Charging is central to routine and plans	<i>Wherever I can, I will plug the car in to get it charged, even to the point of if it means me walking a bit further I'm quite happy to do that. I suppose my lifestyle has adapted slightly to accommodate the car. I kind of revolve around where I can get my car charged.</i>
Uses public charging points during the working day	<i>I use [a charging point at a hotel] which is half a mile from work and I've got a folding bike which I take in the boot of the car...take the car to the charging point at lunch time, cycle back to work, and at night time cycle back to the car and then head home. I filled the car up in May and then I didn't fill the car up again until November. That was over 10,000 miles...the commute is like 92 miles, and I'm just running on electricity until just before I get to work, and then again a few miles before I get home.</i>
Charges overnight on Economy 7 tariff	<i>You can set a time from the time the car starts to charge, and I have it set to use off-peak electricity and be charged just before departing in the morning.</i>
Views on ToU tariff	
Willing to adjust to get the cheapest rate	<i>I would go for something that is the cheapest rate possible, even by, you know, adjusting my charging needs.</i>

Would need to fit charging around work	<p><i>I may not be able to do that though because of the fact that I need to go to work, so I'd have to fit it around that, but I would definitely be interested in getting the cheap as possible.</i></p> <p><i>I might not be able to choose or shift to something that's a bit more suitable to me and pay dearer at other times.</i></p>
Potentially cheaper to use petrol	<p><i>It always boils down to is it cheaper to charge the car at the dearer rate or use petrol. In my case, anyway. That's only because I was reading in one of the forums that a company Charge Master, have started chargers down in Milton Keynes, and for a few Ampere drivers down there it was cheaper for them to use [petrol] than it was to pay to charge the vehicle up. So that would be the downside of coming home and finding I need to use the car again. Oh, no, it's going to cost me more with electricity than if I'd put in petrol.</i></p>
Views on MC tariff	
Flexible in terms of how the required charge is delivered	<p><i>I need at least four hours in total at the full charging rate. I don't mind if it's one hour now, a gap of an hour and then maybe three hours later on.</i></p> <p><i>Providing the car is charged up, I don't mind when the charge is up, as long as it's ready for me, as I say, like six o'clock in the morning.</i></p>
Need for guaranteed charge	<p><i>My only proviso would be that I would be guaranteed to get a full charge within the timeframe that I needed it.</i></p> <p><i>[No disadvantages] that I can see, other than an error, in which case there's not enough power when I'm supposed to get mine. If I'm allocated to get it between say three and six in the morning and for some reason there's insufficient power.</i></p> <p><i>What happens if there's a power cut. More so if it's a pure electric vehicle that I had. You know, you wake up in the morning and find there's been a power cut, well, I suppose that could happen just now anyway. If something happens to the scheduling of that adaptive power supply.</i></p>
Likelihood of adopting either ToU or MC tariff	
Would consider ToU tariff if peak rate was not too high	<p><i>If I can get a four hour window of cheap electricity and providing the other times are not extortionately high, I would seriously consider it.</i></p>
Would adopt MC tariff	<p><i>If I did the calculations and it was going to work out cheaper for me, no problem at all.</i></p> <p><i>[Of the two tariffs] I would have gone for the dynamic [managed charging].</i></p>

5.10.5 Case Study 5: ICE vehicle owner with preference for ToU tariff (P50)

Experience with PiV	
Impressed by PiVs	<p><i>It was a Nissan Leaf, and drove lovely, very quiet. I had no complaints about the car whatsoever.</i></p> <p><i>I probably was more indifferent to negative [before experiencing the EV], and I absolutely loved it; there was nothing about it I hated.</i></p> <p><i>The fact that it was so quiet was fantastic.</i></p> <p><i>The quietness of it all, and the environmental issues.</i></p>
Concerned with price of electricity and taxes	<p><i>You don't have to worry about the petrol prices, however the electricity prices, since I had the car, electricity prices have been talked about in a more volatile way, but typically, I think, with petrol and diesel and the tax that's on them, that's something where I think it's a positive, the battery electric car.</i></p> <p><i>If everyone had electric cars...the government won't receive all the tax they do on the fuel, so they'll probably tax that some other way.</i></p>
Likelihood of purchasing PiV	
Concerned by cost of PiVs	<p><i>I'd love to buy an electric vehicle...[but] unlikely because of still being a single car household.</i></p> <p><i>I would be questioning what an electric car costs would be, and the battery life. If they run out, I'm sure they must be really expensive, and what the warranty is like on that, and those sorts of things very specific to an electric car.</i></p>
Not interested in PHEVs	<p><i>[Having a PHEV] defeats the object of having an electric car, in my view. You have one or not one...it sort of solves the problem...about being somewhere and not being able to charge it, however it sort of doesn't fit why you'd have an electric car, environmentally, I suppose.</i></p>
Experience of charging	
Comfortable charging the car and familiar with Economy 7 Tariff	<p><i>I just thought it was great. I mean, I had an Economy 7 electric rate at home, so my electric overnight was really, really cheap, so it was probably more economical for me than the average person.</i></p> <p><i>I'd have probably done it most nights [if the trial was longer], one, through ease, and two, because it was cheaper.</i></p>
Would charge frequently	<p><i>I'd probably want to charge it every night, or every other night, depending how quickly it went down, to make sure I had the charge ready for whatever might get thrown at me.</i></p>
Views on ToU tariff	
Retained control of charging vehicle	<p><i>It seems like the obvious one because I can control...because I'd be quite organised to have it updated in the night which, it appears to be lower. It's a bit like my Economy 7 at home, isn't it? For me, that would be fine, I'd just charge it up at night and be done with it.</i></p>

<p>Clear pricing structure and financial savings</p>	<p><i>To me it's all about the financial side of things, being...you've got a one salaried household, it's all about saving the money, and I can save 20% lower on that one, but I can't on the other one.</i></p> <p><i>Well, it's very clear pricing, isn't it? You know how much your bill's going to be because you know what you're going to get charged, at what point in the day, whereas the other one, you don't know, because you don't know how the 100% charge is going to be made up because the pricing won't be clear. The pricing will only be clear when you get your bill.</i></p>
<p>Views on MC tariff</p>	
<p>MC than ToU tariff</p>	<p><i>For me personally, it would be more expensive, because it would be cheaper for me to do the 20% lower rate all the time.</i></p> <p><i>You're still getting a better rate, potentially. You're still getting your car charged. So, there's nothing negative about it, but for me personally, the other one is better.</i></p>
<p>Appreciates suitability for others</p>	<p><i>If you had a hectic life, where you weren't necessarily in the same place all the time, the first one wouldn't work. [This] one would be more cost effective for you.</i></p>
<p>Sceptical about energy suppliers' motives</p>	<p><i>My other concern...is that the electricity providers will gain money from that. I don't know quite why I think that, but it just feels like they'll use it to their own advantage... Because they're still in control of when you get it...so they're going to gain, technically, 8% [according to the example] aren't they, which is a lot of money.</i></p>
<p>Effect of high PiV ownership on sustainability of the tariff</p>	<p><i>Other managed charging tariff is the one that will be more sustainable, but if everyone got electric cars and everyone was on tariff one, the night rate would no longer be the cheapest, would it, because it'd be the most in demand.</i></p>
<p>Likelihood of adopting either ToU or MC tariff</p>	
<p>Would adopt ToU tariff</p>	<p><i>[Would adopt ToU because] it appears to be clearer pricing; you are in control more of how much you spend because it's very clear what your pricing brackets are, and you're in control of it, really.</i></p>

5.10.6 Case Study 6: ICE vehicle owner with preference for MC tariff (P52)

Experience with PiV	
Pleasantly surprised by performance and styling of PiVs	<p><i>Actually I came in expecting not to like [the Leaf], but I actually didn't want to give it back at the end of the trial weekend.</i></p> <p><i>More like a normal car than I thought it would be.</i></p> <p><i>[The i3] was amazingly quick, as was the Leaf actually.</i></p> <p><i>I was expecting a G-Wiz to be honest...but either the Leaf or the i3 absolutely no problems either way...I'm quite into cars.</i></p>
Concerns about range	<p><i>I don't think it would have worked as a daily vehicle, because we didn't have charge points at work. So to do a 60 mile round trip on the hope it's going to get me there and back on one charge was possibly a little bit too much than I would have felt comfortable with.</i></p> <p><i>I think 200 miles, something like that would be quite a nice comfortable distance.</i></p>
Likelihood of purchasing PiV	
Would consider a PiV for making short journeys	<p><i>My girlfriend worked just in the town where we lived...about a mile and a half away...something like the Leaf would be absolutely perfect for her. Because she could...do most of the week on a single charge.</i></p> <p><i>I've travelled a silly amount of miles up and down the country picking up parts for mine and my sons' cars. So if this was my only car then that would potentially be an issue for me.</i></p> <p><i>It would not be something that I would definitely say no to. It would be a possibility.</i></p>
Experience of charging	
Charging process was not inconvenient	<p><i>From a hardship point of view it really wasn't a major issue at all.</i></p>
Charged the battery as much as possible	<p><i>It was basically at the end of each evening that I had the car, having done about 40, 50 miles thereabouts, rather than leaving it until it absolutely had to be done. It was just better for me to know that it was done ready for the next day.</i></p> <p><i>It was a preventative thing rather than a necessity as it were.</i></p>
Views on ToU tariff	
ToU concept makes sense	<p><i>It seems to indicate almost a similar charging system to public transport almost. Where you have peak charges at rush hour times, standard charges during the day and cheaper outside of normal hours.</i></p> <p><i>So yeah, it makes a lot of sense.</i></p> <p><i>It's understanding that at these times these will be the charges. So as long as you're aware of that there isn't really much that you can complain about.</i></p>

Would like the off-peak period to start earlier	<p><i>I'm normally home around six-ish...I would probably get home, put the car in the driveway and plug it in at around six o'clock.</i></p> <p><i>I think for me personally it would start a little bit earlier than 8pm.</i></p> <p><i>If it's literally this rigid, I would possibly think twice about it...there are people in the house earlier than 8pm that are using power.</i></p>
Views on MC tariff	
No concerns about using electricity within the 'right' period	<p><i>I think it would be possibly easier...I wouldn't have to worry about making sure I'm using electricity within the right time frame.</i></p> <p><i>Whether it charges between two and four in the morning or four and six in the morning, makes no difference to me. As long as I go out there at 6:30 then it's all good. We're not paying a penalty because we're using other electricity from 4pm to 8pm.</i></p> <p><i>There wouldn't be the mass panic to make sure that everyone was on and off the roads by certain times...if it meant that your car was going to be charged by the time that you needed it. Then you wouldn't feel the need to be out there. So desperately quickly to get in the lower rate charging.</i></p>
MC tariff is more convenient	<p><i>It would seem to indicate that it's a little bit more flexible.</i></p>
Likelihood of adopting either ToU or MC tariff	
ToU tariff adoption would require changes to routine	<p><i>Part of the thing that I'm not massively keen about the time of use tariff is because from 4pm to 8pm weekdays are possible usage times. So anything outside of it would mean that I would then have to make an adjustment to what I would have probably done as part of a routine.</i></p>
Would adopt MC tariff	<p><i>For me it would be the flexibility and there wasn't a possibility of being charged more than a standard rate. But with certain allowances you could potentially make savings.</i></p>

5.11 Summary and implications

This research was focussed on the attitudes and responses of PiV Innovators – people particularly motivated to engage with PiV use in the very early market. We know from the ETI's earlier research (Anable et al., 2016) that innovators' attitudes and responses are not representative of wider, 'mainstream' mass-market consumer driver segments, so its findings cannot be generalised beyond PiV Innovators themselves. Nevertheless they have enabled us to explore similarities and differences in the ways innovators engage with BEVs and PHEVs, as well as pioneer attitudes and responses to managed charging options for integration of PiV charging demand into the wider energy system. Through 60 interviews with existing BEV Innovators, existing PHEV Innovators, and ICE vehicle owners with experience of driving BEVs, a wealth of information regarding PiV Innovators' attitudes towards PiVs and the two hypothetical charging options was gathered. Much of this was in agreement with existing findings, but some new themes have emerged in relation to PiV user attitudes and behaviours, in particular:

- Some unfavourable perceptions held by BEV Innovators towards PHEV Innovators, particularly the view that PHEVs are often purchased to benefit from tax incentives (with the electric power train being rarely used), that PHEV owners are not willing to 'commit' to PiV technology, and that PHEVs prevent BEVs from being able to charge at public charging points (despite BEV owners feeling that it is more critical for BEVs to be able to recharge).
- The current use of timers to take advantage of off-peak charging, either for financial benefit or through a desire to use electricity at times of low demand.
- The use of solar panels to charge their PiV at home, especially amongst those who had owned a BEV for at least 18 months.

5.11.1 Hypotheses and implications for trial design

The purpose of qualitative research is not to test hypotheses, but to allow theories to emerge from the data which could go on to be tested using other research methods. A number of hypotheses related to PiV consumer attitudes and the two charging options can be proposed:

5.11.1.1 EV pioneer attitudes towards PiV use

1. BEV Innovators have poorer perceptions of PHEV Innovators than vice versa

BEV Innovators tended to hold (often negative) opinions about PHEVs and PHEV Innovators; PHEV Innovators however were much less likely to hold strong thoughts on BEVs and BEV Innovators.

2. Once 'converted' to BEVs, consumers tend not to go back

BEV Innovators consistently reported that they would not 'take a backward step', and that future vehicle purchases would also be BEVs. PHEV Innovators also reported that they would purchase another PHEV, but were less keen to move towards fully electric vehicles. ICE vehicle owners who had experienced a BEV tended to state that they would consider purchasing a PHEV, but not a BEV.

5.11.1.2 PiV Innovator behaviours

3. PiV Innovators may be more likely to acquire solar panels than ICE vehicle owners

Amongst the participants, solar panels had been installed on the majority of houses owned by the BEV18 group, and on some of the houses owned by the PHEV and BEV6 group. It is not possible to say how representative this is of the general population, but amongst the sample it was reported that, where possible, charging will be carried out when energy is being produced by the solar panels. This may reduce the attractiveness of either tariff.

Implications for trial design: Whether or not participants currently have or are planning to install solar panels will need to be a key consideration during recruitment and analysis.

4. Improved deployment and reliability of public infrastructure and at-work charging may reduce the amount of at-home charging

As PiV uptake increases, the presence and reliability of public charging infrastructure may also increase. This could decrease the incidence of at-home charging, potentially reducing interest in alternative energy tariffs.

5.11.1.3 PiV Innovator attitudes to the two tariffs

5. Mandatory use of smartphones may deter many from using ToU or MC

It is likely that any tariff system which necessitates the use of smartphones to operate it will not be adopted by a proportion of the population and alternative options for engagement should be considered (e.g. web login).

Implications for trial design: If smartphone use is required, this should be made clear during recruitment. It may be necessary to offer 'tutorials' to some participants to ensure that they are comfortable with using any apps as part of the trial.

6. Among BEV Innovators, those with more experience of BEVs may be more likely to prefer the MC tariff

The interview data suggest that the ToU tariff was overall the most popular choice of the two presented, but that those with at least 18 months' experience of using a BEV were more likely to prefer the MC tariff. If this is the case, it may be because individuals who were early adopters of BEVs are more likely to be early adopters of new technology and ideas in general. It may also be because they are already more familiar with the idea of 'managing' their charging – as one participant said, "what I'm trying to do with my PV panels is do a managed charging process myself" (P24, BEV18).

7. It may be difficult to convince some PiV Innovators to consider either tariff

A proportion of participants did not express a preference for either tariff, stating that neither would be suitable for their needs. In addition, many who did state a preference also stated that, in reality, neither would be attractive to them (e.g. "I don't think that either of them would make any difference because of the fact that we have solar panels." (P24, BEV18)).

8. There will need to be a clear advantage to 'handing over' control of charging to the energy supplier

Many participants felt that they are able or would be able to 'manage' their own charging through the use of timers and time of use tariffs. There would need to be a clear advantage to relinquishing control of charging.

9. The concepts of ToU and especially MC tariffs may be difficult to comprehend in the early market²³

Many of the participants struggled to fully understand the two proposed tariffs based on the brief information provided prior to and during the interviews.

Implications for trial design: It is important that potential participants in the trial have a good understanding of the tariff. During recruitment, the following should be provided:

- *In-depth explanations of the tariffs needed including 'real life' examples.*

²³ The 'early market' is defined by the first two adoption segments in Roger's diffusion theory: "innovators" and "early adopters", those whose times of adoption are more than one standard deviation ahead of the mean time to adoption in the population (i.e. the first 16% to adopt).

- *Explanation of how it could benefit those with no strict charging routine/those who value flexibility above cost saving.*
- *Well-defined cost implications.*
- *Explanation of implications for other household appliance use.*
- *Explanation of whether participants will be able to override the tariff system.*

5.11.1.4 Limitations

Limitations of the study should be acknowledged:

- 45 of the 60 participants were PiV Innovators by definition as they were already among the first 2.5% of UK drivers to adopt. The remaining 15 had also demonstrated a motivation to engage with PiVs through participation in a previous PiV trial. Thus the participants were not, as a group, representative of mainstream consumer drivers.
- Neither were the 60 individuals with experience of PiVs representative of the general population of individuals with PiV experience. The sample was largely self-selected, often through EV forums, and so may represent individuals with a greater general interest in and knowledge of EVs.
- The information provided to participants on the two tariff options was limited, and it is possible that not all participants read the information fully. The tariffs were abstract concepts and therefore by nature challenging to discuss in any detail.

Only one person per household was interviewed, and this was typically the individual that was the sole or main decision maker when purchasing a PiV. Exploring different views within a household towards PiVs and tariff options may provide further useful insight.

6 Key findings

This report is the output for Task 2.1 in Work Package 2, consumers' attitudes and behaviours to PiV adoption and energy demand management.

The following objectives were defined for this task:

- *To update our understanding of consumer attitudes towards ULEV adoption including detail of existing and new barriers to adoption.*
- *To explore what lessons can be learned from previous consumer trials to identify risks and develop recommendations to mitigate the risks.*
- *To qualitatively explore consumer attitudes to managed charging scenarios (with consumers who have experience of a BEV or PHEV).*

To meet these objectives, the following research activities were completed:

- A rapid evidence assessment of literature to establish:
 - a. current knowledge of consumers' attitudes to EV adoption; and
 - b. consumer attitudes to managed charging, particularly expectations and acceptance of energy demand management.
- A review of 'lessons learned' from relevant previous PiV trials.
- In-depth interviews with PiV owners and mainstream consumers.

The key findings emerging from each of these activities, and the implications for the CVEI modelling framework and Stage 2 trial design are detailed below.

6.1 EV uptake

This section summarises key findings from the literature reviewed in Section 3. As noted in Section 3, while the current project is focused on PiVs specifically, it was necessary to adopt more generic terminology for appraising the wider literature. In sections 6.1 and 6.2 the most common term in the literature 'EV' is used rather than 'PiV'. While in most cases this refers to plug-in vehicles only, it is not always clear from publications in the research literature which specific vehicle types are addressed: for instance, some questionnaire studies refer only to "electric vehicles", without distinguishing between BEVs, PHEVs, RE-EVs, or HEVs. Where the specific vehicle type studied is known this is noted (e.g. PiV, BEV, PHEV, RE-EV, HEV).

6.1.1 Financial barriers and incentives to uptake

- Purchase price is a barrier to acceptance of EVs, running cost savings are a motivator. This is an important distinction because barriers can carry more weight than motivators in the process of decision making.
- The disutility associated with the purchase price of conventional vehicles is smaller than for EVs as ICE vehicles are considered a safer investment. Even where optimistic cost parity and range scenarios are tested, ICE vehicles are preferred.
- PHEVs emerge consistently (where differentiated) as more popular than BEVs, even where information on running cost savings is given.

- Current BEV owners are less financially motivated than PHEV owners. For both powertrains, current owners tend to be very aware of how much their car saves them in running costs. However, later adopters may be less willing to perform these calculations.
- The absolute and relative price of petrol, diesel (and electricity) is a confounding factor. The implied payback period of willingness to pay (WTP) may have increased recently as the fuel price has reduced. This means that increased fuel efficiency standards combined with declining petrol prices could be in conflict with incentives to encourage EV uptake.
- Where fuel prices are increasing or volatile, consumers may consider an EV as an insurance policy against future rises.
- Very few studies separate out residual value to test its specific impact. It is possible that during the consideration of a new vehicle technology, resale value 'gets lost' among a whole set of more pressing concerns.
- International comparisons suggest a positive relationship between financial incentives and EV uptake, but there are confounding examples and causal relationships have not been proven.
- For country-to-country market share comparisons to be meaningful, the combined level of incentives on offer needs to be put in the context of the total cost of ownership of the EV relative to an ICE vehicle counterpart in each country.
- All countries with a market share over 1% have had incentives in place for at least three years previously. There is insufficient evidence as to the impact of withdrawing subsidies.
- Consumers do not tend to cite the price incentive as the reason for adopting an EV, but the majority say they would not have done so without it.
- There is overwhelming consensus that upfront purchase cost incentives and circulation tax incentives play a minor role in uptake, but can be the decisive factor for certain people in certain places.
- Purchase incentives are more influential for higher value vehicles.
- Later adopters may be more motivated by material and tangible benefits and so incentives may become more important in the market place.
- Evidence on the role of other monetary and non-monetary (policy) incentives is thin, context specific and sometimes verging on the anecdotal.
- Non-monetary incentives are always introduced in the context of other financial incentives and so their relative role can be very difficult to determine.

6.1.2 Range

- Range is often cited as a greater barrier than price in straightforward attitude surveys. For example, it remains a barrier in Norway where prices of BEVs are essentially the same as an equivalent ICE vehicle.
- Estimates of the implied value of range vary widely and depend on the extent to which compensatory factors are considered (e.g. cheaper running costs).

- This evidence points to the need to estimate the fraction of consumers/households who might consider purchasing a range limited vehicle and to understand psychological barriers, rather than estimating effective costs of range limitations.
- Key factors determining the response to range limitations include: the actual range of the vehicle; the availability of charging infrastructure; the ability to adapt; existing mobility patterns; experience of driving an EV; importance of the 'option value'.
- Range is sensitive to charging time and charging availability.
- Consumers' perception of the compatibility of EVs with their mobility needs is the most important determinant of EV acceptance.
- Availability of another vehicle or travel model is reflected in perceived self-efficacy (or perceived ability for an EV to fit into existing lifestyle). Therefore, the value of range can vary widely between people with different mobility needs and for whom the availability of other travel modes differs.
- Range is widely assumed to be much less of a barrier for PHEVs as opposed to BEVs, but there is little direct evidence quantifying this.
- People do not deal with daily distance budgets with ICE vehicles and so do not have accessible and accurate representations of their needs. Control beliefs, ambiguity tolerance and coping skills play a role in the experience of 'comfortable' range. Perceived range barriers can be overcome with psychological interventions such as information, training and interface design. Experiencing an EV improves these perceptions.
- There is limited evidence on the role of the choice of makes and models. Recent work in the UK found a relatively high value to be placed on the availability of EVs in the consumers' preferred top three brands. This suggests that brand loyalty rather than extensive choice is the issue and this finding may explain why choice experiments that have used more generic metrics for the number of models available have found a limited effect of this attribute.
- A range of different aspects of owning and using an EV can change as a result of gaining some experience: performance and overall driving experience, comfort, fuel costs, home charging, flexibility, range, public charging and battery life, maintenance and resale value.
- On balance, the literature suggests perceptions are improved after some experience is gained. Nevertheless, there is still some debate in the literature as to how this then translates into intention to purchase an EV. Further, there are substantial methodological weaknesses in most of the studies in the literature, and the above suggestion is robustly contradicted, for BEVs, by the more rigorous TRL-Shell randomised controlled trial, which found that direct experience of using a BEV reduced willingness to consider having one (even though evaluations of the driving experience were positive).

6.1.3 Charging

- Examination of the role of charge availability and charging time is split into studies which examine the impact on uptake of EVs and those which examine charging behaviour after adoption.
- Public charging infrastructure may have an equal or greater impact on EV uptake than financial incentives and there is a strong suggestion that this may only be true for BEV uptake rather than PHEV uptake, but the evidence for this comes with several caveats.
- Whilst macro studies of the relationship between charging infrastructure and EV uptake at the national or regional level suggests a link, this does not take account of temporal dependence or spatial dependence (i.e. which comes first: the charging infrastructure or the uptake) and how a heterogeneous distribution of charge stations might influence EV adoption.
- The perceived lack of public charging infrastructure has been frequently highlighted by non-EV owners as a barrier to EV uptake, but the evidence on the link is weak.
- There is evidence to suggest that awareness of a low or intermediate number of available charge points has very little impact with regard to perceived charger *abundance*.
- In terms of the role of different types of charging availability (e.g. home vs. workplace; fast vs. slow), the acknowledgement by prospective consumers of availability of home-based charging is a consistently strong predictor of acceptance.
- No studies comparing the value of charging time for PHEV owners and BEV owners were found and little consideration has been given to the importance of charging from the perspective of PHEV ownership.
- There is general agreement in the evidence that charging behaviour is primarily being driven by EV owner preferences, convenience and habit rather than the availability or cost of public charging infrastructure.
- Recent evidence is consistent with older evidence suggesting that private owners charge their EV mainly at home, on a daily basis, and generally in the evening.
- Low overall levels of utilisation of public charge points are likely to mask wide variations between charge points in different areas and at different types of venues.

6.1.4 Financing and ownership models

- Virtually no evidence was found on different ways of purchasing and financing vehicles despite directed effort within the search strategy of the review.
- The literature focuses on business model innovation (particularly battery leasing) with little regard for consumer perspectives and data collected from consumers directly to test acceptance.

6.1.5 Consumer psychology

- The greatest proportion of socio-psychological research in relation to EV uptake has been dedicated to an examination of the role of ethical motives of environmentally friendly buying behaviour.
- Straightforward surveys of the motivators of EV adoption suggest that environmental benefits of EVs tend to only constitute a minor purchase motivation when ranked alongside other motives.
- An indication that environmental motives may be important in the purchase decision is not the same as suggesting that this is *the reason* for adopting an EV.
- Studies that have investigated the link between levels of awareness and acceptance of environmental problems suggest it is not enough for people to see a link between EVs and their environmental credentials but must be aware and sympathise with environmental issues in the first place, must believe that EVs are indeed pro-environmental and this must fit with their self-identity.
- A person can be highly motivated by environmental issues, but if they do not believe EVs are a solution, this will not matter.
- Attitudes towards ICE vehicles (i.e. the 'pull' of their attractive features or the 'push' of their negative consequences) are possibly more important than the intrinsic benefits of EVs and so both of these must be understood.
- An important generalizable omission in the evidence base is the role of emotions in EV adoption.
- Emotions can be broken down into visceral (perceptions of instrumental and visual attributes of EVs such as style, design, and size), behavioural (from using and experiencing driving EVs) and reflective (related to self-image and identity connected to driving an EV). More positive perceptions of instrumental attributes of EVs lead to more positive emotions towards EVs (perceived pleasure, joy, pride, (lack of) embarrassment), which in turn positively influence the intention to adopt EVs.
- Studies that have attempted to incorporate symbolic motives have 'suffered' from a form of social responsibility bias that has been empirically proven: that people fail to reveal symbolic meanings as important as they tend to stress instrumental and environmental attributes, especially when asked directly.
- EVs do not currently have established symbolic meanings and these are likely to develop over time. This makes it all the more important to include a variety of measures of symbolism in any surveys to understand their emerging associations.
- Symbolic motives and self-identity are not expected to be a motivation to buy an EV in and of themselves. However, the evidence shows collective norms and more personalised relationships that define people's social identity crucially facilitate the process of diffusion, whereby a new behaviour is adopted by increasing numbers of consumers as they see others around them adopting it.
- Further, the TRL-Shell RCT found that self-congruity (the degree of fit between the symbolic meaning of a BEV and the personal identity of the person considering it) was associated with willingness to consider having a BEV with

present (2016) range, though had less evident impact on willingness to consider BEVs with substantially longer ranges.

- There is empirical evidence that social negotiation (i.e. discussing EVs with others) has been found to change individual perceptions of EVs, particularly where this process is reflexive.
- The role of information provision (including improved awareness of charging infrastructure) is understudied. The most common form of information provision is directed at private functional motives (costs, performance and availability of charging infrastructure etc.) but evidence is very thin on what actually works to shift consumer attitudes.

6.1.6 Characteristics of EV owners

- There is not much difference between the key characteristics that emerge from studies of existing EV owners and from stated preference type surveys which attempt to identify the next tranche of early adopters.
- The segmentation literature makes clear current characteristics are not the best means by which to predict future mainstream EV adopters.
- Comparative data across countries seems to suggest that current EV owners are predominantly male, middle aged, with above average education, affluent, family oriented, urban-based in multi-car households. However, these characteristics cannot be taken as definitive as the evidence is not strong enough to say whether the characteristics of EV owners is any different to new car buyers in general. There is also some suggestion that younger males are a key adopter group.
- There is a general lack of understanding of household composition including the presence of children and employment status (and potentially occupation) of all the adults in the household.
- In the most mature EV markets, there has been a gradual widening of the demographic (in California) and a more marked change (in Norway) towards younger, single car households.

6.1.7 EV usage

- Forecasts of future ownership and use are based on assumptions that EVs will mainly be used as a second household car. However, to the contrary, EVs are typically being used as the main car, relied upon for the majority of day-to-day journeys to work, education and other local destinations. Other cars in the household are typically being used for infrequent, longer journeys.
- Recent research with current EV owners in the UK and elsewhere indicates EVs are being driven for comparable mileages to ICE vehicles.
- It is possible there is a lifestyle learning process whereby drivers learn about the unique attributes of an EV and incorporate these discoveries into their lifestyles, or routine practices. Drivers take into account the restricted range of the EV, implement a daily charge process, and develop new behaviours related to trip planning.

- There is some evidence to suggest that travel patterns of EV owners start to change upon adoption, possibly even increasing the number of trips undertaken by car. But the evidence on whether public transport use increased or decreases after adoption is mixed. One study suggests its use is reduced, another hints that incentives which encourage the joint use of EVs and public transportation are not attractive, and another suggests that public transport usage increases after EV adoption.
- Compared to those examining trip patterns, many more references exist relating to changes in driving style after adoption. Unlike the latter, these findings are much more consistent, tending to suggest that driving behaviour changes to become more economical.

6.2 Energy demand management and EVs

- Across a number of non-EV trials in the UK and further afield, consumer feedback on tariffs and interventions aimed at encouraging energy demand management was generally positive and consumers generally accept automation and direct control.
- In a recent non-EV related trial in the UK for general electricity demands, the majority of UK participants said they did not want to switch to a ToU tariff. Dynamic pricing (day-to-day) was the least popular. Adding the option of automation had little effect on the popularity of the static ToU tariff, but made the dynamic time of use tariff more attractive. Direct load control in return for lower flat rate was the most popular a tariff (with caveats).
- Most Economy 7 consumers in the UK already allow remote control of their electric storage heaters and this indicates that some consumers are willing to accept a degree of automation of their electricity use. These people were more likely to say they would switch to the next generation static ToU tariff.
- Behavioural theory would suggest that automation could be popular as it eliminates the need for consumers to repeatedly go through a previously described process, and often requires no action at all on the part of end-users. On the other hand, theory would also suggest that, to gain greater acceptance, direct control systems should cultivate a sense of consumer control in order to foster environmental identity. This would require greater consumer engagement in the behaviour, not less.
- This theory is backed up to some extent as evidence shows that initial doubt about participation can be mitigated by providing consumers with the options to override any automated response, be flexible with curtailment levels and pre-programme charging sessions. Accordingly, direct control programs that do not foster a sense of control will likely have lower program enrolment compared to programs that do so.
- The willingness to accept tariffs and shift time of use varies according to what the electricity is being used for. However, overall there is limited evidence on the way consumers shift their electricity use in response to incentives and, with the exception of air-conditioning, storage heating and dishwashers, it is not clear which appliances consumers are willing to use in a flexible way (including EVs).

- After automation, the literature suggests a combination of economic incentives and enhanced information generally delivers the greatest demand response.
- In addition, there is debate over the longevity of any behaviour changes and whether behaviours persist over time if demand management is not automated or directly controlled.
- There is limited evidence to suggest that EV owners may be more willing than the average consumer to accept various types of tariff but this may apply more to innovators than mainstream adopters.
- There is also limited evidence to suggest the acceptability of tariffs may be related to the travel patterns and flexibility of consumers.
- Exploration of the financial incentives necessary to encourage EV owners to participate in demand response programs is even more limited.

6.2.1 *Impact on charging behaviour*

- The empirical evidence for behavioural impacts in response to financial stimuli through different tariff structures is at best mixed.
- There is a general consensus in the literature that time-based rates are successful at encouraging greater off-peak charging.
- There is limited evidence on the role of the strength of the price signal. Evidence on the importance of the size of peak to off-peak price differentials is mixed for ToU tariffs, but points towards higher differentials resulting in higher peak demand reductions for critical peak tariffs.
- Very few studies have examined the behavioural response of EV owners to different electricity tariff structures.
- In the UK, evidence suggests the pricing tariffs of public and workplace charging points can be managed to influence demand.

6.2.2 *TRL-Shell trial*

The literature review highlighted that, despite many studies of the potential uptake of EVs, there remain substantial weaknesses in the existing picture.

Many of the studies have relied on quantitative surveys or choice experiments with participants who have not had any direct experience of EVs on which to base their responses.

Those studies where participants have been provided with a direct experience of using and EV have frequently involved biased samples that are not representative of mainstream consumer drivers.

Most trials have been vulnerable to “Hawthorne” effects. These occur when participants change their behaviours, attitudes or preferences because they are aware that they are participating in research, rather than in response to the research stimuli.

To address these weaknesses, TRL (commissioned and funded by Shell) carried out a randomised controlled trial (RCT) investigating mainstream consumer responses to 2012 model BEVs.

The results contradict the general sense in the literature that experience of using a BEV increases willingness to adopt. Much of that literature was based on research with biased (PiV Innovator) samples: the difference in findings from a controlled study using a mainstream consumer sample highlights the critical importance of doing so if the data is to be used to model potential uptake by the general car user population.

Both dynamic and cruising performance of the BEV were evaluated as better than those of the equivalent ICE vehicle.

The study found that a typical BEV user would be significantly higher than average in the five-factor traits of openness, conscientiousness and agreeableness, and no different than average in extraversion and neuroticism. He/she would be of higher than average status, more likely than average to have high relationship investment, and more likely to be older than 35.

6.3 Lessons learned

The review of previous EV trials highlighted the following areas for the Stage 2 trial design to learn from.

- **Methodological weakness**
 - Lack of control over confounding variables
 - Self-selecting samples or lack of control over sampling characteristics
 - Poor comparability of data
 - Inability to apply data and results to future scenarios
- **Technological challenges**
 - Vehicles
 - Charge point installation
 - Communication technology
- **Participant information and support**
 - Lack of detailed information
 - Not enough resource to handle support
- **Practical challenges**
 - Day-to-day handovers
 - Staffing
 - Vehicle cleaning and maintenance between handovers
 - Vehicle charging between handovers
- **Volume of data**
 - Lack of preparedness to manage telematics data
- **Time**
 - Set-up
 - Administration
 - Analysis
- **Simplicity**
 - Temptation to over-complicate study designs can impact on the validity of measuring core variables

6.4 Consumer interviews

6.4.1 Current charging routines

- Charging typically takes place at home.
- Routine charging is common, with many reporting a preference to keep the battery fully charged whenever possible.
- Solar panel ownership is common amongst those who had owned a PiV for at least 18 months; those with solar panels prefer to charge their PiV when the panels are generating electricity.
- Time of use tariffs were rarely used by participants, and were only reported amongst BEV and PHEV Innovators.
- Timers and apps are used to charge when grid demand is lower and/or to take advantage of cheaper electricity.
- Some participants had comprehensive knowledge of their electricity usage and cost, others had little awareness.

6.4.2 Advantages of PiVs

- PiVs have financial benefits including reduced running costs and tax benefits. These were mentioned by the vast majority of participants.
- PiVs remove or reduce the need to visit petrol stations.
- PiVs are pleasant to drive, often exceeding expectations.
- PiVs have environmental benefits. This can be a deciding factor in PiV purchase, or a pleasant consequence of PiV ownership.

6.4.3 Disadvantages of PiVs

- Unreliable electric range as displayed on the dashboard.
- Poor public charging infrastructure, in terms of availability and reliability.
- Inconvenience of plugging vehicles in to charge.
- Uncertainty about the long term future of PiVs.
- High initial purchase cost and uncertainty over residual value.

6.4.4 Advantages of BEVs

- BEVs are seen as a practical vehicle for shorter journeys and as a second car.
- The price of electricity is perceived to be more stable than that of petrol or diesel.
- BEV innovators may self-identify as a 'trailblazer' and feel that they are promoting a new technology to the general population.

6.4.5 Disadvantages of BEVs

- The limited range of the vehicle was by far the most frequently-mentioned disadvantage of BEVs.

- Concerns over being able to charge during longer journeys were common.
- The extra planning required to undertake journeys and ensure adequate charge was seen as a disadvantage.
- The long-term reliability of PiV batteries was a concern to some.

6.4.6 Advantages of PHEVs

- PHEVs are seen as a positive means of introducing PiVs into the car pool whilst avoiding range anxiety amongst drivers.
- PHEV drivers do not need to plan their journeys as much as BEV drivers.

6.4.7 Disadvantages of PHEVs (PHEV owners)

- PHEV Innovators did not tend to report any disadvantages of their vehicles in addition to those related to PiVs in general.

6.4.8 Disadvantages of PHEVs (BEV and ICE vehicle owners)

- Some BEV and ICE vehicle owners expressed the view that PHEV Innovators are not willing to commit to PiVs.
- The idea that PHEVs (especially company cars) are purchased solely based on their tax benefits was asserted by some BEV innovators.
- A disadvantage of PHEVs to BEV innovators is that they are reported to 'block' public charging points; BEV innovators tend to feel PHEV Innovators are not as reliant upon charging their vehicle to the same extent that as BEV innovators.
- The merit of PHEVs in relation to emissions and reduced fuel consumption were also questioned by BEV innovators.

6.4.9 Next car purchase

- The vast majority of participants who currently own a BEV, and a small proportion who own a PHEV or ICE vehicle, stated that they would purchase a BEV as their next car, particularly if it was a second car or had a higher range than currently available on most BEVs.
- The vast majority of participants who currently own an ICE vehicle but had experience of a BEV reported that they would not consider buying a BEV as their next vehicle, largely due to initial cost and range anxiety.
- Most current PHEV Innovators said that they would purchase another PHEV, as did a number of ICE vehicle owners, who stipulated that they would consider a PHEV but not a BEV.
- A handful of participants ruled out buying a PiV as their next vehicle.
- There was a general expectation amongst participants that PiV technology will improve in the future, making them more attractive to buyers.

6.4.10 Future tariff scenarios

- Participants were provided with an information sheet describing managed charging and time of use tariffs prior to the interview. The tariffs were described again during the interview. Many participants appeared to grasp the concept well, however during some interviews, it emerged that the participant's comprehension of the two tariffs was not correct. This is not surprising given the fairly high level of informational distance and the abstract thinking required to fully comprehend the two charging options. The result also replicates similar challenges reported in undertaking consumer interviews on this issue (Bailey & Axsen, 2015; *in personal communication*).

6.4.11 Advantages of time of use tariff

- The ToU tariff was considered to be simple, particularly compare to the MC tariff; participants generally felt that they understood how the tariff would work.
- Again, compared to the MC tariff, the ToU tariff was perceived to offer the consumer a greater degree of control over the charging of their vehicle.

6.4.12 Advantages of managed charging tariff

- The MC tariff system was recognised as optimising the available energy, and was principally seen as offering an advantage to the energy supplier rather than to consumers.
- Some BEV innovators felt that MC did offer wider benefits to society
- The idea of allowing the supplier to manage their vehicle's charging was seen as an advantage by a number of BEV innovators.

6.4.13 Disadvantages to both tariffs

- Participants regularly expressed concern over any requirement to use a smartphone app to operate the tariff.
- The potential for emergency situations to arise when the PiV did not have adequate charge was another key concern.
- The additional time and effort associated with the MC and ToU tariffs was expected to be an inconvenience to some participants.

6.4.14 Disadvantages of time of use tariff

- Participants felt that the ToU tariff was best suited to those with a charging routine who would be able to take advantage of the cheaper charging periods, and would therefore disadvantage those who are not able to regularly charge at these times.
- Similarities between the ToU tariff and the existing Economy 7 tariff were identified by many participants, who felt that ToU did not offer any additional advantages.
- The potential negative effect on the grid of encouraging many people to charge in off-peak periods (if PiV uptake increased) was another disadvantage discussed by participants.

6.4.15 Disadvantages of managed charging tariff

- The requirement to place trust in energy suppliers and relinquish some aspects of control to them when charging a PiV was a key issue.
- Concern was also expressed about the potential for fragmented charging to damage the PiV battery.

6.4.16 Savings

- The general consensus was that neither tariff would result in substantial savings for consumers.
- In order to move to either tariff, some participants suggested that they would require a bill reduction of between 25% and 60%.
- A commonly-held opinion was that financial savings are not important, as the current cost of charging a PiV is generally very low.
- Some participants reported that they value flexibility of charging above financial savings.

6.4.17 Tariff preference

- In our sample, some participants preferred the ToU tariff and some preferred the MC tariff. The ToU tariff was the most popular option, with a statistically significant difference in preference ($p < 0.05$, one-sample chi squared test, 46 participants stated a preference).
- The MC tariff was slightly more popular amongst BEV innovators than PHEV or ICE vehicle owners. This was particularly true for those who had owned a BEV for more than 18 months.
- Some participants did not state a preference, either because they were not able to decide between the two options, or because they could not envisage either option fitting their lifestyle.

6.5 Implications for WP1a CVEI modelling framework and WP1b Stage 2 trial design

6.5.1 Literature reviews

- The findings of the literature reviews highlight the critical importance of valid, unbiased sampling of the mainstream car user population. This is particularly important where the research findings from Stage 2 are to feed into the modelling framework to assess the potential for PiV uptake in that population.
- The findings also suggest that models of uptake of BEVs and PHEVs based on research with mainstream consumer car users who have not themselves had direct experience of using a BEV may over-estimate such uptake. This highlights the critical importance of basing models of EV uptake by mainstream car users (such as ECCo) on data obtained from samples of mainstream car users who have had direct experience of using modern PiVs.
- There remains a substantial gap in our knowledge of the responses of mainstream car users to PHEVs, after direct experience of using them.

- The literature review identified significant gaps in current knowledge. To maximise the validity of models of PiV uptake by mainstream car users, further research is therefore needed. Such research should: sample the mainstream car user population, rather than PiV Innovators; take the form of an RCT in which mainstream users' psychological distance from PiVs is reduced through direct experience; and provide participants with direct experience of both a modern BEV and a modern PHEV, along with an equivalent control ICE vehicle.

6.5.2 *Lessons learned*

The review of lessons learned suggests the following actions should be taken to mitigate limitations and risks highlighted from previous trials:

- Ensure the development of a trial that focuses on the primary aims of the project without the inclusion of unnecessary complications.
- Employ scientifically robust study design with control for confounding variables.
- Sample mainstream car consumers stratifying for potential confounding variables.
- Ensure the collection of only data necessary to answer and explore findings related to the defined research questions and aims of the project.
- Maturing market presents more vehicle options. Choose popular comparable mid-range OEM vehicles.
- Ensure all materials are well designed and piloted. Ensure processes for participant follow-up and support.
- Work with experienced suppliers to provide charge point installation and communication network.
- Adhere to established installation guidelines.
- Careful planning and piloting of the handover process.
- Plan for vehicle maintenance checks and cleaning between handovers.
- Plan data management and data cleaning.
- Ensure accurate and adequate resourcing of the trials.

6.5.3 *Consumer interviews*

The following findings from the consumer interviews have the potential to impact on the design of experimental conditions in Stage 2.

- **Mandatory use of smartphones may deter many from using ToU or MC**

If smartphone use is required, this should be made clear during recruitment. It may be necessary to offer 'tutorials' to some participants to ensure that they are comfortable with using any apps as part of the trial.

- **Households with solar panels could confound the trial due to a desire to charge when most suited to energy supply from the panels.**

The presence of solar panels should be asked during recruitment and participants with solar panels excluded from participation in any trials of charging behaviour.

- **The interview data suggest that the ToU tariff was overall the most popular choice of the two presented**

ToU tariff should be considered as one of the experimental conditions in Stage 2 given the preference indicated by the majority of consumers.

- **There will need to be a clear advantage to 'handing over' control of charging to the energy supplier**

Many participants felt that they are able or would be able to 'manage' their own charging through the use of timers and time of use tariffs. There would need to be a clear advantage to relinquishing control of charging.

- **The concepts of ToU and especially MC tariffs may be difficult to comprehend for mainstream consumers**

Many of the participants struggled to fully understand the two proposed tariffs based on the brief information provided prior to and during the interviews.

It is important that potential participants in the trial have a good understanding of any tariff presented. During recruitment, the following should be provided:

- *In-depth explanations of the tariffs needed including 'real life' examples*
- *Explanation of how it could benefit those with no strict charging routine/those who value flexibility above cost saving*
- *Well-defined cost implications*
- *Explanation of implications for other household appliance use*
- *Explanation of whether participants will be able to override the tariff system*

6.6 Conclusions that inform modelling of the integration of PiVs into the energy system

The literature reviews established some key findings that have implications for modelling the integration of PiV energy demand with the wider energy system:

- Purchase price remains a key disincentive to PiV adoption; so long as there are substantial price premiums over ICE vehicles, adoption of (and so electricity demand from) PiVs will be low. This can be offset through policy interventions that reduce the effective purchase price seen by consumers.
- Short range and resultant restricted utility of BEVs will continue to greatly reduce their appeal to most consumers. Growth in PiV electricity demand will be limited until BEV range has been substantially improved
- Running cost savings versus ICE vehicles are a substantial incentive to PiV adoption. However both falling petrol/diesel prices and increased ICE fuel efficiency would reduce the PiV advantage over ICE. This should be taken into account in modelling PiV adoption.
- There is very little research evidence on adoption of PHEVs; the evidence there is supports the view that PHEVs are preferred over BEVs by the majority of consumers because they do not have the same restricted utility.
- Vehicle choice is known to be influenced by symbolic motives (whose influences are difficult to measure in choice experiments). The influence of the symbolism of

PiVs on adoption has been very little researched, so this adds substantially to uncertainty over adoption rates. This suggests the importance of sensitivity analyses around overall PiV adoption rates in the CVEI analysis.

- The role of public charging infrastructure in driving PiV adoption is not well understood.
- Existing consumer users primarily charge their PiVs at home, in the evening. Thus consumer PiV use is largely restricted to households with the ability to charge at home. It is not known how far an extensive network of public chargers would facilitate adoption of PiVs by households that cannot charge them at home.

In addition, the review confirmed that there are that significant gaps in knowledge in the field. Some topics (such as adoption of and charging behaviour with PHEVs, managed or charging of PiVs) have been under-researched, while substantial methodological weaknesses (such as generalisation of conclusions from PiV Innovator responses to the wider population) have undermined the value of the evidence base for others. These have significance for the scope and design of the Stage 2 trials.

- Previous field trials measuring attitudes towards adoption of PiVs have used samples with substantial biases towards PiV Innovators (particularly those studies where participants' own PiVs were used). None of these studies can be used to make valid predictions regarding mainstream consumers' attitudes towards adoption of PiVs. Research with mainstream consumers is therefore essential if we are to accurately model PiV adoption rates and electricity demand.
- The literature regarding attitudes towards adoption of PHEVs, and charging behaviour with a PHEV, is very sparse. Research on both PHEV adoption and charging behaviour is essential to accurately model PiV adoption rates and electricity demand.
- Research evidence of any kind relating to managed charging of PiVs is also sparse. At the moment in modelling PiV energy demand only plausible assumptions can be made about consumer response to PiV managed charging value propositions. Measurement of actual responses by users is essential if to accurately model ways in which PiV energy demand can be integrated into the wider UK energy system.
- Methodological quality of much of the research in the field, including most field trials with PiVs, is weak, using uncontrolled designs that are vulnerable to the effects of confounding variables and from which it is difficult to draw valid conclusions. Robust modelling of the integration of PiVs into the energy system needs to be grounded in controlled field studies from which valid conclusions about causal relationships can be drawn.

6.7 Key findings that inform both the overall design of the Stage 2 Trial and where appropriate, more specific details of its execution.

6.7.1 Lessons learned

While many previous trials have methodological weaknesses that limit their value in informing modelling of the integration of PiVs into the wider energy system, they nevertheless have encountered and addressed many of the practical problems associated

with running field studies involving participants in using and charging PiVs. Such practical, operational details are not typically included in research publications but form part of the researchers' stock of "know-how". The review of lessons learned aimed to tap into such know-how, to identify where possible key practical problems that have already been encountered, and solutions that have already been identified, so as to mitigate practical risks to the Stage 2 trials. The review suggests the following actions would contribute to the minimisation of operational risks in Trial execution:

Focus trial design on the primary aims and research questions of the project, avoiding as far as possible secondary aims and additional independent and dependent variables that complicate analyses and reduce statistical power.

- Ensure the collection only of the data necessary to answer and explore the pre-defined research questions. Trials can all too easily generate large volumes of data, the processing of that inhibits rather than enhancing, analysis. Post-hoc "fishing" for associations in data can lead to statistical errors.
- To maximise generalisability, vehicles selected for trial should represent popular vehicle categories and mid-range models. The generalisability of results obtained with less popular vehicle categories (e.g. 2-seater vehicles) is low.
- Ensure all materials are well designed and have been tested in advance through piloting.
- Ensure processes for participant follow-up and support are in place.
- Work with experienced suppliers to provide charge point installation and communication network. Inexperienced suppliers can be a cause of delay and loss of data.
- Adhere to established electrical equipment installation guidelines.
- Ensure careful planning and piloting of the process of vehicle handover to/from participants.
- Avoid vehicle downtime during trials by planning for vehicle maintenance checks and cleaning between handovers.
- Some trials have struggled as a result of inadequate or inappropriate allocation of staff resources. Ensure accurate and adequate resourcing of the trials.

6.7.2 Consumer interviews

The consumer interviews were necessarily restricted to PiV Innovators since they concerned long term experience of having and using PiVs. Thus caution is needed in generalising from the findings on attitudes to PiVs. However the interviews established some key findings in relation to charging behaviour and the responses of those with experience of charging their own PiVs to managed charging propositions. These findings have implications for modelling the integration of PiV energy demand with the wider energy system.

- In general, users' perceptions of the advantages and disadvantages of BEVs aligned with those identified in the literature review, though with an emphasis on the positives that we interpret as reflecting participants' Innovator motivations.
- PHEV were seen by their users as conferring many of the benefits of PiVs without the dis-utilities of restricted range and the burden of planning required to make

long journeys. However BEV users were often critical of PHEVs and their users who they characterised as not willing to commit to PiVs. PHEVs were also seen by BEV users as a nuisance, “blocking” public charge points even though not as dependent on them as BEV users.

- Most users charged their vehicles (BEVs and PHEVs) at home, overnight, following a well-established routine. There was a general preference among both BEV and PHEV users for fully recharging their vehicles whenever possible.
- Participants were not generally enthusiastic about either time of use or managed charging tariffs, seeing little benefit unless reductions in charging costs of between 25% and 60% could be achieved. Even such savings were not generally seen as important, as the cost of PiV charging is perceived as already low.
- Two-thirds of participants expressed a preference for time of use tariffs over managed charging tariffs, based on simplicity, retention of personal control, and reduction of perceived risk that vehicle would not be fully charged at the end of the planned charging period. Those that favoured managed charging tended to be BEV Innovators, who saw advantages to society as a whole that perhaps aligned with their symbolic motivations for having a BEV in the early market.

Some specific findings provide information that will help the design of the Stage 2 Trials, including the specific design of User-Managed and supplier-managed charging experimental conditions:

- Managed charging propositions are unfamiliar to potential participants, and will require clear explanation at recruitment (to ensure informed consent) and in briefing prior to participation. This should include information on whether/how users could over-ride the managed charging system when they felt this was required.
- The supplier-managed charging tariff condition will need to offer participants a clear advantage to ‘handing over’ control of charging to the energy supplier, to maximise engagement with it during their participation.
- Mandatory use of smartphone apps may deter many from using ToU or MC. If use of a smartphone app is required, this should be made clear during recruitment. Participants should be fully briefed in its use to ensure that they are comfortable with using it as part of the trial.
- Households with solar panels could confound the trial due to a desire to charge when most suited to energy supply from the panels. The presence of solar panels should be determined during recruitment and participants with solar panels excluded from participation in any trials of charging behaviour.

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Appendix A Table of links to trial publications

Study ref	Trial	Links to study reports, publications or online information
1	Assessing the viability of EVs in daily life (Cenex/Oxford Brookes University)	http://www.cenex.co.uk/wp-content/uploads/2014/02/ULCV-Demonstrator-final-report.pdf
2	My Electric Avenue (EA Tech Ltd.)	http://myelectricavenue.info/trial-results
3	Green eMotion	http://www.greenemotion-project.eu/upload/pdf/deliverables/D11_8-Final-publishable-summary-report-V1_4.pdf
4	Berlin Mini E trial (Chemnitz University of Technology & BMW)	http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=5784170&url=http%3A%2F%2Fieeexplore.ieee.org%2Fiel5%2F4149681%2F5784165%2F05784170.pdf%3Farnumber%3D5784170 https://www.tu-chemnitz.de/hsw/psychologie/professuren/allpsy1/pdf/110902_methods_EVs_CUT_postprint.pdf http://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=6&cad=rja&uact=8&ved=0ahUKEwjGgbjCpNfKAhWCVhQKHfErDcsQFggwMAU&url=http%3A%2F%2Fwww.rmi.org%2FContent%2FFiles%2FBMW%2520Mini-E%2520Field%2520Trial%2520Results.pdf&usg=AFQjCNG70s049hKUs_EBg9Re8ZVUPQ-PBA&bvm=bv.113034660,d.ZWU
5	Low Carbon Vehicle Procurement Programme (Cenex)	http://www.cenex.co.uk/press-releases/lcvppp-summary-report/
6	Smart Move (Cenex)	http://www.cenex.co.uk/wp-content/uploads/2013/06/2011-11-21-Smart-Move-Case-Studies.pdf

7	Crome (EDF)	http://crome-project.eu/ http://pulse.edf.com/en/crome-le-reseau-de-vehicules-electriques-europeen http://crome.forschung.kit.edu/english/57.php
8	PI-FI (Energy Savings Trust, EDF, Route Monkey)	http://www.routemonkey.com/media/uploads/Plugged-InFleetsInitiative-ChargingForward_1.pdf
9	Kleber Toyota trial (Toyota, EDF)	http://webtvgroup.edf.com/plug-in-hybrid-electric-vehicles-first-trial-in-strasbourg-video-865.html http://www.toyota-global.com/innovation/environmental_technology/plugin_hybrid/magazine09.html http://insideevs.com/toyota-presents-final-conclusions-from-3-year-prius-plug-in-hybrid-trial/ http://media.toyota.co.uk/2009/03/edf-and-toyota-announce-large-scale-demonstration-of-plug-in-hybrid-vehicles-in-strasbourg-france/
10	SAVE project (Renault)	http://media.renault.com/global/en-gb/alliance/media/pressrelease.aspx?mediaid=49711
11	G4V (Grid for Vehicles) project	http://www.g4v.eu/about.html http://cordis.europa.eu/docs/publications/1396/139611831-8_en.zip
12	Sacramento Municipal Utility District (SMUD)'s SmartSacramento project	https://www.smartgrid.gov/files/SMUD-Project-Description_final.pdf Also featured in: http://energy.gov/sites/prod/files/2014/12/f19/SGIG-EvaluatingEVcharging-Dec2014.pdf
13	Evaluating Electric Vehicle Charging Impacts and Customer Charging Behaviours (US Dept. of Energy)	http://energy.gov/sites/prod/files/2014/12/f19/SGIG-EvaluatingEVcharging-Dec2014.pdf

Appendix B Registration of interest survey

Background to the research

TRL (the UK's Transport Research Laboratory) are talking to people with experience of driving and charging plug-in cars, as part of some research commissioned by ETI (the Energy Technologies Institute).

We would like to speak to people to find out about their experiences of using and driving a plug-in vehicle.

People will be randomly selected from those who register their interest and invited to take part in a telephone interview. The interview would last no longer than an hour.

Participation is entirely voluntary and you can withdraw at any time without reason.

With your permission, the discussion would be recorded for analysis, but you would not be personally identified in any way.

To say thank you for taking part in the interview, you will receive a £30 Amazon voucher or can choose to have £30 donated on your behalf to one of three charities:

1. Cancer Research UK
2. NSPCC
3. RSPCA

If you are interested in taking part, please complete this short survey, which will ask for some basic information. We will use this to ensure we interview a broad range of people to speak to about their experiences.

If you have any questions about the research, please email contact@trl.co.uk

Do you OWN or LEASE a battery electric vehicle or plug-in hybrid electric vehicle, and regularly charge it at home? *

- Yes - battery electric vehicle (e.g. Nissan Leaf, Renault Zoe, Mitsubishi i-MiEV)
- Yes - plug-in hybrid electric vehicle (e.g. Toyota Prius Plug-in Hybrid, Mitsubishi Outlander P-HEV, Vauxhall Ampera)
- No

[BEV owners only] When did you purchase or lease your electric vehicle? (If you are unsure of the exact date, please estimate to the nearest month) *

DD/MM/YYYY

What type of car do you own? *

- BMW i3
- BYD e6
- CHEVROLET Spark EV
- CITROEN C-Zero

- FORD Focus electric
- KIA Soul EV
- MERCEDES-BENZ B-Class Electric Drive
- MITSUBISHI i-MiEV
- NISSAN Leaf
- PEUGEOT iOn Electric
- RENAULT Fluence Z.E
- RENAULT Twizy
- RENAULT Zoe
- SMART ForTwo electric drive
- TESLA Model S
- TESLA Model X
- VW e-Golf
- VW e-Up!
- Other (please specify):

[PHEV owners only] When did you purchase or lease your plug-in hybrid vehicle? (If you are unsure of the exact date, please estimate to the nearest month) *

DD/MM/YYYY

What type of car do you own? *

- AUDI A3 e-tron
- BMW i8
- CHEVROLET Volt
- FORD C-Max Energi
- FORD Fusion Energi SE
- MITSUBISHI Outlander P-HEV
- PORSCHE Panamera S E-Hybrid
- TOYOTA Prius Plug-in
- VAUXHALL Ampera

- VOLVO V60 Plug-in Hybrid
- VOLVO XC90 T8
- VW Golf GTE
- VW XL1
- Other (please specify):

Do you own or lease a diesel/petrol vehicle?

- Yes
- No

[Non-BEV/PHEV owners only] Have you had any experience of driving a fully electric vehicle and charging it at home? (Cars that run solely on electricity and do not have a conventional engine; this does not include plug-in hybrid electric vehicles) *

- Yes
- No

Which vehicle(s) do you have experience of driving and charging at home? (Please select all that apply) *

- AUDI A3 e-tron
- BYD e6
- CITROEN C-Zero
- FORD Focus electric
- KIA Soul EV
- MERCEDES-BENZ B-Class
- MITSUBISHI i-MiEV
- NISSAN Leaf
- NISSAN e-NV200
- RENAULT Fluence Z.E
- RENAULT Kangoo Maxi
- RENAULT Zoe
- SMART ForTwo electric drive
- TESLA Model S
- VW Golf GTE

- VW e-Golf electric
- VW e-Up!
- Not sure
- Other (please specify):

[All participants] Please provide your:

Full name:

Contact phone number:

Alternative contact phone number:

Email address:

It would be helpful to us if you would be willing to provide some additional information about yourself, so that we can ensure we are talking to a wide variety of people. You do not have to answer any or all of these questions if you would prefer not to.

Are you:

- Male
- Female

Which age group do you belong to?

- 17-25
- 26-35
- 36-45
- 46-55
- 56-65
- 66-75
- 76-85
- 86+

Are you the person responsible for paying your household's energy bill, that is, electricity and mains gas (if you have it)?

- Yes - solely responsible
- Yes - jointly responsible
- No - not responsible

Do you currently have a 'time of use' electricity tariff (where electricity is cheaper at certain times of day - e.g. Economy 7)?

- Yes
- No
- Don't know

What type of accommodation does your household occupy?

- Detached whole house or bungalow
- Semi-detached whole house or bungalow
- Terraced whole house or bungalow (including end terrace)
- Flat or maisonette in a purpose built block
- Flat or maisonette in a converted or shared house
- Flat or maisonette in a commercial building (for example: in an office building, or
- hotel, or over a shop)
- A caravan or mobile home or other temporary structure

Other (please specify):

What is the total number of cars owned or leased in your household?

- 1
- 2
- 3
- 4
- 5+

What is the first part of your postcode? (E.g. for RG40 3GA, type 'RG40' in the box)

How many miles do you typically drive in a year?

- 1-5,000
- 5,001-10,000
- 10,001-15,000
- 15,001-20,000
- 20,001+

If you are invited to take part and complete an interview you will receive £30. How would you prefer to receive your £30? *

- Amazon voucher (this will be emailed to the address you have provided)
- Donation to Cancer Research UK on my behalf
- Donation to RSPCA on my behalf
- Donation to NSPCC on my behalf

Appendix C Interview information sheet

CAR TYPES

There are different types of cars which use electric batteries...



Plug-in Hybrid Electric Car

- Has both a petrol/diesel engine and an electric motor
- Battery can be charged by plugging it in to a normal electrical socket or dedicated charging point
- Battery is also charged when the engine is running
- If you run out of charge you can continue driving as long as there is petrol or diesel in the tank
- The car will use the electric motor whenever possible to save fuel, but also uses power from the petrol/diesel engine when required
- Plug-in hybrids will typically have an all electric range of around 10-40 miles before having to switch to the conventional engine



Battery Electric Car

- Powered ONLY by a battery which is charged by plugging it in to a normal electric socket or dedicated charging point
- No petrol or diesel is required
- Vehicles will typically travel up to 100 miles on a full charge

Also available...

Hybrid electric vehicles

- Has a petrol/diesel engine and an electric motor powered by a small battery
- Battery is charged when the engine is running
- Does not need to be plugged in to charge the battery
- Battery power is mainly used at lower speeds, such as in traffic, to save fuel

CHARGING OPTIONS



- Demand for electricity in the UK varies through the day with peaks in the morning (e.g. 7-9 am) and in the early evening (e.g. 4-8 pm).
- However, it is more energy efficient for energy production when demand is constant rather than going up and down.
- Charging a plug-in electric vehicle obviously adds demand to the electricity network.
- In future, there may be energy tariffs that seek to manage the charging of electric vehicles in order to manage overall demand on the network.
- On average, people pay around 15p per unit of electricity used. One unit is equivalent to half a cycle of a washing machine. A full charge (i.e. 0-100% range) of a Nissan Leaf, for example, would cost approximately £3.00.
- Two examples of future tariffs are explained on the next page.

CHARGING OPTIONS

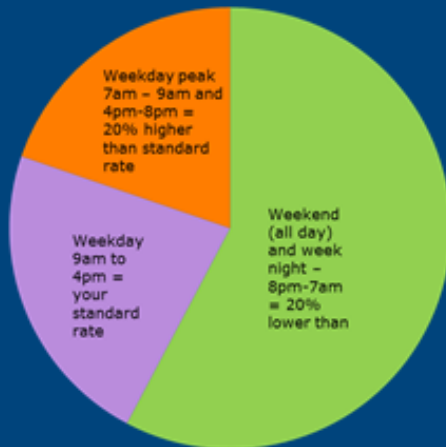
Examples



1

Time of use tariff

- Your electricity supplier offers variable rates depending on when you use your electricity, e.g...



- Using your smartphone you can tell the supplier the minimum charge you need the next day, and the time you need it.
- Your supplier then schedules your charging to make maximum use of the low price periods (i.e. overnight and weekends)

2

Dynamic managed charging tariff

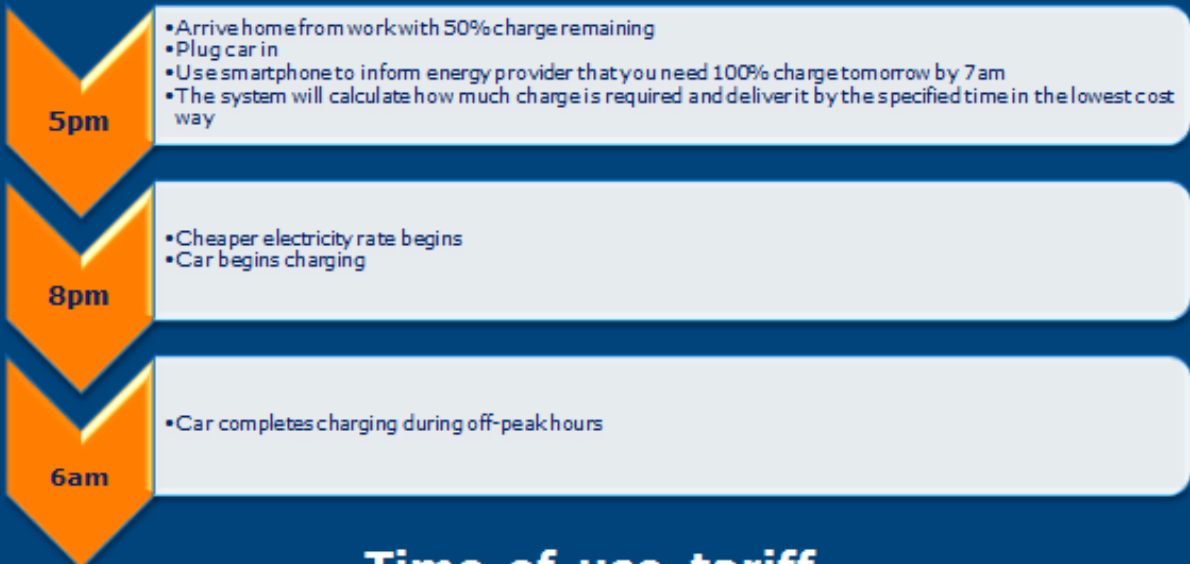
- Your electricity supplier controls the timing of the charging of your car within a time window you specify. This helps them make optimum use of the overall energy system and you are rewarded with a lower price.
- Using your smartphone you can tell the supplier the minimum charge you need the next day and the time when you next need the car.
- Your supplier will switch charging on and off remotely to deliver your required charge on time while making optimum use of the overall energy network.
- There are no specific time limits and the energy supplier will use the cheapest rate possible during the time window.
- The tariff may look like this:
 - Your standard rate
 - Dynamic charging rate = your standard rate MINUS 12%

CHARGING OPTIONS - EXAMPLES



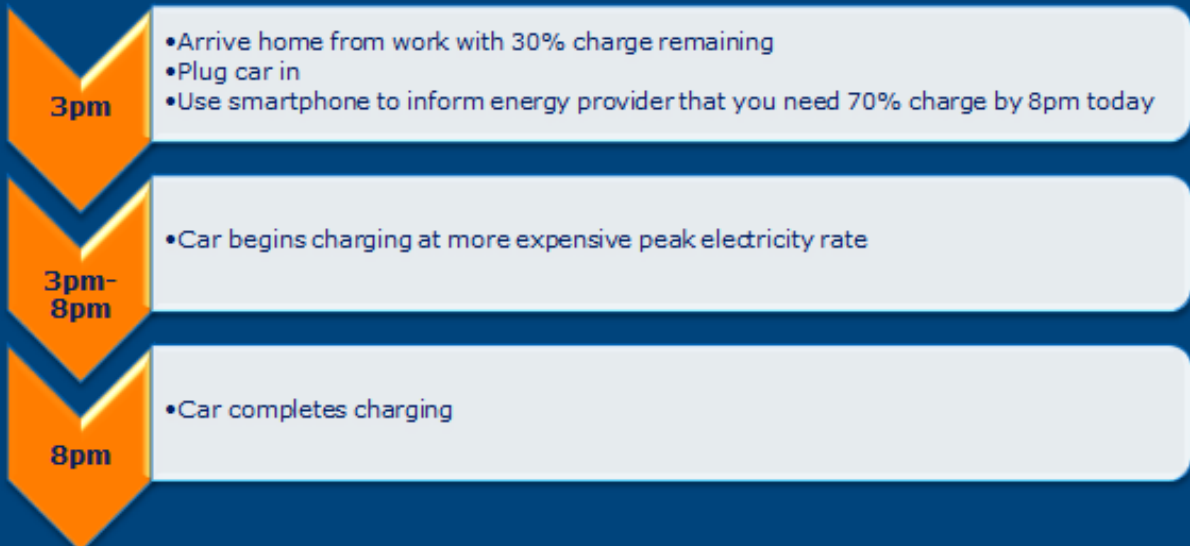
Time-of-use tariff

Example 1



Time-of-use tariff

Example 2



Appendix D Participant demographics

No.	Group	Type of car (BEV/PHEV owners only)	Also own an ICE vehicle?	Gender	Age group	Annual mileage	Number of cars in house- hold	Type of house	Currently have a ToU tariff?
1	BEV<6 months	Nissan Leaf	No	F	26-35	10,001-15,000	1	Flat/maisonette	No
2	BEV<6 months	Nissan Leaf	Yes	F	36-45	10,001-15,000	2	Detached	No
3	BEV<6 months	Nissan Leaf	Yes	M	36-45	10,001-15,000	2	Terraced	No
4	BEV<6 months	Tesla Model S	Yes	M	46-55	15,001-20,000	2	Terraced	No
5	BEV<6 months	Nissan Leaf	Yes	M	56-65	10,001-15,000	3	Detached	No
6	BEV<6 months	Nissan Leaf	Yes	M	46-55	15,001-20,000	3	Detached	No
7	BEV<6 months	Renault Zoe	Yes	M	26-35	5,001-10,000	2	Detached	No
8	BEV<6 months	Renault Zoe	No	M	76-85	5,001-10,000	2	Detached	No
9	BEV<6 months	Renault Zoe	Yes	M	36-45	10,001-15,000	2	Detached	No
10	BEV<6 months	Renault Zoe	No	M	36-45	5,001-10,000	1	Terraced	Yes
11	BEV<6 months	BMW i3	Yes	M	26-35	5,001-10,000	2	Detached	No
12	BEV<6 months	Renault Zoe	No	M	46-55	10,001-15,000	1	Semi-detached	No
13	BEV<6 months	Tesla Model S	No	M	26-35	10,001-15,000	1	Flat/maisonette	Yes
14	BEV<6 months	Nissan e-NV 200	Yes	M	56-65	15,001-20,000	4	Detached	Yes
15	BEV<6 months	Renault Zoe	Yes	M	36-45	5,001-10,000	2	Terraced	No

No.	Group	Type of car (BEV/PHEV owners only)	Also own an ICE vehicle?	Gender	Age group	Annual mileage	Number of cars in household	Type of house	Currently have a ToU tariff?
16	BEV>18 months	Renault Twizzy	Yes	F	56-65	10,001-15,000	2	Detached	No
17	BEV>18 months	Nissan Leaf	Yes	M	-	10,001-15,000	2	Detached	No
18	BEV>18 months	Nissan Leaf	Yes	M	46-55	10,001-15,000	2	Detached	No
19	BEV>18 months	Renault Zoe	Yes	M	46-55	10,001-15,000	3	Detached	No
20	BEV>18 months	Renault Zoe	No	M	46-55	10,001-15,000	2	Detached	Yes
21	BEV>18 months	Nissan Leaf	Yes	M	66-75	10,001-15,000	3	Detached	No
22	BEV>18 months	Nissan Leaf	Yes	M	56-65	10,001-15,000	2	Semi-detached	No
23	BEV>18 months	Nissan Leaf	Yes	M	36-45	15,001-20,000	2	Detached	No
24	BEV>18 months	Nissan Leaf	Yes	M	36-45	10,001-15,000	3	Semi-detached	No
25	BEV>18 months	Nissan Leaf	Yes	M	46-55	15,001-20,000	2	Detached	Yes
26	BEV>18 months	Nissan Leaf	Yes	M	46-55	20,001+	2	Detached	No
27	BEV>18 months	Tesla Model S	No	M	56-65	10,001-15,000	3	Semi-detached	No
28	BEV>18 months	Peugeot iOn Electric	No	M	46-55	10,001-15,000	2	Detached	No
29	BEV>18 months	Nissan e-NV200	No	M	46-55	5,001-10,000	2	Detached	No
30	BEV>18 months	Nissan Leaf	Yes	M	56-65	10,001-15,000	2	Detached	No

No.	Group	Type of car (BEV/PHEV owners only)	Also own an ICE vehicle?	Gender	Age group	Annual mileage	Number of cars in household	Type of house	Currently have a ToU tariff?
31	PHEV	Mitsubishi Outlander	No	F	56-65	10,001-15,000	1	Terraced	No
32	PHEV	VW Golf GTE	No	M	46-55	5,001-10,000	1	Detached	No
33	PHEV	Mitsubishi Outlander	Yes	M	46-55	10,001-15,000	2	Detached	No
34	PHEV	Mitsubishi Outlander	No	M	56-65	10,001-15,000	1	Detached	Yes
35	PHEV	Vauxhall Ampera	Yes	M	56-65	20,001+	3	Semi-detached	Yes
36	PHEV	Mitsubishi Outlander	Yes	M	26-35	10,001-15,000	2	Terraced	No
37	PHEV	Mitsubishi Outlander	No	M	56-65	10,001-15,000	1	Detached	No
38	PHEV	Mitsubishi Outlander	Yes	M	56-65	15,001-20,000	2	Semi-detached	No
39	PHEV	Mitsubishi Outlander	No	M	66-75	5,001-10,000	2	Flat/maisonette	Yes
40	PHEV	Mitsubishi Outlander	No	M	46-55	20,001+	3	Detached	No
41	PHEV	Vauxhall Ampera	No	M	46-55	5,001-10,000	2	Detached	Yes
42	PHEV	Mitsubishi Outlander	Yes	M	36-45	10,001-15,000	2	Detached	No
43	PHEV	Mitsubishi Outlander	Yes	M	46-55	15,001-20,000	2	Detached	-
44	PHEV	Porsche Panamera S E-Hybrid	No	M	36-45	5,001-10,000	1	Detached	No
45	PHEV	Mitsubishi Outlander	Yes	M	66-75	5,001-10,000	2	Flat/maisonette	No

No.	Group	Type of car (BEV/PHEV owners only)	Also own an ICE vehicle?	Gender	Age group	Annual mileage	Number of cars in household	Type of house	Currently have a ToU tariff?
46	ICE	n/a	n/a	F	46-55	10,001-15,000	4	Detached	No
47	ICE	n/a	n/a	F	46-55	5,001-10,000	2	Terraced	No
48	ICE	n/a	n/a	F	46-55	5,001-10,000	3	Detached	No
49	ICE	n/a	n/a	F	46-55	15,001-20,000	3	Detached	No
50	ICE	n/a	n/a	F	36-45	10,001-15,000	1	Semi-detached	No
51	ICE	n/a	n/a	F	36-45	1-5,000	2	Detached	No
52	ICE	n/a	n/a	M	46-55	20,001+	3	Semi-detached	No
53	ICE	n/a	n/a	M	66-75	5,001-10,000	2	Semi-detached	No
54	ICE	n/a	n/a	M	26-35	5,001-10,000	2	Detached	No
55	ICE	n/a	n/a	M	56-65	5,001-10,000	2	Flat/maisonette	No
56	ICE	n/a	n/a	M	66-75	1-5,000	1	Detached	No
57	ICE	n/a	n/a	M	56-65	5,001-10,000	2	Detached	No
58	ICE	n/a	n/a	M	56-65	10,001-15,000	3	Detached	No
59	ICE	n/a	n/a	M	46-55	5,001-10,000	2	Detached	No
60	ICE	n/a	n/a	M	36-45	15,001-20,000	3	Detached	No