PROJECT REPORT

Consumers, Vehicles and Energy Integration
Project PPR917

Deliverable D5.3 - Consumer Charging Trials Report: Mainstream consumers' attitudes and behaviours under Managed Charging Schemes for BEVs and PHEVs

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Abbreviations

AER	All-Electric Range
ASC	Alternative Specific Constants
BEV	Battery Electric Vehicle
BIT	Behavioural Insights Team
CAN	Controller Area Network
CPMS	Chargepoint Management System
CTL	Control
CVEI	Consumers, Vehicles and Energy Integration project
DfT	Department for Transport
DVLA	Driver and Vehicle Licensing Agency
DVSA	Driver and Vehicle Standards Agency
ECCo	Electric Car Consumer Model
EE	Element Energy
EV	Electric Vehicle (including all plug-in vehicles)
ETI	Energy Technologies Institute
GB	Great Britain
GPS	Global Positioning System
ICE	Internal Combustion Engine
MC	Managed Charging
MDSI	Multi-Dimensional Driving Style Inventory
NTS	National Travel Survey
OBD	On-Board Diagnosis
ONS	Office for National Statistics
PHEV	Plug-in Hybrid Electric Vehicle
PiV	Plug-in Vehicle
RCT	Randomised Controlled Trial
RPM	Revolutions Per Minute
SMC	Supplier-Managed Charging
SOC	State of Charge
ToU	Time of Use
TRL	Transport Research Laboratory
ULEV	Ultra Low Emission Vehicle
UMC	User-Managed Charging
VW	Volkswagen

WLTP	Worldwide Harmonised Light Vehicle Test Procedure
WTP	Willingness-to-pay

Glossary

Item	Description
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 developed by the CVEI Project Team and applied to future scenarios to help understand what 'good looks like' for mass market deployment and use of ULEVs. The framework comprises various analytical tools relating to vehicle adoption and the energy system which are used to help inform the quantitative assessment as well as a set of supporting qualitative assessment metrics.
Attitudes (affective)	The emotions and feelings evoked by owning and using a vehicle.
Attitudes (instrumental)	Attitudes towards factors relating to general practical or functional attributes of driving a vehicle.
Attitudes (symbolic)	What the vehicle says about its owner/driver in terms of social status, social conscience and personal values.
Battery Electric Vehicle (BEV)	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.
Consumer segments: 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.
Consumer segments: Early adopters	Those who adopt after Innovators, and only after awareness, knowledge, and positive attitudes have diffused to them from Innovators. Times to adoption are between one and two standard deviations before the mean time to adopt.
Consumer segments: Mainstream Consumer	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. Includes everyone except innovators.
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.
Managed charging	This refers to the management (by users or systems) 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.

Plug-in Hybrid Electric Vehicle (PHEV)	A vehicle that is equipped so that it may be powered both by an external electricity source and by liquid fuel.
Ultra Low Emission Vehicle (ULEV)	A vehicle that emits less than 75gCO_2/km.

D5.3 Summary

Background

The Consumers, Vehicles and Energy Integration (CVEI) project investigated challenges and opportunities involved in transitioning to a secure and sustainable low carbon vehicle fleet. The project explored how integration of vehicles with the energy supply system can benefit vehicle users, vehicle manufacturers and those involved in the supply of energy. The project's objective was to inform UK Government and European policy, and to help shape energy and automotive industry products, propositions and investment strategies. In addition to developing new knowledge and understanding, the project developed an integrated set of analytical tools that can be used to model future market scenarios in order to test the impact of future policy, industry and societal choices.

Project scope

The CVEI project consisted of two stages: Stage 1 aimed to characterise 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. Stage 1 also involved developing the research design for real-world trials. Stage 2 aimed to fill knowledge gaps and validate assumptions from Stage 1 through scientific research, including delivering the real-world trials with private vehicle consumers and a set of case studies with business fleets.

Purpose and scope of this deliverable

There are concerns that Plug-in Vehicle (PiV) charging demand may add substantially to the overall demand for electricity, at a time when increasing deployment of renewable supply sources will make supply-demand balancing more difficult. Experience in the early market for PiVs suggests that users tend to charge PiVs in the early evening, when other demands are high. Managed Charging (MC) aims to shift PiV charging load to times when other demands are low (such as overnight) to facilitate better integration of PiV charging demand into the wider energy system, better operation within network constraints, and/or minimisation of network reinforcement costs, and potentially make use of unused renewable supply which may otherwise need to be curtailed. The CVEI Consumer Charging Trials measured the charging behaviours of Mainstream Consumers using BEVs and PHEVs under two forms of MC, and compared with charging behaviours when not participating in an MC scheme. It also measured preferences among Mainstream Consumers for various charging schemes after experience of MC in the trial. The results provide inputs to the CVEI Analytical Framework to allow more accurate prediction of the likely volume and timing of PiV charging by Mainstream Consumers, and the potential impact of MC on UK aggregated PiV charging demand.

Method

The Consumer Charging Trials consisted of two separate parts: in the Battery Electric Vehicle (BEV) Charging Trial, 127 participants were provided with a VW e-Golf BEV for eight weeks, and in the Plug-in Hybrid Electric Vehicle Charging Trial, 121 participants were provided with a VW Golf GTE (PHEV) for eight weeks. The trial ran from November 2017 to September 2018, covering both Summer and Winter periods. Key aspects of the method are summarised below:

1. Within each trial, participants were randomly allocated to one of three charging groups: (1) User-Managed Charging (UMC) in which participants were incentivised to charge at times of day when the supply-demand balance is favourable through a structured tariff; (2) Supplier-Managed Charging (SMC) in which participants specified the charge they required and time they required it by, and were incentivised to allow the supplier to control the timing of charging to maximise cost savings; or (3) a Control group who did not experience a MC scheme and were not incentivised to charge in a particular way.
2. Mainstream Consumers were recruited rather than PiV Innovators who have participated in most UK PiV trials to date, and whose attitudes towards PiVs are known not to represent Mainstream Consumers.
3. Participants were provided with a smartphone app to enable them to interface with their MC scheme; such as scheduling charge start times (UMC) or setting Desired SOC (SMC) (or in the case of the Control group, to check their vehicle's state of charge).
4. Participants were provided with a dedicated 3.6kW Mode 3 charging unit at their home. Data on home charging events were collected via the charging unit and vehicle telematics. The telematics data also recorded vehicle usage and away-from-home charging.
5. Socio-demographics, travel patterns, vehicle ownership information and self-reported attitudes were collected before and after the trial experience.
6. Participants completed a choice experiment following their experience of using and charging the vehicles, in order to characterise preferences for MC schemes and the relative importance of MC scheme attributes.

Key Findings and Conclusions

- Participants whose charging was not managed (the Control group) usually charged at home in the late afternoon/early evening (3-8pm), with a peak in weekday charging between 5-6pm for PHEV participants, and 6-7pm for BEV participants. At weekends the peak in charge events was less pronounced, with a greater share of charge events starting earlier in the day. This shows that when charging is not managed, Mainstream Consumers are likely to charge in the early evening when other electricity demands are high.
- Compared with unmanaged charging, the proportion of home charge events starting between 4-7pm was more than halved in the UMC and SMC groups. The greatest reduction was observed in the SMC group. The majority of charging was shifted to later in the evening (UMC) or overnight (SMC). This effect was observed for both weekday and weekend charging. A small minority of participants were responsible for the majority of away-from-home charging sessions, suggesting that some Mainstream Consumers adopted regular charging habits away-from-home.
- Participants' attitudes towards UMC and SMC after their trial experience were generally positive. Averaged across groups, just under 90% of participants indicated that, in future, they would choose either UMC or SMC over unmanaged charging, whether they had a PHEV or a BEV. Experience with UMC or SMC tended to increase the share of BEV participants who would choose the option they had experienced.
- Even participants in the Control group, who had not experienced MC during the trials, expressed a preference for MC over unmanaged charging: these participants were substantially more likely to choose UMC over SMC, resulting in an overall preference for UMC over SMC for the majority of participants.
- Choice experiment results showed that the value BEV participants attached to MC tended to be higher if there was nearby public charging, and it increased the nearer the public charging was to their homes. It is suggested that nearby public charging was perceived as a back-up in case the vehicle was needed sooner than planned and had not yet charged to the level required.
- Participants were found to be more likely to choose a MC scheme the greater the expected annual cost savings, but increasing the cost of charging at peak time reduced the scheme's attractiveness. An override feature enabling users to change charge event settings once input was seen as a desirable feature in SMC.
- More than 50% of participants, across the whole sample, indicated that the availability of a UMC or SMC scheme would make them at least "a little more likely" to purchase a BEV or PHEV.

Executive Summary

Background to the Consumers, Vehicles and Energy Integration Project

The Consumers, Vehicles and Energy Integration (CVEI) project investigated challenges and opportunities involved in transitioning to a secure and sustainable low carbon vehicle fleet. The project explored how integration of vehicles with the energy supply system can benefit vehicle users, vehicle manufacturers and those involved in the supply of energy. The project's objective was to inform UK Government and European policy, and to help shape energy and automotive industry products, propositions and investment strategies. In addition to developing new knowledge and understanding, the project aimed to develop an integrated set of analytical tools that can be used to model future market scenarios in order to test the impact of future policy, industry and societal choices.

The CVEI project consisted of two stages: Stage 1 aimed to characterise 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 aimed to fill knowledge gaps and validate assumptions from Stage 1 through robust research, including real world trials with private vehicle mass market / Mainstream Consumers and case studies with business fleets.

As part of Stage 2 of the CVEI project, the Consumer Charging Trials provided mainstream vehicle consumers (all current petrol or diesel vehicle owners) with 8-weeks experience of living with and charging a BEV or PHEV. The trials sought to explore Mainstream Consumers' real-world charging behaviour and response to consumer-focused approaches for the management of Plug-in Vehicle (PiV) charging demand. Managed Charging (MC) aims to shift PiV charging load to times when other demands are low (such as overnight) to facilitate better integration of PiV charging demand into the wider energy system.

Policy and industry context

The UK government is committed to encouraging the uptake of Ultra-Low Emission Vehicles (ULEV) to meet its climate change targets and to improve air quality. In October 2017, as a part of the government's Clean Growth Strategy, the UK pledged to spend £1bn to enable the transition away from Internal Combustion Engine (ICE) vehicles. By 2040, the government intends that the sale of conventional petrol and diesel cars and vans in the UK will cease. To support the uptake of PiVs, a £400 million Charging Infrastructure Investment Fund has also been announced by the government to support the expansion of the PiV charging network by 2020 (including home, on-street, workplace and wireless charging).

PiV charging demand, resulting from increased uptake, will add substantially to the overall demand for electricity, at a time when increasing deployment of renewable supply sources will make supply-demand balancing more difficult. As the national electricity infrastructure needs to be built around peak demand rather than average demand, this presents major infrastructural challenges.

Understanding consumer charging behaviour is critical for implementing policy and market directions that contribute to a balanced energy system that avoids expensive infrastructure development. Experience in the early market for PiVs suggests that users tend to charge PiVs in the early evening; a time when electricity demand is already high. If Mainstream Consumers also choose to charge their vehicles in the early evening peak period, the demands on the grid will significantly increase. However, if consumers are willing to subscribe to MC tariffs, then demand can be shifted to meet available supply.

An understanding of how best to integrate vehicles with the energy system to manage charging demand is, therefore, crucial. There are three key aims for closer integration; avoiding further load to the existing peak in demand in the early evening, enabling spare capacity which is available during the overnight period to be used for charging, and maximising the use of low-carbon electricity while avoiding using the highest-carbon electricity. In this context, MC will be at the heart of the infrastructure transformation to enable the penetration of electrified transport while reducing, if not improving, overall energy demand and the impact on the existing grid network.

The trials

The Consumer Charging Trials consisted of two discrete arms: 127 participants were provided with a VW Golf BEV for eight weeks, and 121 participants were provided with a VW Golf PHEV for eight weeks.

Within each arm, participants were randomly allocated to one of three charging groups:

(1) User-Managed Charging (UMC) in which participants were incentivised, through a structured tariff, to charge at times of day when the supply-demand balance is favourable;

(2) Supplier-Managed Charging (SMC) in which participants specified the charge they required and the time they required it by, and allowed the supplier to control the timing of charging to maximise cost savings;

(3) a Control group who did not experience a MC scheme and were not incentivised to charge at any particular time or in any particular way.

This is first controlled trial of both BEVs and PHEVs known to recruit Mainstream Consumers (i.e. current ICE owners); PiV Innovators have participated in most UK PiV trials to date. The attitudes of PiV Innovators towards PiVs are known to be unrepresentative of those of Mainstream Consumers, so it is inappropriate to assume that they will share the same charging behaviours; yet in a developed future market, it will be Mainstream Consumers who perform the majority of PiV charging.

Participants were provided with a smartphone app to enable them to interface with their MC scheme (or in the case of the Control group, to check their vehicle's state of charge).

Participants were provided with a dedicated 3.6kW Mode 3 charging unit at their home. Data on home charging events were collected via the charging unit. Telematics data from the vehicle recorded vehicle usage and away-from-home charging data.

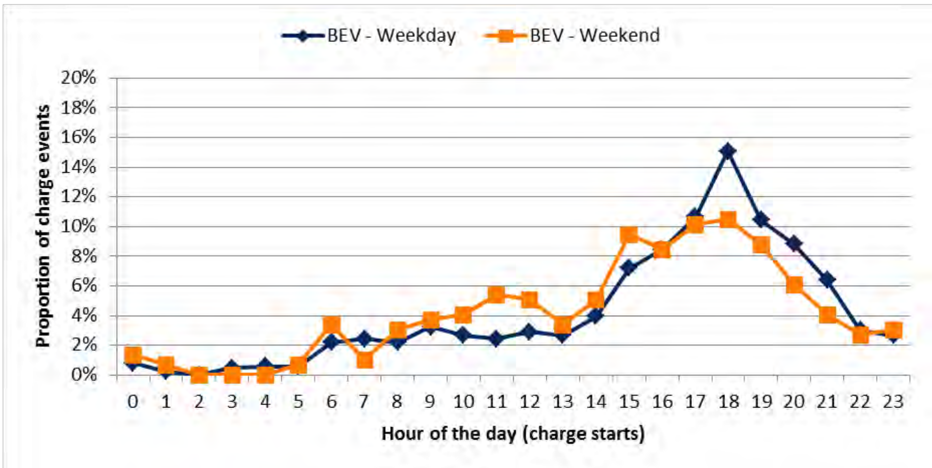
The key dependent variables[1] in the Consumer Charging Trials were a series of measures of home-charging behaviour such as the frequency of home charging, the distributions of plug-in time, and charge-start time. Aspects of charging away from home were also measured. It

[1] The variables being studied and measured in an experimental design.

was anticipated that charging behaviours might differ at weekends because of potentially greater behavioural flexibility, so these measures were recorded separately for weekdays and weekend days. Self-reported attitudes and willingness to adopt MC schemes were also collected, before and after the trial experience. Finally, participants completed a choice experiment following their experience of using the vehicles, in order to characterise preferences for MC schemes and the relative importance of MC scheme attributes.

Key findings

Participants whose charging was not managed (the BEV and PHEV Control groups) usually charged at home in the late afternoon/early evening (3-8pm, with a peak in charging between 5-6pm for PHEV participants, and between 6-7pm for BEV participants) (Figure S1).



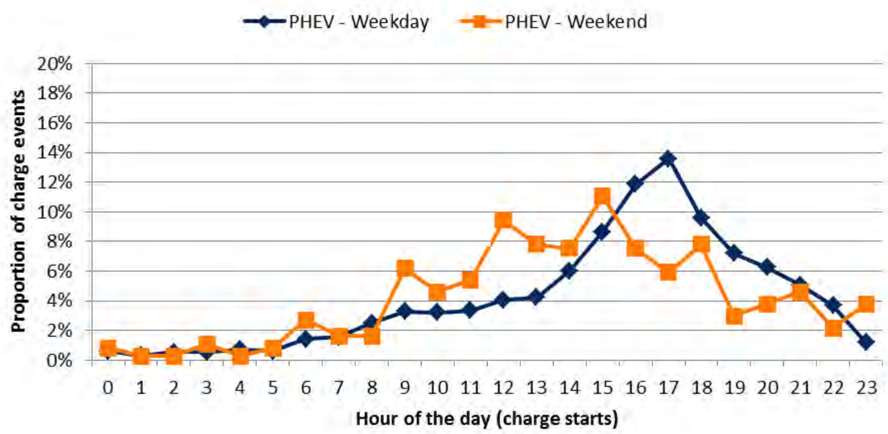


Figure S1: Proportion of control group home charge weekday and weekend charging events starting in each hour of the day (BEV – top, PHEV – bottom)

At weekends the peak in charge events was less pronounced, with a greater share of charge events starting earlier in the day. This result confirms that when charging is not managed, Mainstream Consumers are likely to charge their vehicles in the early evening when other electricity demands are high.

About 76% of BEV participants and 58% of PHEV participants charged their vehicles away from home, mostly in the mornings. Across all home charges, 76,569kWh of energy were delivered; 50,695kWh in the BEV Charging Trial, and 25,873kWh in the PHEV Charging Trial. By comparison, charges away from home accounted for 10,824kWh and 3,338kWh of energy delivered in the BEV and PHEV Charging Trials, respectively. Thus, charging away from home represented about 17% of all energy delivered in the BEV trial, and about 11% in the PHEV trial. A small minority of participants were responsible for a majority of charging events which took place away-from-home charging.

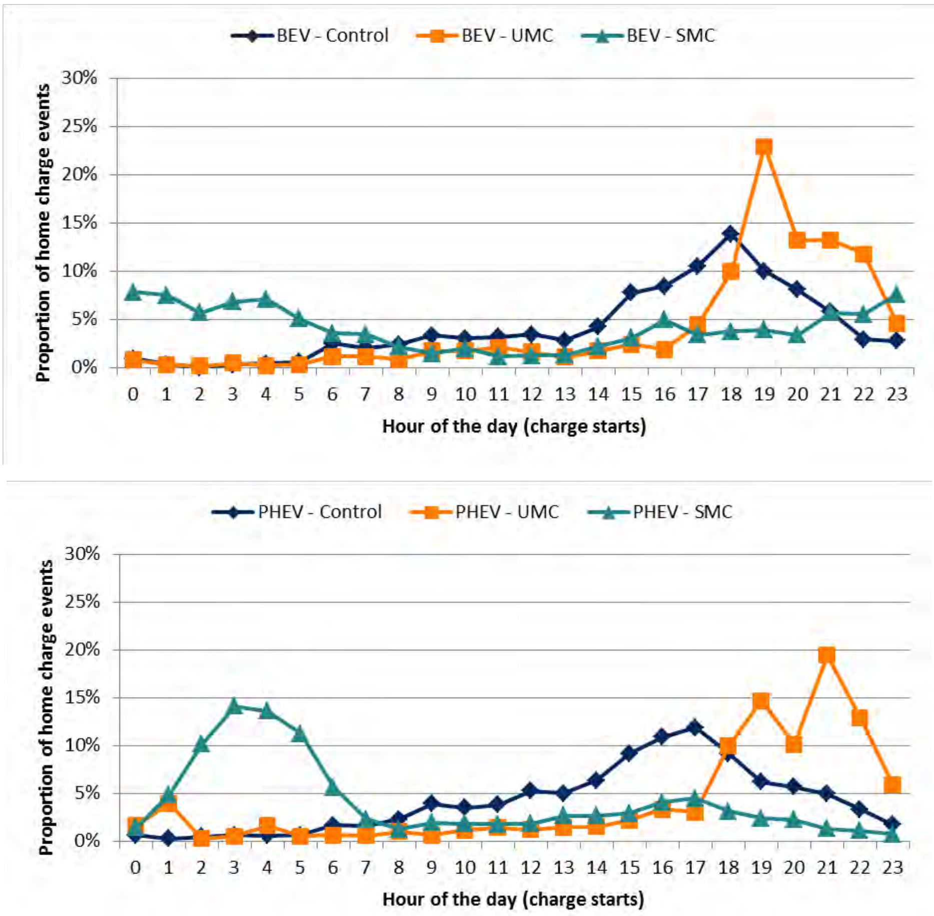


Figure S2: Proportion of home charge events starting in each hour for Control, UMC and SMC participants (Top – BEV, Bottom – PHEV)

Both UMC and SMC were effective at shifting this PiV charging at home demand to later in the evening (UMC) or overnight (SMC) when other electricity demands are lower. This effect was observed for both BEV and PHEV participants; as shown in Figure S2 (above), which shows the distributions of charge start times by each hour of the day, and Figure S3 (below), which shows the average energy delivered per participant per hour of the day [2]. (Data shown in these figures have been aggregated over both weekdays and weekend days; the differences between weekday and weekend day profiles are shown in the main body of this report).

[2] The profile of SMC charge start times was influenced by the way in which the chargepoint management system (CPMS) was set-up for the trial. The peak in SMC PHEV charges between 3-4am can be explained by this and real-world implementation would likely smooth this load – this is discussed further in section 3.5.

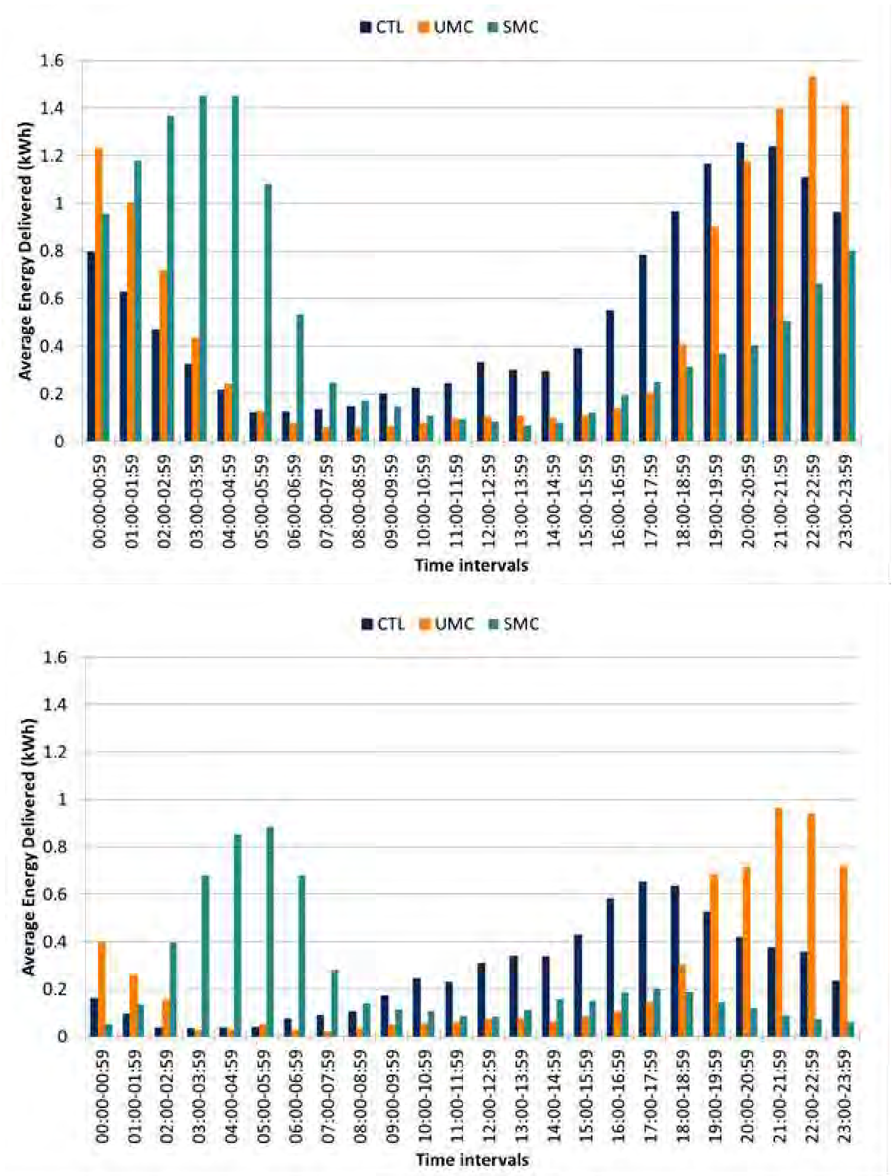


Figure S3: Average energy delivered per participant per hour of the day for Control, UMC and SMC participants (N = 3,822) (Top – BEV, Bottom – PHEV)

The data from these trials shows that UMC was effective at shifting charging demand to later in the evening compared to unmanaged conditions, suggesting consumers were incentivised by the savings available in the Low tariff band. In a real-world implementation of UMC, consideration should be given to the risk of creating a new peak in demand; as it is likely that consumers will shift demand to the first or early hours of the cheap period (e.g. 6pm onwards), creating a new peak. This would cause problems in itself, especially if large clusters of PiV drivers in a local area follow the same UMC tariff band structure.

Not only were UMC and SMC effective at shifting the timing of PiV charging away from the early-evening period; the majority of participants in the UMC and SMC groups were either satisfied or very satisfied with the managed charging scheme they had experienced in the trial. Further, participants' attitudes towards UMC and SMC after their trial experience were found to be very positive. Averaged across groups, just under 90% of participants would choose either UMC or SMC over unmanaged charging, whether they had a PHEV or a BEV. Experience with UMC or SMC tended to increase the percentage of BEV participants who would choose the option they had experienced. Thus both forms of MC appear to have been both effective at time-shifting charging demand, and appealing to Mainstream Consumers using both BEVs and PHEVs.

Even participants from the Control groups, who had not experienced MC during the trial, expressed a preference for MC over unmanaged charging: this suggests that the basic concept of MC has appeal to PiV users even when they have not experienced it for themselves. These participants were substantially more likely to choose UMC over SMC, resulting in UMC being preferred to SMC by a majority of the participants taken as a whole.

Choice experiment results showed that the value participants attached to MC tended to be higher if there was nearby public charging, and the perceived value increased the nearer the public charging was to their homes. It is suggested that nearby public charging was seen as a back-up in case the vehicle was needed sooner than planned and had not yet charged to the level required, especially by SMC participants, who perhaps perceived less control over when their vehicles were being charged than did UMC participants. The close proximity of public charging was found to be more valuable for BEV participants; it is possible that this is because they do not have a back-up option to run on fuel. In addition, for BEV participants the nearby public charge point was stated as a 50kW+ rapid charger, whereas for PHEV participants this was limited to 7kW, which is the maximum charging rate of the PHEV model used in the trial; hence public charging may have been perceived as more valuable to BEV than PHEV participants.

Participants were found to be more likely to choose a managed charging scheme the greater the expected annual cost savings, but increasing the cost of charging at peak times reduced the scheme's attractiveness (see section 3.6.4). An override feature enabling users to change their settings once entered, was a desirable feature for SMC. Participants did not attach much value to the accuracy of estimates of cost saving, or to anticipatory charging in SMC (where the system charges the vehicle more than the user has specified if electricity is cheaper than anticipated in the immediate few days). Most participants specified a desired charge of >90% (see Section 3.6.4.5), settings that leave less opportunity for anticipatory charging to offer benefit.

More than 50% of participants, across both trials, indicated that the availability of a UMC or an SMC scheme would make them at least "a little more likely" to purchase a BEV or PHEV.

Conclusions

- In unmanaged charging conditions, participants usually charged at home in the late afternoon/early evening (3-8pm). At home, weekday charge start times in the control group peaked between 5-6pm for PHEV participants, and between 6-7pm for BEV participants. At weekends the peak in charge start events is less pronounced, with a greater share of charge start events starting earlier in the day.
- Compared with unmanaged charging, the proportion of home charge events starting between 4-7pm was more than halved in the UMC and SMC groups. The greatest reduction was observed in the SMC group. The majority of charging was shifted to later in the evening (UMC) or overnight (SMC). This effect was observed for both weekday and weekend charging.

- Managed Charging is more appealing than unmanaged charging to the majority of Mainstream Consumers who have had experience living with a PiV, even when they have not had any direct experience of Managed Charging.
- In general, after receiving information about both MC schemes at the end of the trial, participants indicated that UMC schemes have higher appeal than SMC. However, BEV drivers who have had direct experience of SMC were more likely to prefer an SMC scheme. While depedent on the wider context of the consumer offering, this suggests that experience with SMC may be important for adoption of that type of Managed Charging scheme.
- Participants in both MC conditions initiated the majority of charges using the Default settings suggesting that engagement with MC can be encouraged by making it as easy as possible for consumers. Setting new parameters following plug-in was more common in the SMC group than the UMC group; it is possible that users engage more with an SMC scheme than UMC because of the nature of the system (e.g. setting Desired SOC and Departure Time versus simply setting a charge start time).
- The key attributes which contribute to an attractive MC scheme for consumers include high annual cost savings, low peak electricity costs, and nearby public charging. Features which make SMC in particular more attractive include an override function where users can change settings for a charge event after they have been input (even if in doing so they lose all financial benefit for that event), and availability of a public charge point within five minutes drive of the users' homes (to act as a back-up in case their car is needed earlier than expected). This was particularly true for BEV drivers who, unlike PHEVs, do not have the back-up option to drive under fuel if their batteries are not charged.
- Most charge events away from home started in the morning; peaking between 7-8am for PHEV drivers and 8-10am for BEV drivers. This contrasts with the control group home charges (which were also in unmanaged conditions), where peaks were observed between 5-6pm for PHEVs and between 6-7pm for BEVs. Self-report questionnaire data suggests that a large proportion of these morning charges away from home were at participants' places of work or education. Weekday charge events away from home were more likely to start overnight or in the early morning, compared with weekend charge events.

1 Introduction

The UK government is committed to encouraging the uptake of Ultra-Low Emission Vehicles (ULEVs) to meet its climate change targets and to improve air quality. In October 2017, as a part of the government's Clean Growth Strategy, the UK pledged to spend £1bn to enable the transition away from Internal Combustion Engine (ICE) vehicles. By 2040, the government intends that the sale of conventional petrol and diesel cars and vans in the UK will cease (OLEV, 2018). To support the uptake of PiVs, a £400 million Charging Infrastructure Investment Fund has been announced by the government to support the expansion of the PiV charging network by 2020 (including home, on-street, workplace and wireless charging). The UK government's Office for Low Emission Vehicles (OLEV) has shown commitment to smart charging technologies through its Road to Zero Strategy (OLEV, 2018), for example, providing continued grant support for smart-enabled home chargepoints through the Electric Vehicle Homecharge Scheme (EVHS) until March 2019, and driving an intitative for all government-funded home chargepoints to be smart from July 2019. Further, the Automated and Electric Vehicles Bill will enable government to regulate that all new chargepoints are smart.

There are concerns that PiV charging demand, resulting from increased uptake, may add substantially to the existing peak demand for electricity (Greenleaf, Chen, & Stiel, 2014; Hardman *et al*., 2018). Given the need for national electricity infrastructure to be built around peak demand rather than average demand, this presents major infrastructural challenges, particularly as we begin to decarbonise the country's electricity supply.

The electrification of the transport network could either make this problem worse, or contribute to solving it, and the difference will depend largely on consumer behaviour. Experience in the early market for PiVs suggests that users tend to charge PiVs in the early evening, already a time when electricity demand is high (see section 1.2). However, if consumers are willing to engage with Managed Charging (MC), then it may be possible to shift PiV charging to avoid existing peak demand and meet available supply. An understanding of how best to integrate vehicles with the energy system to manage charging demand is, therefore, crucial.

1.1 The Consumer Charging Trials within CVEI

The Consumers, Vehicles, and Energy Integration (CVEI) project sought to explore how the integration of PiVs with the energy supply system could benefit vehicle users, vehicle manufacturers and energy suppliers. The project developed an Analytical Framework that considered a range of possible configurations of ULEV[3] deployment and use, and their integration within the wider energy system. The Framework can be used to explore which configurations are optimal, considering commercial and market structures and customer propositions. The Framework includes estimates of the scale and pace of development of PiV charging demand nationally, based on estimates of PiV uptake.

The Consumer Uptake Trial in the CVEI project (see Deliverable D5.2) was aimed at reducing uncertainty in the estimates of PiV uptake, by understanding changes in Mainstream Consumers' attitudes towards BEV and PHEV adoption. The role of the Consumer Charging Trials was to investigate Mainstream Consumer charging behaviour with PHEVs and BEVs, and

[3] PiVs play a key role in the Analytical Framework, but ICEVs and Fuel Cell Vehicles are also considered

their responses and attitudes to alternative MC consumer propositions, which aim to manage electricity demand associated with charging PHEVs and BEVs. The results provide inputs to the Analytical Framework to allow more accurate prediction of the likely charging behaviour and use of MC schemes, and the resulting impact on the UK energy system.

Two types of MC scheme were investigated in these trials; User-Managed Charging (UMC) and Supplier-Managed Charging (SMC). In a UMC scheme, consumers control the timing of charging themselves but are incentivised, through a banded tariff, to charge at times of day when the supply-demand balance is favourable; this allows them to reduce their cost of charging. An SMC scheme, on the other hand, incentivises consumers to allow a 'supplier' to directly manage when their PiV is charged; in return for providing this flexibility, the supplier passes on a share of cost savings to the consumer[4].

1.2 PiV charging behaviours: gaps in existing knowledge

1.2.1 Innovators and Mainstream Consumers

The design of the Consumer Charging Trials made a clear distinction between consumers who are "Innovators" with respect to PiVs, and "Mainstream Consumers".

Mainstream Consumers were defined as all consumer segments in Rogers' (2003) Diffusion Model except for Innovators; that is the Early Adopter, Early Majority, Late Majority, and Laggard segments. Innovators are distinctive in the Diffusion Model in that they are the sources of awareness, knowledge, and positive attitudes towards the innovation. All others in the population act first as receivers of this information, and then become sources for further diffusion themselves. The last few to adopt are receivers only.

For the purposes of the CVEI project these groups (i.e. all apart from Innovators) were collectively referred to as Mainstream Consumers. Diffusion Model segments are defined statistically in terms of their position on the adoption curve (see Figure 1).

Innovators are 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 those whose times to adoption lie between two and one standard deviation earlier than the mean time to adoption (a further 13.5% of the population), and so on. In this report, the term Innovator is used to refer to a private car consumer who is among the first 2.5% to choose a PiV[5].

[4] In real-world implementation the level of savings to the supplier, that could be be subsequently shared with the consumer, are more complex. Calculations used for the trial are detailed in Deliverable 1.3: Market Design and System Integration.

[5] A report of case studies with fleets as part of this project is also available (D6.1 Fleet Study Report).

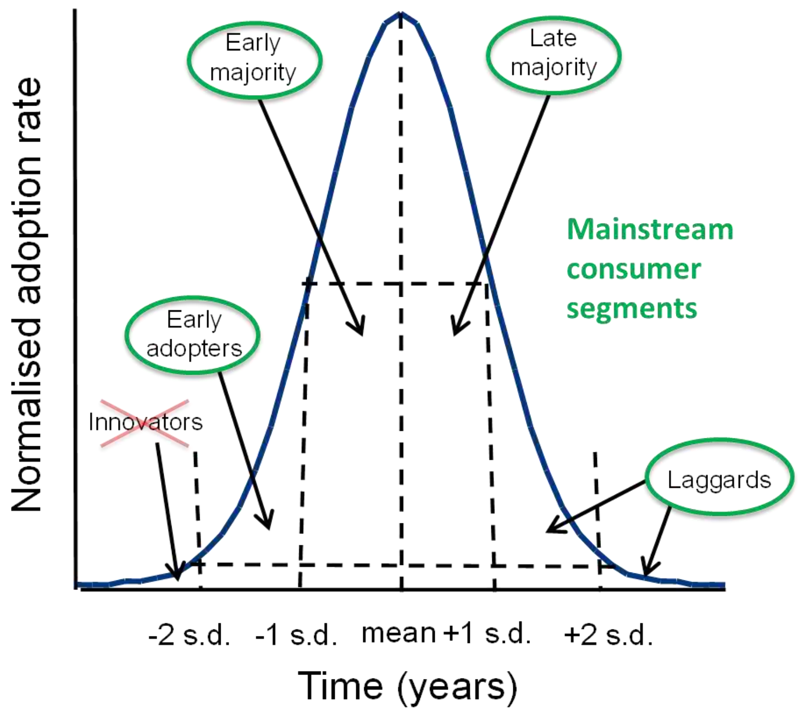


Figure 1: Segments from Rogers' (2003) Diffusion Model that are included in the 'Mainstream Consumer' population

In the UK there are approximately 32 million cars (DfT, 2018a). At the end of Quarter 2 of 2018, the UK Department for Transport reported there were 150,000 registered plug-in cars (DfT, 2018a); approximately 0.5% of the total car fleet. For the same time period, PHEV and BEV sales accounted for 2.5% of all new car sales, an increase from 1.4% at the end of 2016 and 1.8% at the end of 2017 (DfT, 2018b). These figures can't be directly related to the first 2.5% of the population as described in Rogers' adoption curve, but nevertheless they confirm PiVs are still an early market and present owners/users of PiVs are likely to be Innovators. Most previous PiV research has focused on these current PiV owners (particularly owners of BEVs); however, the attitudes and behaviours of Innovators cannot be used to accurately predict those of Mainstream Consumers (Anable, Kinnear, Hutchins, Delmonte & Skippon, 2011). The Consumer Charging Trials aimed to address this gap by collecting empirical data on the charging behaviours of Mainstream Consumers.

1.2.2 Charging behaviour of Mainstream Consumers

The daily profile of aggregated PiV charging demand is central to the CVEI Analytical Framework. Beyond the earliest stages of PiV uptake, the daily time profile of aggregated PiV charging demand will increasingly be determined by the charging behaviours adopted by Mainstream Consumers.

Research on charging behaviour of current BEV users suggests they tend to charge their vehicles at home in the early evening (e.g. Anable, Schuitema, & Stannard, 2014; Brook Lyndhurst, 2015; Morrissey, Weldon & O'Mahony, 2016). Franke and Krems (2013) reported participants charged on average three times a week; and there usually remained a substantial reserve of energy in the battery when a charge was initiated. The 'My Electric Avenue' trial with PiV Innovators found peaks in weekday charging in the morning and evening (before and after work), and peaks in weekend charging between 10am and 6pm (My Electric Avenue, 2016). Initial results from the follow-up ‘Electric Nation’ trial, again with PiV Innovators, suggest peaks of charge start times between 5pm and 6pm (Electric Nation, 2018).

At present the limited information available on the charging behaviour of PHEV users suggests that it is similar to that of BEV users (Brook Lyndhurst, 2015). In the U.S.A., PHEV users have been reported as charging more frequently than BEV users (ECOtality, 2013, cited by Brook Lyndhurst, 2015). Anable, *et al*. (2014) concluded that most users run their PHEVs on electricity as much as possible (accounting for over 70% of mileage in the ECOtality study). Nevertheless, the lack of reported studies of PHEV users’ charging behaviour mean that it is not possible to draw firm conclusions at this stage, and further research is necessary.

Participants in these previous studies have largely been PiV Innovators, and extrapolation to potential Mainstream Consumer charging behaviour depends on the assumption that it would be similar to that of Innovators. The segmentation analysis performed for the ETI’s PiV project (Anable *et al*., 2011) provides clear evidence that Innovators’ attitudes towards PiVs differ markedly from those of each of the variety of Mainstream Consumer segments identified. Innovators’ attitudes towards PiVs, in general and particularly towards ownership of a BEV or PHEV, are much more positive than those of Mainstream Consumer segments. The study also found that Innovators were predominantly highly educated young males with high annual incomes who had a low occurrence of commuting by car (Anable *et al.,* 2011). While this information does not directly bear on the question of whether their charging profiles might differ, it does suggest that Innovators are atypical not only in their attitudes to PiVs but also in their demographics. Therefore, considerable caution is needed in making assumptions of similarity between Innovators and Mainstream Consumers.

Further, the qualitative interviews with Innovators, undertaken in WP2.1 of Stage 1 (Kinnear, Anable, Delmonte, Tailor & Skippon, 2017), indicated that a majority exhibited pro-environmental motivations for their vehicle choice. It was also found that the main benefits that Innovators could see in engaging with Supplier-Managed Charging were that it would benefit society or benefit the environment. It is reasonable to hypothesise that other motivations might need to be harnessed for Mainstream Consumers (e.g. cost benefits through dynamic electricity pricing).

In summary, other UK trials have measured only the charging profiles of Innovators, and there is no *a priori* case to assume that their charging behaviour will accurately reflect that of Mainstream Consumers. This represents a major gap in present (2018) knowledge. There is a clear need to provide the Analytical Framework with new empirical data from measurements of the actual charging behaviours of Mainstream Consumers. In addition, there is a need to provide empirical data on the charging profiles of Mainstream Consumer PHEV users, particularly if PHEVs were to dominate adoption of PiVs initially (see D5.2).

1.2.3 Impacts of Managed Charging

Demand on electricity networks is predicted to increase as Mainstream Consumer adoption of PiVs becomes widespread. Measuring the charging behaviour of Mainstream Consumers will enable an accurate picture of charging demand to be incorporated into the Analytical Framework. That is not enough on its own, however, to enable the framework to be used to investigate how far charging demand can be optimally integrated within the wider energy system to provide systemic benefits; Mainstream Consumer responses to Managed Charging (MC) must also be considered.

MC is used here as a general term to describe consumer propositions that aim to modify consumer PiV charging demand. To be able to model the systemic effects of MC schemes, there is a need for robust data relating to Mainstream Consumers' charging behaviours under particular sets of conditions that represent the major types of possible MC schemes. Likewise, to be able to make valid causal inferences about the effect of engagement with various MC schemes on charging behaviour (and as such, the potential benefits of MC), the charging behaviour of Mainstream Consumers in unconstrained conditions (when not using a MC scheme) must also be understood. This was the key objective of the Consumer Charging Trials; to obtain empirical data on Mainstream Consumer charging behaviour when in unmanaged charging conditions (serving as a baseline) and when engaged with MC schemes.

The two types of MC scheme investigated in these trials were as follows:

- A **User-Managed Charging (UMC)** scheme, analogous to a Time-of-Use Tariff (such as Economy 7 tariffs in the UK).
    - In a UMC scheme, the user controls the timing of charging themselves, either simply through manually adjusting the times at which they plug-in and plug-out their vehicles, or via smart charging technologies which enable them to specify a schedule for charging (e.g. via a smartphone app connected with the home charger or the vehicle, or programmable functions in the vehicle itself[6]).
    - The user is incentivised to charge at particular times of day.The user can benefit from reduced energy costs by choosing to charge at times of day when prices are low; these price differentials are reflected in a banded tariff structure.
- A **Supplier-Managed Charging (SMC)** scheme, where the user is encouraged to allow a third-party, such as an energy supplier,, to directly manage when their PiV is charged.
    - A SMC scheme has the greatest potential for systemic optimisation because it provides the supplier with flexibility to directly time-shift charging demand to periods of favourable supply-demand balance and lower wholesale cost.
    - The user can set conditions for charging, for example by requesting a minimum level of charge and specifying when they need the vehicle for their next journey.
    - In principle the user benefits from engagement with a SMC scheme by having their charging needs met at the lowest cost compatible with those needs, without the need to manage the charging themselves.

The CVEI Stage 1 qualitative research with Mainstream Consumers found that attitudes towards UMC schemes were generally more positive than SMC schemes. Users in such a scheme can choose to maximise their benefit by charging at the cheaper times, whilst retaining full control of precisely when the charging occurs, so as to minimise (perceived) risk. The research in Stage 1 of the project was limited in that it collected only qualitative data from a small sample of Mainstream Consumers who had no direct experience of using a MC scheme. The Consumer Charging Trials in Stage 2, therefore, sought to collect empirical data

[6] For these trials, a dedicated smartphone app was used (see section 2.3), and scheduling functions through the vehicle OEM's smartphone app were disabled to remove potential conflict.

on real-world Mainstream Consumer charging behaviours when directly using UMC and SMC schemes, and when in unmanaged charging conditions (the Control group).

1.3 Research questions

The research questions addressed by the Consumer Charging Trials are shown in Table 1.

This report provides an overarching summary of the trial method, the main findings, and a discussion of their implications. A fuller description of the method, analyses, and the specific answers to each of the research questions is provided in the Technical Appendix.

Table 1: Research Questions

	Consumer Charging Trials Research Questions
1	What is the charging behaviour of Mainstream Consumers when not participating in a Managed Charging scheme?
2	How does the charging behaviour of Mainstream Consumers when participating in a Managed Charging scheme compare with their behaviour when they are not?
3	How does the charging behaviour of Mainstream Consumers when participating in a Supplier-Managed Charging scheme compare with their behaviour when participating in a User-Managed Charging scheme?
4	What are the diurnal, weekly and seasonal time profiles of charging when participating (or not) in a given Managed Charging scheme?
5	What are the between-participant variabilities in Mainstream Consumer charging behaviour when participating (or not) in a given Managed Charging scheme?
6	How does charging behaviour vary with time over the first eight weeks of using and charging a PiV, whether participating in a Managed Charging scheme or not?
7	How do Mainstream Consumers interact with specific features of User- and Supplier-Managed Charging?
8	What preferences do Mainstream Consumers have between Supplier-Managed Charging, User-Managed Charging, and no Managed Charging?
9	What factors influence preferences between Supplier-Managed Charging, User-Managed Charging, and no Managed Charging?
10	What are the impacts of different User-Managed Charging tariffs and Supplier-Managed Charging schemes on a Consumer's likelihood to participate in these arrangements?
11	What are the impacts of different User-Managed Charging tariffs and Supplier-Managed Charging schemes on the likelihood of car buyers choosing a PHEV/BEV over other powertrains?

2 Summary of method

2.1 Trial design

Two separate charging trials were conducted:

- a PHEV Consumer Charging Trial to investigate the charging behaviours, attitudes and responses of Mainstream Consumers living with a PHEV, and;
- a BEV Consumer Charging Trial to investigate the charging behaviours, attitudes and responses of Mainstream Consumers living with a BEV.

Participants in both trials were given a plug-in vehicle for a period of eight weeks to use for their normal day-to-day journeys. Participants in the BEV Consumer Charging Trial were given a VW e-Golf hatchback 5dr (2017 model); participants in the PHEV Consumer Charging Trial were given a VW Golf GTE 1.4 TSI PHEV hatchback 5dr (either 2016 or 2017 model). A Mode 3 chargepoint was installed in participants' homes to enable them to safely charge the BEV and PHEV during the trial. These chargepoints were 3.6kW. Although faster (7.2kW) home chargers were available, 3.6kW chargers were used on the basis that these would lead to charging times consistent with those that will be experienced with vehicles with larger battery capacities in the future market.

The trials sought to replace participants' own vehicles with the trial vehicles for their everyday driving over the 8-week period. For practical reasons, it was not possible to replace and store every participant's own vehicle for the duration of the trial. Instead, participants retained their own personal vehicles in most cases, except for circumstances where they were asked to leave their vehicles with the research team:

1. Where the number of drivers exceeded the number of vehicles in the household.
2. Where there was insufficient off-street parking to accommodate an additional vehicle.

This resulted in a total of 98 participants storing their personal vehicle with the research team (approximately 40% of the sample).

Participants were recruited for the two trials from the 50-mile radii surrounding the head offices of TRL (Crowthorne, Berkshire) and Cenex (Loughborough, Leicestershire). There was an approximate 50/50 split of participants between these two locations for each of the BEV and PHEV Charging Trials.

The recruitment target was 240 Mainstream Consumer participants (120 participants for the BEV Charging Trial and 120 for the PHEV Charging Trial). To ensure that the PHEV Charging Trial sample was representative of the driving population in Great Britain, a stratified sampling approach based on driving licence data from the Driver and Vehicle Standards Agency (DVSA), and population and travel data from the National Travel Survey (NTS) and the Office of National Statistics (ONS) was used. The target sample for the BEV Consumer Charging Trial was defined as 120 Mainstream Consumers whose vehicle needs were met by the current capabilities of BEVs available in the market at the time of the trial; i.e. Mainstream Consumers for whom the vast majority of return journeys are shorter than 80 miles. This required an opportunistic sampling approach; whereby interested individuals from the target population who met the travel pattern eligibility criteria were recruited. With the opportunistic sampling approach, there was less opportunity to stratify the sample by other factors such as age, gender and location (as was done in the PHEV Consumer Charging Trial).

While the final BEV and PHEV trial samples were in-fact similar, as the sampling criteria were different between the two trials[7], direct statistical comparisons between them were not possible, and the data were analysed separately for each.

Each trial adopted a between-participants Randomised Controlled Trial (RCT) design, in which participants were randomly allocated to one of three groups:

1. a Control (CTL) Group, in which participants were free to charge their vehicles as they wished;
2. a User-Managed Charging (UMC) group, in which participants were incentivised to actively shift their charging to certain periods, through a banded tariff structure, or;
3. a Supplier-Managed Charging (SMC) group, in which participants were encouraged to delegate control of their charging to a simulated energy supplier in exchange for consequent savings on overall charging cost.

The trials did not directly manipulate participants' actual household energy tariffs or their energy bills; engagement with the trial was instead incentivised through a 'Savings Points' system whereby UMC and SMC participants could earn points for particular home charging behaviours (see section 2.2). Savings Points earned for home charging were converted to cash at the end of the trial, and so served as an incentive for charging the vehicle. Control group participants were not incentivised to charge in a particular way; however, to ensure they were incentivised to use the vehicle and engage with the trial, they were awarded Points for driving a minimum of 50 miles per week (which were also converted to cash at the end of the trial). Charging behaviours away from participants' homes were not incentivised directly in the trial; participants were free to charge away from home if they wished, and were provided with an access card for the POLAR Plus network.

The Consumer Charging Trials accounted for seasonal variation in charging behaviour, PiV use and energy prices, in particular, the distinct differences in energy prices and price differentials between 'summer' and 'winter' periods. In winter there are much higher daily price differentials than in summer. Because of this, the UMC and SMC experimental groups were evenly split into two sub-groups:

- A Summer sub-group, in which the Savings Points participants could earn were based on low daily energy price differentials, and;
- A Winter sub-group, in which the Savings Points were based on high daily energy price differentials.

As a result, the maximum cash value of the Savings Points which participants could earn differed between the Control group and four UMC/SMC sub-groups:

- Control: up to £150
- UMC-Summer: up to £20

[7] Other recruitment criteria were applied consistently across the two trials, including a requirement for participants to drive regularly (at least once every two or three days), an exclusion of company car drivers, and specification of minimum driving licence and insurance requirements. These are documented in full in the Technical Appendix.

- UMC-Winter: up to £125
- SMC-Summer: up to £30
- SMC-Winter: up to £150

This in turn allowed exploration of the effect of different reward levels in the UMC and SMC groups. The relative sizes of these incentives reflected the relative differences in cost savings that would occur seasonally in future UMC and SMC charging offerings, as modelled in Deliverable D7.1[8] (see Deliverable D7.1 for a full explanation of the seasonal variation in energy prices for the UMC and SMC conditions). Because the value of the Savings Points differed between the experimental groups (see above), a final "top-up" payment was made at the point of participant debrief whereby participants were given Amazon vouchers worth whatever value was required to bring their total reward package up to the value of £250. Participants were not informed about the top-up payment until the end of the trial. This ensured that the effect of the incentives could still be examined whilst also ensuring all participants received an equal amount of overall reward.

Participants were given access to a smartphone app which linked with their home chargepoint and the trial vehicle. For Control group participants this provided a simple interface which showed them the status of their home chargepoint and the current State of Charge (SOC) of their vehicle. For the UMC and SMC participants, the app provided a mechanism for participants to engage with the MC scheme (see section 2.3).

Data from a vehicle telematics dongle connected to the OBD-II port and data from the chargepoint in participants' homes was collected during the trial. These data provided information on how participants used and charged the vehicles. In addition, usage and preference data was obtained from the smartphone app.

Attitudinal data were collected from a series of questionnaires administered during the trial (section 2.4.3), and a choice experiment administered at the end of the trial (section 2.4.4).

2.2 Managed charging groups

The following sections provide a summary of the ways in which participants in the UMC and SMC groups earned Savings Points. A full explanation of the method by which points were calculated is provided in the Technical Appendix.

2.2.1 User-Managed Charging (UMC) group

In the UMC group, participants were able to make savings by actively managing the charging of their vehicle so that their energy use was highest at times when the cost of energy is typically lowest. Savings were delivered to the participants via the accumulation of Savings Points, which were accumulated by undertaking charges.

Participants were able to maximise the Savings Points they earned by charging in the Low Tariff band (see Table 2). Points were only earned if charge was delivered to the vehicle (i.e. they did not earn points for plugging in if the battery was already full, to avoid perversely

[8] Rix, O., Bird, N., Greenleaf J., (2017) Deliverable 7.1 Data Inputs for Consumer Charging Trials.

encouraging unnatural charging behaviours). As such, the Savings Points served as an incentive to charge the car at the desired times, when it needed charging.

Table 2: UMC Tariff bands for Summer and Winter sub-groups [9]

UMC-SUMMER TARIFF BANDS

Tariff band	Time period	Savings Points available
Low	18:00-03:59	**Most**
Standard	04:00-08:59	
Medium	09:00-13:59	
High	14:00-17:59	**Least**

UMC-WINTER TARIFF BANDS

Tariff band	Time period	Savings Points available
Low	19:00-04:59	**Most**
Standard	05:00-09:59	
Medium	10:00-14:59	
High	15:00-18:59	**Least**

2.2.2 Supplier-Managed Charging (SMC) group

In the SMC group, participants were able to accumulate Savings Points by delegating control of their charging to the simulated energy supplier. Participants were incentivised to plug their vehicle in for as long as possible and only request the level of SOC they required for their next journey (the Desired SOC). They were also asked to specify the time they next needed the vehicle (the Departure Time). The system then configured the participants' charging so as to deliver the Desired SOC by one hour before the Departure Time (providing a buffer), and deliver the maximum amount of Savings Points[10].

2.3 Chargepoint Management System (CPMS)

The Chargepoint Management System (CPMS) was a cloud-based system that was used to manage individual charging operations and collect and process data from the vehicles and chargepoints. An overview of the interactions between the CPMS and other components of the wider system is shown in Figure 2.

[9] Both the UMC tariff bands and SMC savings points system were based on modelled energy prices for the year 2030; a full explanation of this modelled price series can be found in Deliverable D7.1.

[10] A full explanation of how the managed charging systems were implemented can be found in the Technical Appendix.

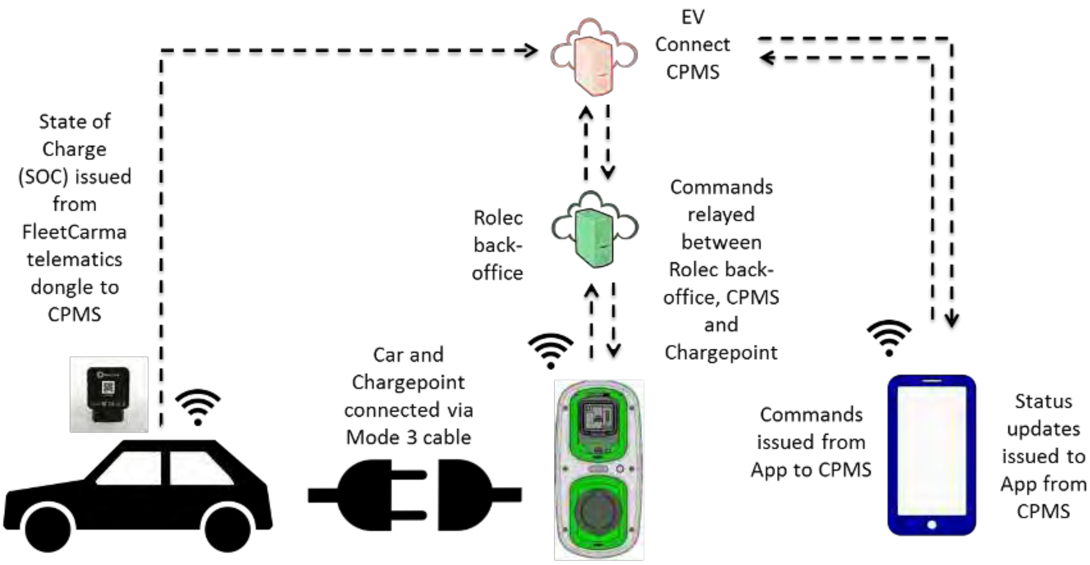


Figure 2: Overview of interactions between CPMS and other components

In the Control group, charging began automatically upon plug-in at the home chargepoint. For this group, a passive version of the app was provided which displayed the current vehicle status and SOC, allowing participants to monitor battery charge levels remotely.

In the UMC and SMC groups, plug-in at the chargepoint initiated a 15-minute window in which participants could input their charging preferences via the smartphone app. These user inputs were processed by the CPMS in order to determine when the charge would begin. If there were no inputs then the defaults were selected.

In the UMC group, charging either began immediately (if participants chose to 'Charge Now') or it was scheduled on the basis of 'Start Time' and 'Stop Time' inputs (either default inputs or new inputs from the user) (see Figure 3).

Figure 3: Example UMC app screenshot

This information was fed into the CPMS so that the system knew when to start (and stop) charging the vehicle. If no stop time was requested by the user, then the system charged the vehicle until it reached 100% or until the user ended the charge session (e.g. by unplugging).

In the SMC group, charging either began immediately (if participants chose to 'Charge Now') or it was scheduled on the basis of 'Desired SOC' and 'Departure Time' inputs (either default inputs or new inputs from the user) (see Figure 4). Using these inputs, the CPMS defined:

- a 'Charging Requirement': the number of hours of charge needed to charge the battery from the current SOC (obtained via the vehicle telematics system) to the Desired SOC (input from User App), and;
- a 'Time Window': the amount of time available for charging from the current time to the required departure time.

The CPMS used these parameters to generate appropriate commands to the chargepoint.

Figure 4: Example SMC app screenshot

2.4 Data collection and analysis

2.4.1 Vehicle telematics

The trial vehicles were equipped with a telematics device ('dongle') in the form of a self-contained lightweight cellular data logger fitted to the OBD-II port. The devices collected GPS coordinates, event-based data (e.g. at ignition on/off, charge start time, charge stop time), journey data (e.g. speed, distance, engine RPM, fuel/SOC level, etc.) and charging data (e.g. SOC level, battery temperature, current and voltage) at up to 1Hz whilst the vehicles were being driven/charged. The data were output into raw datasets and aggregated 'Journey logs' and 'Charge logs', containing summarised data for each journey and charge event. Vehicle telematics were used to capture data from charge events away from participants' homes, and those undertaken at participants' homes, to supplement the home chargepoint data collected from the CPMS (see section 2.4.2).

2.4.2 Home chargepoint data

Data from participants' home chargepoints was collated by the CPMS (see section 2.3). These data included date and timestamps of plug-ins, SOC at plug-in, user-entered charging preferences (including whether or not defaults were used in UMC and SMC groups) and Savings Points earned for charge event.

2.4.3 Questionnaires

Participants completed a number of questionnaires during the trial including a two-stage filter survey process to inform recruitment, a pre-trial questionnaire, and an attitudinal questionnaire which was repeated before and after the trial.

The Pre-trial questionnaire was used to collect demographic and descriptive participant data. It also contained questions relating to the participant's household, vehicle ownership history, travel patterns, attitudes about owning and driving a car, driving style, mobility-as-a-service, attitudes about new technology, personal travel and the environment.

The Time Point 1 (TP1) questionnaire was used to understand participants' attitudes towards BEVs and PHEVs, household energy use, and awareness of public charge points before experience of the vehicles. The questionnaire contained BEV and PHEV specific questions comparing them with conventional cars. It measured symbolic, affective and instrumental attitudes towards BEVs and PHEVs, and propensity to adopt a BEV or PHEV as a main or second car.

The Time Point 2 (TP2) questionnaire was an extended version of the TP1 questionnaire aimed at understanding how attitudes changed with experience of the vehicles. In addition to all the questions in the TP1 questionnaire, this contained additional questions on preferred charging locations, feedback on the usage of charging schemes experienced in the trial, attitudes towards Managed Charging, a personality inventory and the choice experiment.

2.4.4 Choice experiment

A 'stated preference' choice experiment was included as part of the TP2 Questionnaire (i.e. once participants had real-world experience of living with and charging a PiV) to investigate how participants valued different attributes of Managed Charging. This is based on Discrete Choice Analysis which simulates as far as possible the process consumers follow when choosing between different MC schemes in the real world. Participants were presented with several hypothetical choices between a user-managed, a supplier-managed and an unmanaged charging scheme, and in each case had to choose which one they would use to charge the BEV or PHEV they drove during the trial, if they owned it in future. The scheme attributes which were investigated are presented in Table 3.

Table 3: Description of each attribute and their levels in the choice experiment

Attribute	Description
Expected annual charging cost savings	Expected net annual financial benefit for participating in each MC scheme (assuming consistent trip patterns).
Accuracy in the estimate of annual charging cost savings (SMC only)	Maximum deviation between the expected and actual annual savings assuming driving patterns remain consistent.
Additional cost of charging during peak hours relative to unmanaged charging	Cost of charging at peak times relative to the fixed electricity price available with unmanaged charging. Participants were also shown an indicative cost in terms of increased pence per mile, and the cost per mile when charging with unmanaged charging.
Access to rapid charging (BEV participants only) or 7kW public charging (PHEV participants only) near home	Proximity of public charging to home to mitigate risk of car being needed before managed charging has finished. Expressed in driving time to chargepoint.
Existence of an override function (SMC only)	Ability for user to override charging configuration if circumstances change, and associated penalty. Participants were shown one of three levels of override capability: • Complete flexibility to change settings once set • Changing settings results in loss of all financial reward for that charge • Settings cannot be changed once set
Anticipatory charging (SMC only)	Maximum additional savings from system charging above set end SOC if prices are low and time available. Participants were told they were not guaranteed these additional savings, particularly if they frequently set their desired SOC to 100%.

Each participant was randomly assigned 10 choice questions. An example choice question is shown in Figure 5.

	User-managed charging	*Supplier-managed charging*	*Unmanaged charging*
Net annual savings	**£50** per year	**£200 (+/- £100)** per year	*None*
Additional cost of charging during peak hours relative to unmanaged charging	No additional cost compared with the unmanaged charging rate	**60 p/kWh more** than the unmanaged charging rate (adding about 15p per mile)	*N/A*
Access to 7kW public charging close to home	Public charge point within 5 minutes of house	Public charge point within 15 minutes of house	*N/A*
Availability of an override function	*No override function necessary*	Override available, but changing settings results in loss of all financial reward for that charge event	*N/A*
Anticipatory charging	*N/A*	Yes, giving up to £40 extra saving per year	*N/A*

If you could choose between these three charging schemes, which one would you choose?

☐ ☐ ☐

If you had to choose between one of the managed charging schemes, which one would you choose?

☐ ☐

Figure 5: Example choice question featured in the choice experiment

An explanation of how the choice experiment results were analysed is provided in the Technical Appendix. The outputs of the choice experiment are a set of choice coefficients, one for each attribute, that describe the relative weighting that participants place in each attribute. Each coefficient can be expressed in terms of 'willingness-to-pay' (WTP), which represents the annual savings participants are willing to forego in order to have a scheme with that particular attribute. For example, if the WTP for an attribute is £50/year, adding that attribute to a scheme while reducing its annual savings by £50 will have no impact on the share of participants predicted to choose that scheme.

Separate sets of choice coefficients were derived for both the sample of BEV participants and PHEV participants.

3 Results and discussion

3.1 Mainstream Consumer sample

The Consumer Charging Trials collected empirical data on Mainstream Consumer behaviours when using and charging both BEVs and PHEVs. A total sample of 248 participants took part in the trials; 127 participants were given a BEV and 121 participants were given a PHEV. The split of these participants across the Control, UMC and SMC groups is shown in Table 4.

Table 4: Number of participants in each experimental group

Group	BEV Charging Trial			PHEV Charging Trial		
	Summer	Winter	Total	Summer	Winter	Total
Control	n/a	n/a	**41**	n/a	n/a	**41**
Supplier-Managed Charging (SMC)	22	18	**40**	16	23	**39**
User-Managed Charging (UMC)	24	22	**46**	20	21	**41**
Total			**127**			**121**

The sample of PHEV drivers was stratified using age, gender and resident area (urban/rural) so as to be representative, on these variables, of the GB driving population. Due to the opportunistic nature of the BEV sample, no target stratification criteria were set for the BEV Charging Trial sample. Nevertheless, the proportions of participants across age groups, gender and resident area broadly matched the PHEV sample (see Table 5).

Table 5: Stratification of sample by age, gender and resident area

Resident area	Age group	BEV Charging Trial			PHEV Charging Trial		
		Gender		Total	Gender		Total
		Male	Female		Male	Female	
Rural	19-29	3	3	**6**	1	0	**1**
	30-49	9	5	**14**	7	3	**10**
	50+	10	2	**12**	9	4	**13**
Urban	19-29	10	8	**18**	13	5	**18**
	30-49	25	15	**40**	23	17	**40**
	50+	24	13	**37**	21	18	**39**
Totals		**81**	**46**	**127**	**74**	**47**	**121**

In both the BEV and PHEV Trial, there were no statistically significant[11] differences in the characteristics of the Control, UMC and SMC participants in terms of gender, age, resident

[11] Statistical significance refers to the outcome of a statistical test whereby the 'p-value' is less than 0.05. this mean there is more than 95% probability that the results observed did not occur by chance alone.

area, annual mileage and household income. In the BEV Trial, 'extraversion' personality scores[12] were found to be significantly different between the SMC and UMC groups; however, the difference was small (mean scores of 6.78 and 5.63, respectively)[13]. Similarly, a significant but small difference was found in the 'openness' personality score[14] in the PHEV SMC and Control groups (mean scores of 8.64 and 6.95 respectively). No other personality scores were found to be significantly different between groups. Further, no differences were found in self-reported driving style, as measured by the Multidimensional Driving Style Inventory (MDSI; Taubman-Ben-Ari, Mikulincer & Gillath, 2004). Taken together these findings suggest that the random allocation of participants to one of the three experimental groups was successful; ensuring there were no biases associated with imbalance between the groups.

The extent to which the samples were representative of the wider population on other socio-demographic variables (aside from age, gender and resident area) was assessed through comparison with National Travel Survey data[15] and national datasets from the Office of National Statistics[16]. Overall, the study provided a relatively representative sample in terms of the spread of annual mileages, household incomes, types of cars owned and educational statuses. However, some expected differences were found due to the recruitment criteria for the trials (see research limitations in section 3.8). For example, participants were required to have access to their own private vehicle (ruling out households with no cars). In addition, participants were required to have off-street parking for at least one vehicle, meaning the majority of participants lived in houses with driveways and/or garages where it is more common for there to be multiple vehicles compared with other types of accommodation. Further, the energy requirements (and, therefore, the charging behaviours) of drivers who travel less than 5,000 miles per annum, and company car drivers who have relatively high annual mileage, are likely to differ from the private consumers recruited for this study. Generalisation of the findings to these subsets of the population should be treated with caution.

As explained in section 2.1, the sampling criteria were different between the two trials; participants in the BEV Charging Trial were recruited subject to a constraint that their typical vehicle usage patterns could be met by a BEV, whereas PHEV Charging Trial participants were recruited into a stratified sample representative of GB licensed drivers. As such, direct statistical comparisons between the two trials were not possible, and the data were analysed separately for each.

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[12] Measured using the Newcastle Personality Assessor (NPA). Extraversion is a "broad personality trait, and, like introversion, exists on a continuum of attitudes and behaviors. Extraverts are relatively outgoing, gregarious, sociable, and openly expressive." (APA Psychology Dictionary: https://dictionary.apa.org/extraversion)

[13] For comparison, the previous ETI PiV survey study with 2,743 participants resulted in mean extraversion scores of 6.31, and a standard deviation of 1.19 (Anable et al., 2011).

[14] Also measured using the NPA. 'Openness to experience' refers to "individual differences in the tendency to be open to new aesthetic, cultural, or intellectual experiences" (APA Psychology Dictionary: https://dictionary.apa.org/openness-to-experience)

[15] https://www.gov.uk/government/collections/national-travel-survey-statistics#data-tables

[16] https://www.ons.gov.uk/

3.2 Overview of charging data

Data from a total of 10,633 charge events were recorded over the course of the trials. The data captured charge events at participants' homes, and charge events away from home. Around 80% of all charge events recorded during the trial were at home (see Table 6).

Table 6: Number of charge events by location (home and away from home)

Location	BEV Charging Trial		PHEV Charging Trial		Total	
	N	%	N	%	N	%
Home	3,788	*78.5%*	5,026	*86.5%*	8,814	*82.9%*
Away from home	984	*20.4%*	780	*13.4%*	1764	*16.6%*
Undefined (GPS missing)	51	*1.1%*	4	*0.1%*	55	*0.5%*
Total	4,823	*100.0%*	5,810	*100.0%*	10,633	*100.0%*

All participants charged at home, whereas a smaller sub-set of the samples charged away from home. Based on the charge event data that was captured, 76% of BEV drivers and 58% of PHEV drivers charged away from home at least once during the trial. On average, BEV drivers charged 38 times during the trial, compared with an average of 48 charges undertaken by PHEV drivers. The reason for this difference cannot be determined from the trial data. One possibility is that the shorter AER of the PHEVs required drivers to plug-in and charge the battery more frequently. This is supported by journey telematics which showed that around 28% of PHEV journeys ended with an SOC less than 10%, compared with only 0.6% of BEV journeys.

Across all home charges, 76,569kWh of energy were delivered; 50,695kWh in the BEV Charging Trial, and 25,873kWh in the PHEV Charging Trial. By comparison, charges away from home accounted for 10,824kWh and 3,338kWh of energy delivered in the BEV and PHEV Charging Trials, respectively. Thus, charging away from home represented about 17% of all energy delivered in the BEV trial, and about 11% in the PHEV trial. The reason for the greater incidence of charging away from home by BEV drivers compared with PHEV drivers is unknown, but may be due to BEV drivers having the option of using rapid chargepoints, which were not compatible with the VW Golf GTE PHEV.

The analysis presented in this report, and in the accompanying Technical Appendix, investigates the charging profiles for home and away-from-home charge events, on weekdays and weekends, and within each experimental group. The number of weekday and weekend charge events at each location, and for each experimental group, are shown in Table 7.

Table 7: Number of charge events at home and away from home on weekdays and weekends for each experimental group

Location and day of week	BEV Charging Trial			PHEV Charging Trial		
	CTL	SMC	UMC	CTL	SMC	UMC
Weekday – Home	863	999	963	1,281	1,344	1,291
Weekday – Away from home	274	204	249	168	204	291
Weekend – Home	296	356	311	371	388	351
Weekend – Away from home	137	56	64	27	44	46
Total	**1,570**	**1,615**	**1,587**	**1,847**	**1,980**	**1,979**

The sample of home charge events is sufficiently large to enable robust conclusions to be drawn, both for weekday and weekend charging. However, caution is advised when interpreting the findings for charge events away from home, for which there is only a small sample of data available. This is particularly evident for weekends where only 257 BEV charges and 117 PHEV charges were captured. When splitting this sample of charge events into the three experimental groups, the sample size becomes too small to enable robust conclusions to be drawn; particularly for the PHEV Charging Trial where less than 50 weekend away-from-home charge events per experimental group were captured. As such, discussion of charge events away from home in this report has not included investigation of differences between the experimental groups (see section 3.7). Some comparisons between the groups, subject to the caveats made here, are provided in the Technical Appendix.

3.3 Mainstream Consumer home charging behaviour in unconstrained conditions (Control group)

This section summarises the home charging behaviours of Control group participants. A total of 41 control group participants took part in the BEV Charging Trial, and 41 control group participants in the PHEV Charging Trial. The charging behaviours of these individuals were analysed to provide understanding of how Mainstream Consumers use and charge their vehicles in the absence of Managed Charging, i.e. in unconstrained conditions where consumers are free to charge as they wish without incentives for charging in particular ways.

Figure 6 shows the proportion of home charge events by charge start time for control group BEV and PHEV participants. There was a clear pattern of charge events starting in the late afternoon and early evening between about 3pm to 8pm, with the peak in charge start times between 5pm-6pm for PHEVs, and 6pm-7pm for BEVs.

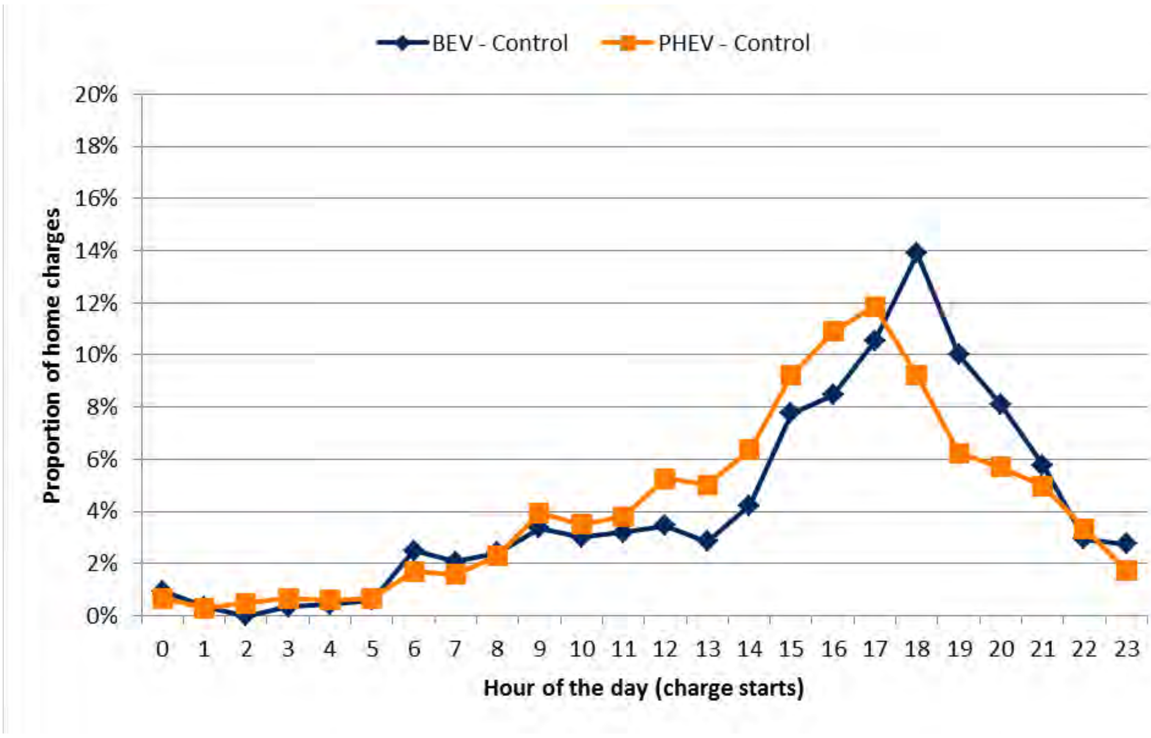
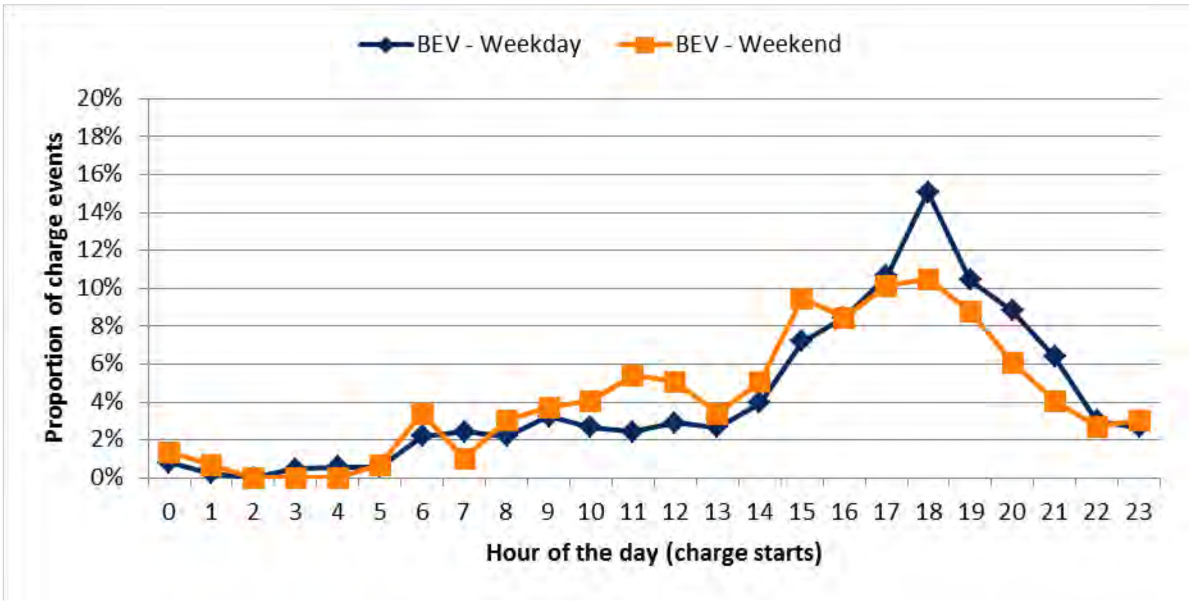


Figure 6: Proportion of Control group home charge events by charge start hour (BEV N = 1,159, PHEV N = 1,652)

The proportion of weekday and weekend events by charge start time are shown in Figure 7. There was a statistically significant difference in the distribution of charge start times between weekdays and weekends. The weekend charging behaviours of BEV drivers showed a similar overall pattern to weekday events, but the peak in charge start times was less pronounced due to an increased number of events earlier in the day (between 10am-4pm). The peak in PHEV charging was shifted to between 3pm-4pm at weekends, and again was less pronounced than on weekdays.



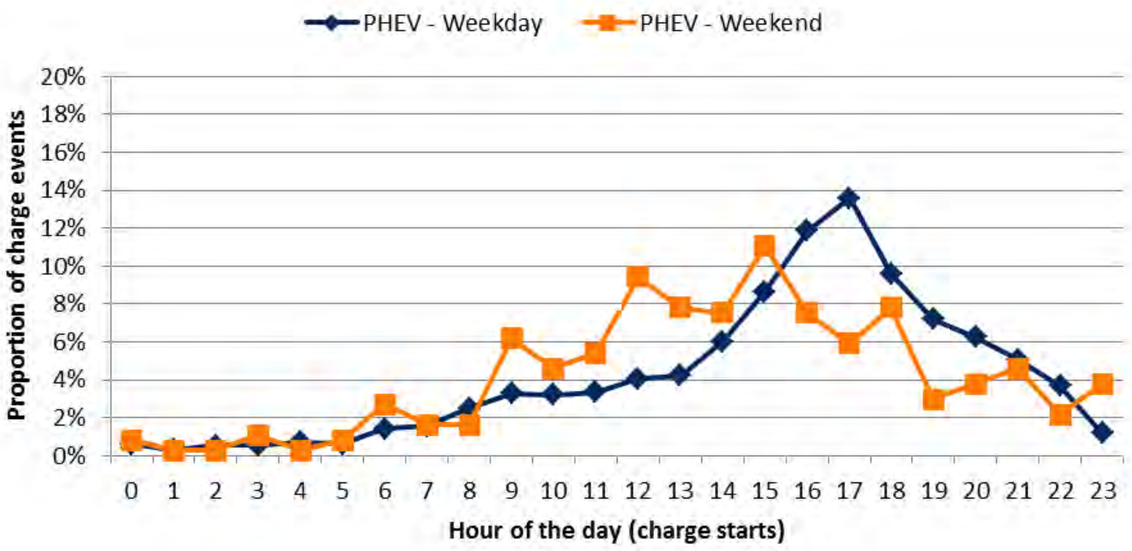


Figure 7: Proportion of Control group home charge weekday (BEV N = 863, PHEV N = 1,281) and weekend (BEV N = 296, PHEV N = 371) events by charge start hour (BEV – top, PHEV – bottom)

The difference in charging profiles on weekdays compared with weekends is clearly due to activity patterns at the weekend differing from those on a typical weekday for most people. Weekday and weekend journeys that ended at participants' home destinations are shown by journey end time in Figure 8. This figure shows a clear pattern in which a greater proportion of journeys end at home in the early parts of the day (9am-2pm) on weekends compared with weekdays. This suggests there was more opportunity for charging during these times at weekends, when the car was parked at participants' homes.

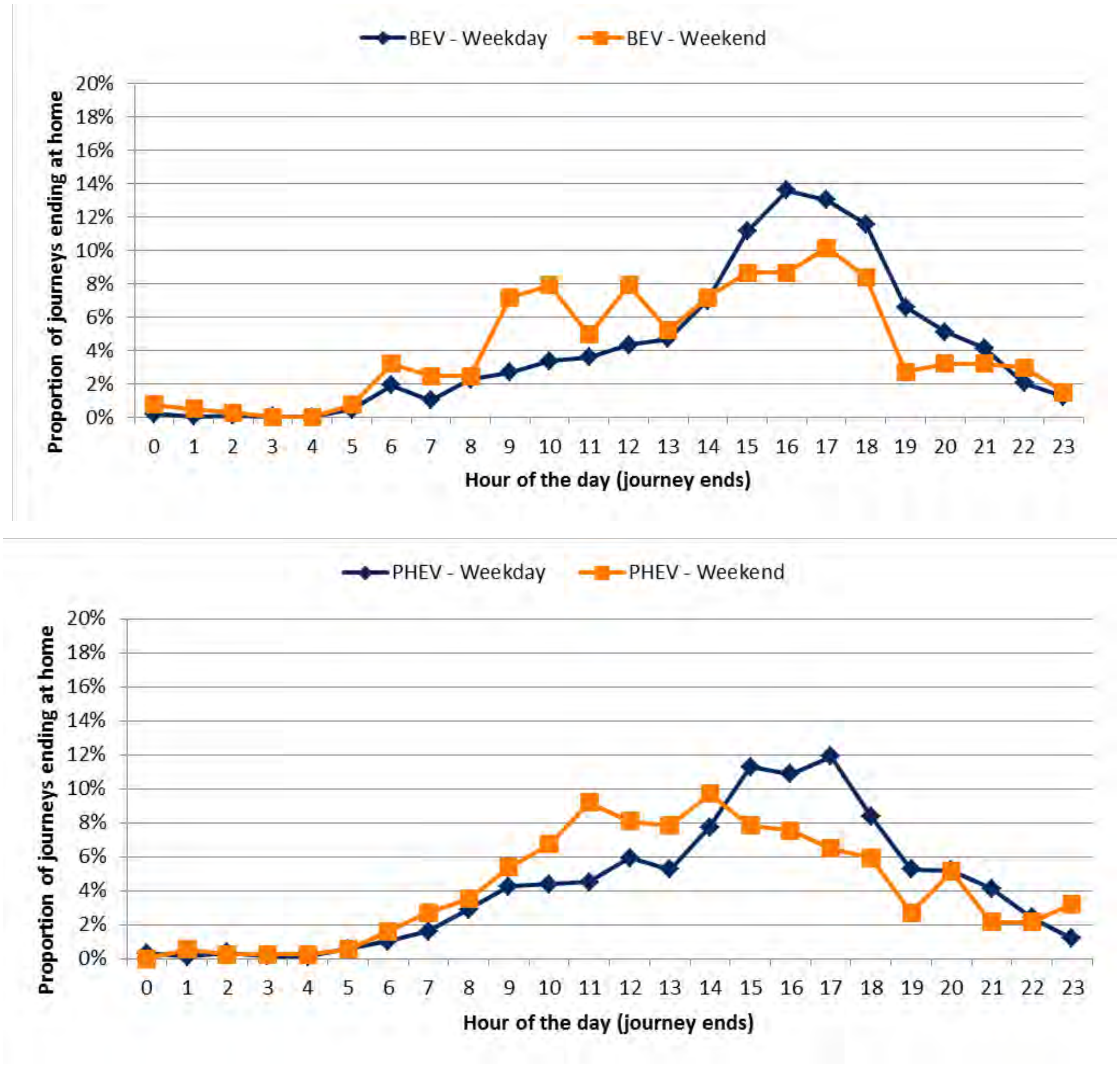


Figure 8: Proportion of Control group journeys ending at home on weekdays (N = 4,713) and weekends (N = 775) by journey end hour (BEV – top, PHEV – bottom)

Taken together, the following conclusions can be drawn from these data:

- At home, weekday charge start times peaked between 5pm-6pm for PHEV Control group drivers, and between 6pm-7pm for BEV Control group drivers, i.e. during the existing electricity system peak demand period. In general, the spread of home charge start times was similar to the times when drivers arrive home.
- At weekends this peak in charge start times was less pronounced, with a greater share of charge events starting earlier in the day. This may be explained by the journey data which showed a greater proportion of weekend journeys ending at home in the early parts of the day (9am-2pm) compared with weekday journeys. This suggests a greater opportunity for charging during these times at weekends.

3.4 Mainstream Consumer home charging behaviour in response to User-Managed Charging

This section summarises the charging behaviours of participants in the UMC group to understand the impact of user-managed charging on charging profiles. A total of 46 participants in the BEV Charging Trial and 41 in the PHEV Charging Trial experienced user-managed charging.

Figure 9 shows the distribution of home charge plug-in times for UMC participants compared to Control group participants. Note that plug-in time is not necessarily the same as charge start time, since UMC participants could plug in their vehicles but delay charging until a later, low-tariff time using the app (see section 2.1).

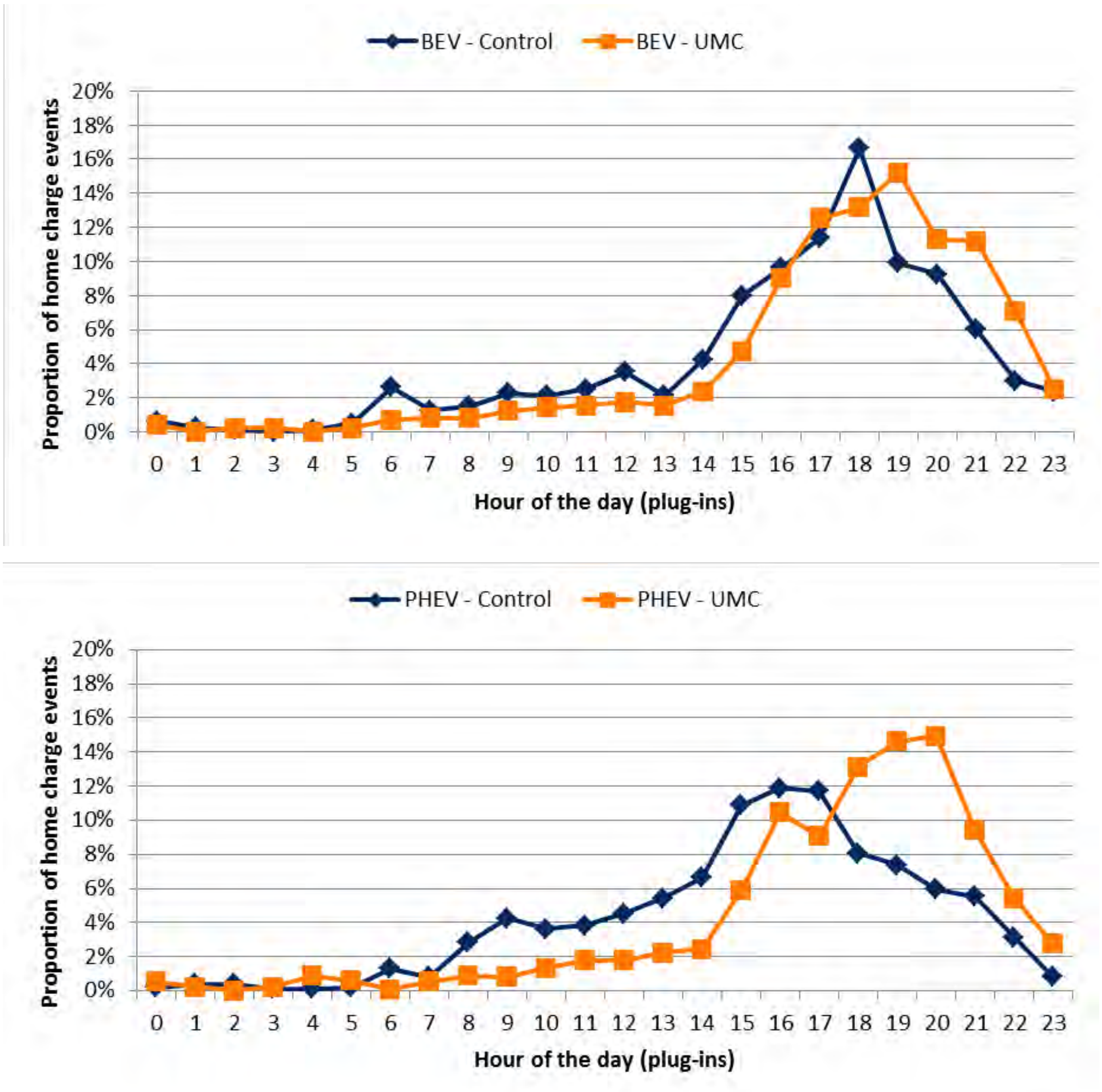
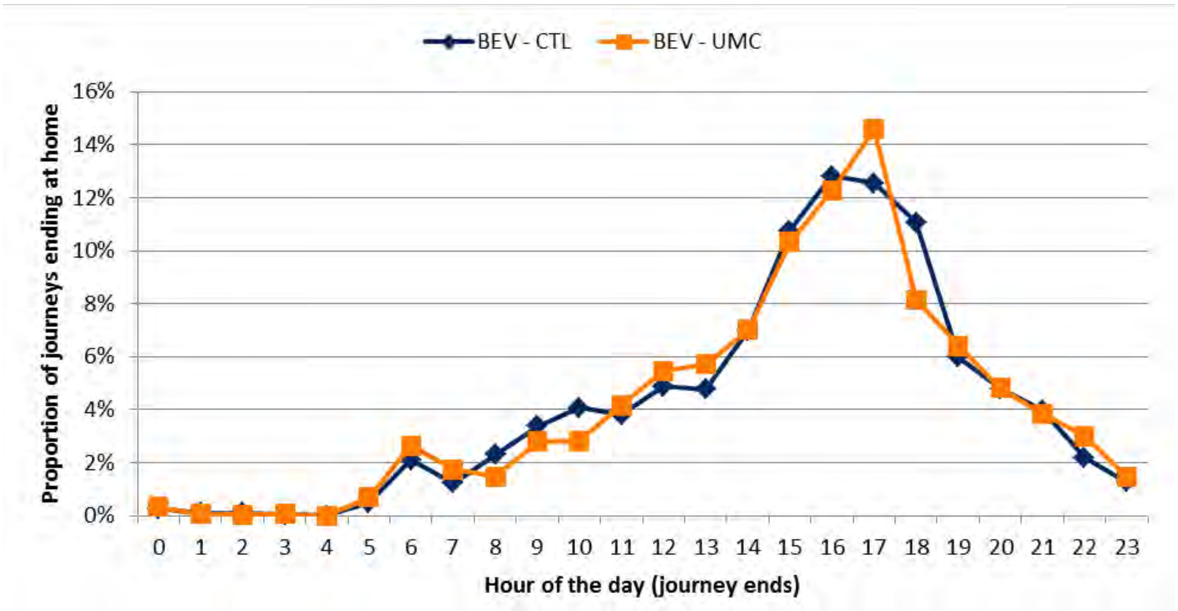


Figure 9: Proportion of home charge events by plug-in hour for Control and UMC participants (N = 4,111) (Top – BEV, Bottom – PHEV)

There were significant differences in the distribution of plug-in times between the UMC and Control groups on weekdays and weekends. Whilst the broad pattern of most plug-ins occurring in the late afternoon and early evening (3pm-9pm) was similar between the groups, there was a shift in the peak of plug-in times to later in the evening for UMC participants compared with Control group participants. The difference in peak plug-in time between the UMC and Control groups appears substantially greater in the PHEV trial than in the BEV trial (although differences between the BEV and PHEV trial were not tested statistically due to the different samples – see section 2.1).



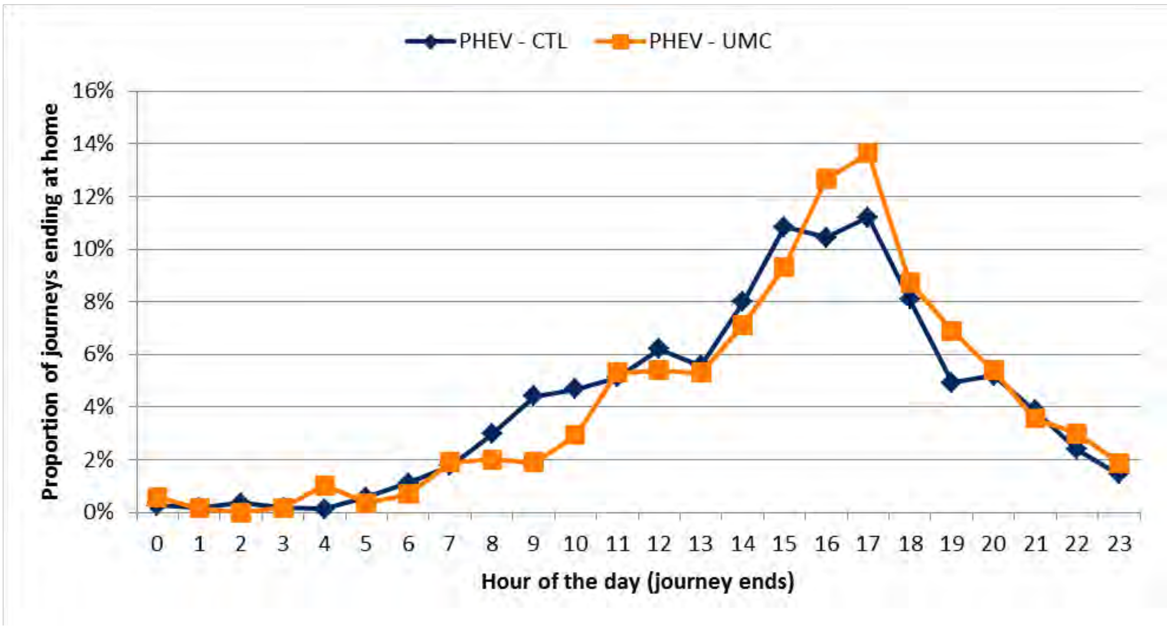


Figure 10: Proportion of Control and UMC group journeys ending at home (BEV N = 4,716, PHEV N = 4,891) by journey end hour (BEV – top, PHEV – bottom)

On the assumption that participants plugged-in as soon as they arrived home, a possible explanation for the difference in plug-in times would be a difference in the times at which Control and UMC participants arrived at home. However, there is no corresponding difference in journey end times between Control and UMC groups, in either the BEV or PHEV Charging Trial (see Figure 10).

In the UMC group, peaks in journey end times can be observed between 4pm-6pm; however, as shown in Figure 9, the peaks in plug-ins were between 6pm-7pm in the BEV Trial and 6pm-8pm in the PHEV Trial. This suggests that, at least for some charge events, there was a greater tendency for participants in the UMC group to delay plugging in their vehicles after arriving at home, compared with those in the Control group. This may be due to the Savings Points incentives on offer to commence charging in the Low tariff band; whilst participants could have plugged in at any time and scheduled the charge to start later in the evening, perhaps some participants chose to manually delay plugging in.

Figure 11 shows the proportion of home charge events by charge start time for Control and UMC participants in each trial.

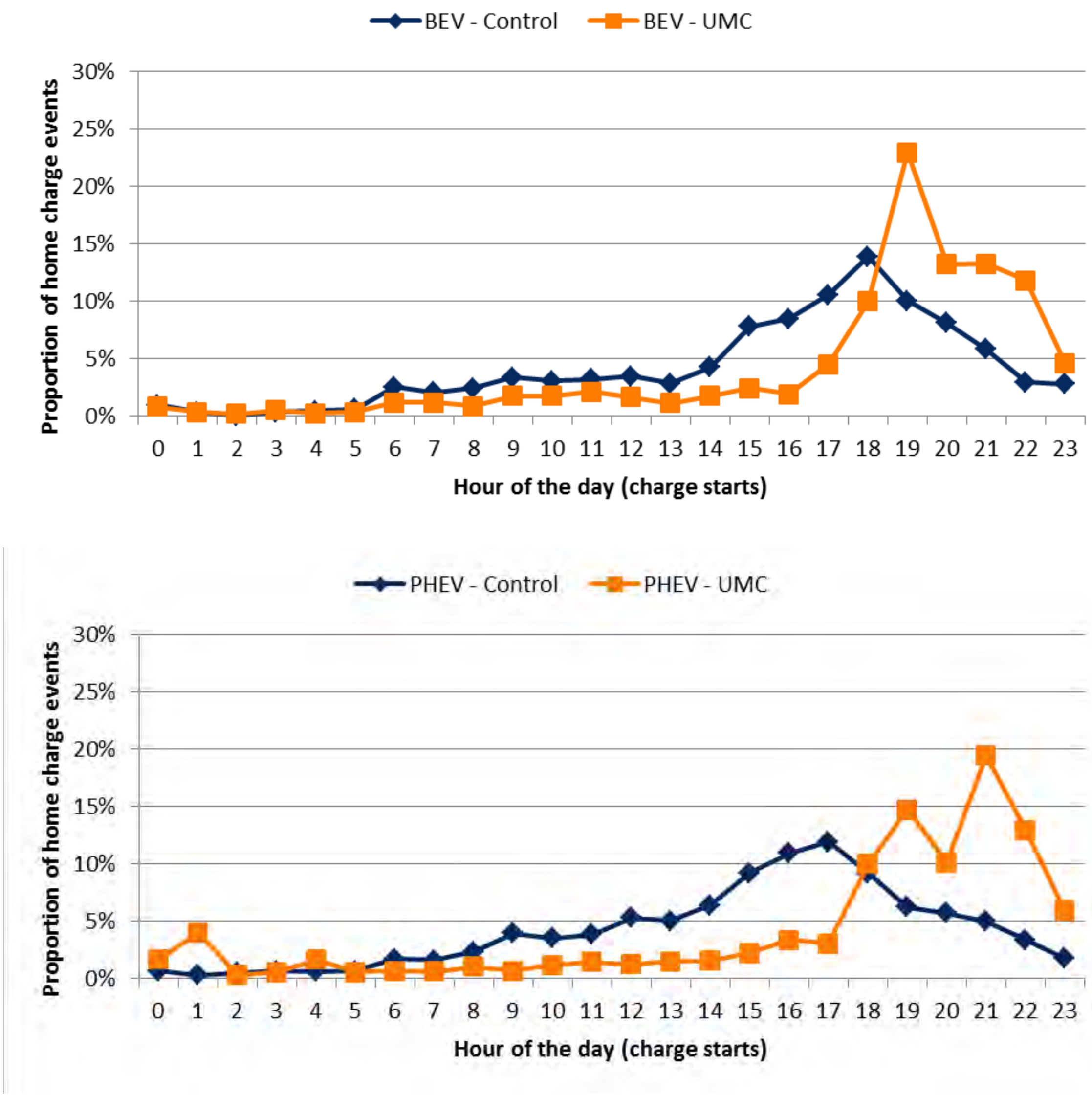


Figure 11: Proportion of home charge events by charge start hour for Control and UMC participants (BEV N = 2,433, PHEV N = 3,294) (Top – BEV, Bottom – PHEV)

Significant differences in the distribution of charge start times were identified between the UMC and Control groups. The figure clearly shows this difference; for BEV participants charge start times peaked between 7pm-8pm and for PHEV participants they peaked between 9pm-10pm (with a secondary peak between 7pm-8pm).

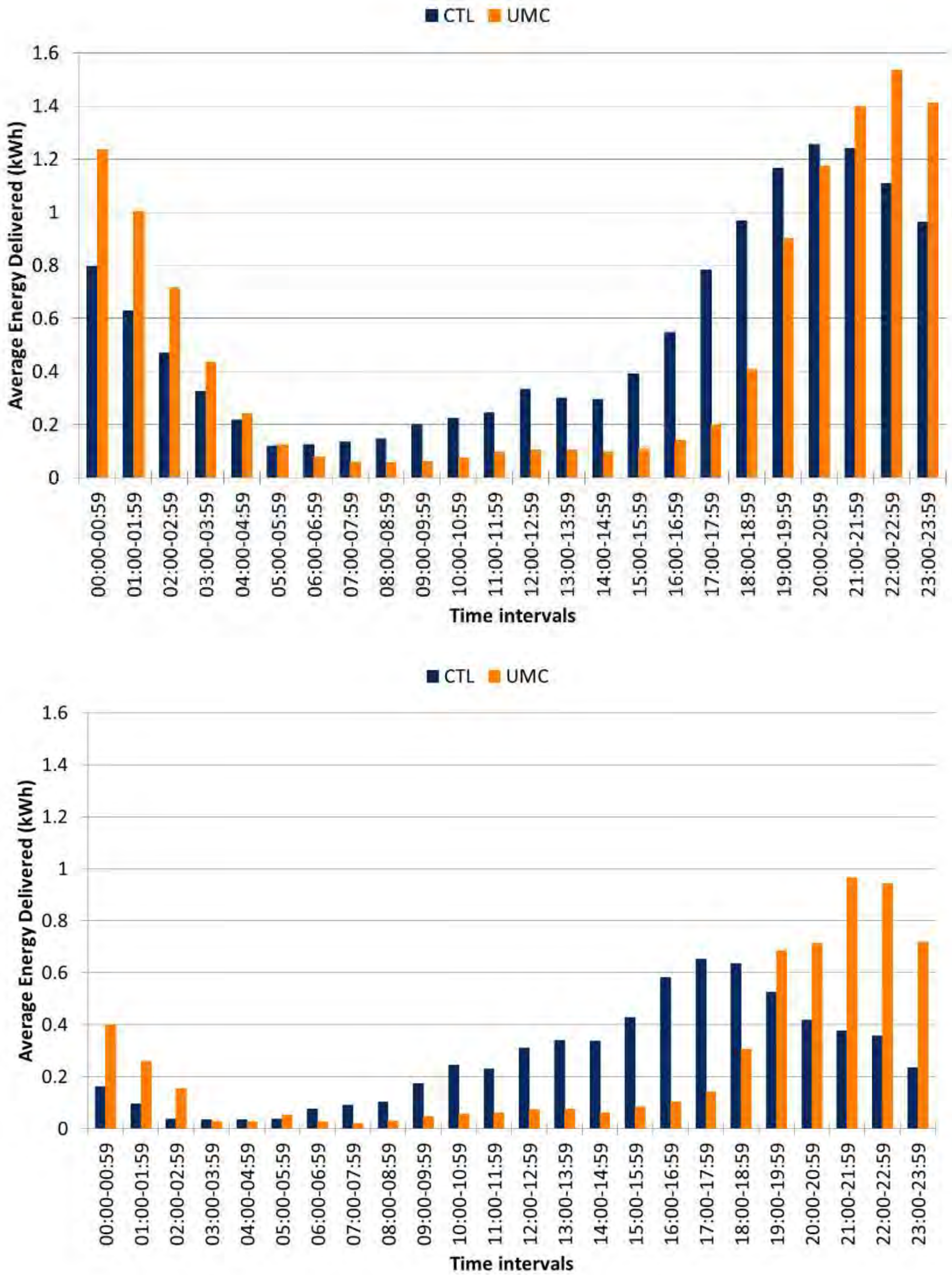
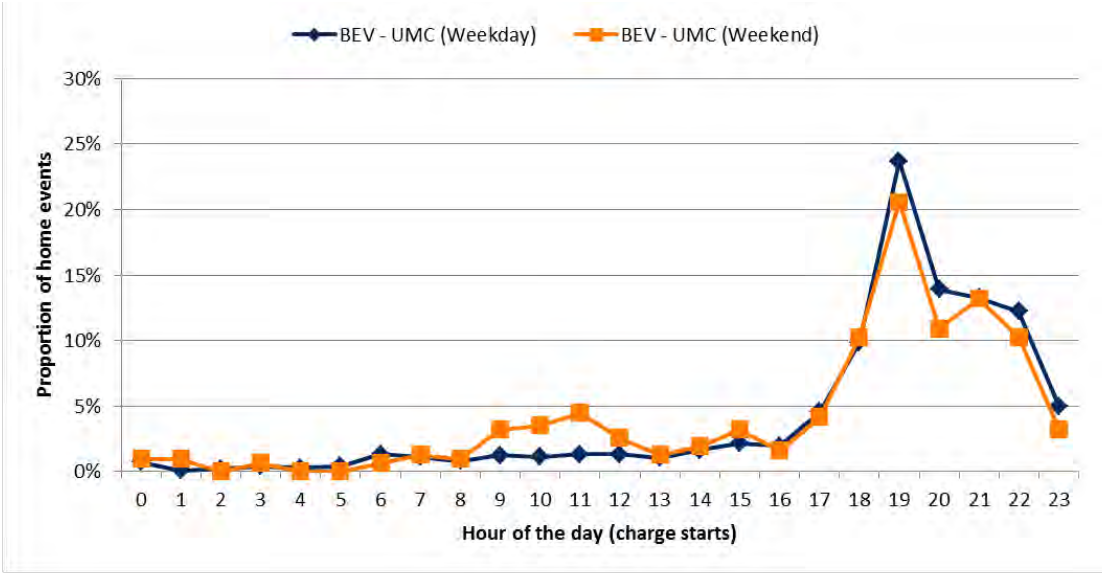


Figure 12: Average energy delivered per participant per hour of the day for Control and UMC participants (BEV N = 2,365, PHEV N = 3,179) (Top – BEV, Bottom – PHEV)

This effect is also observed in Figure 12 which shows the average energy delivered (kWh) per participant17 per hour of the day for the Control and UMC groups. As shown in the profile of charge start times above, the UMC group shifted energy demand to later in the evening compared with the control group.

[17] For the purpsoes of this calculation, a static charging rate over the duration of each charge event was assumed.

The data shown in Figure 11 and Figure 12 are aggregated weekday and weekend charge start times. Separate UMC charging profiles for weekends and on weekdays are shown in Figure 13.



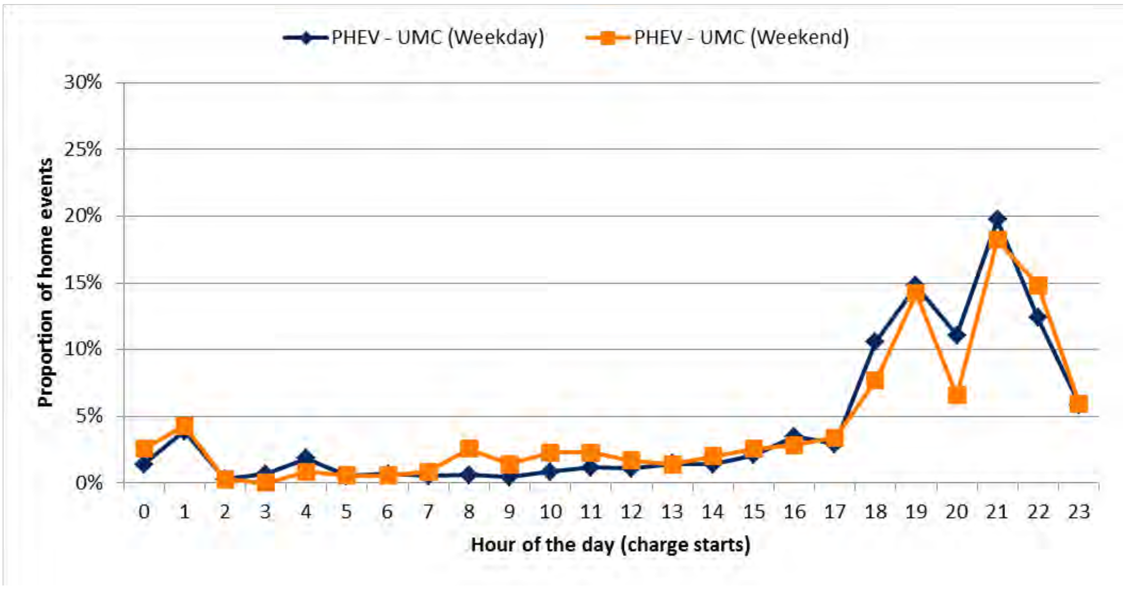


Figure 13: Proportion of home charge events by charge start hour for UMC participants on weekdays and weekends (BEV N = 1,274, PHEV N = 1,642) (Top – BEV, Bottom – PHEV)

The proportion of UMC charge start times by tariff band for weekdays and weekends can also be seen in Table 8. These distributions show that there was a slightly higher proportion of events starting in the Medium band, and a slightly lower proportion of events starting in the Low band on weekends than weekdays, particularly for BEV drivers. There were statistically significant differences in the distribution of BEV charge events across the four UMC tariff bands between weekdays and weekends; however, the differences in the PHEV trial were not statistically significant. Nevertheless, the large majority of charging started in the Low tariff band both on weekdays and weekends, suggesting that UMC was successful in shifting charging away irrespective of the day of the week.

The data from these trials shows that UMC was effective at shifting charging demand to later in the evening compared to unmanaged conditions, suggesting consumers were incentivised by the savings available in the Low tariff band. In a real-world implementation of UMC, consideration should be given to the risk of creating a new peak in demand; as it is possible that consumers will shift demand to the first or early hours of the cheap period (e.g. 6pm onwards), creating a new peak. This could cause problems in itself, especially if large clusters of PiV drivers in a local area follow the same UMC tariff band structure.

Table 8: Proportion of weekday and weekend UMC charge start times by Tariff Band; times shown for UMC-Summer tariff, UMC-Winter tariff shifted forward by one hour (BEV N = 1.274, PHEV N = 1,642)

Tariff Bands	BEV		PHEV	
	Weekday	Weekend	Weekday	Weekend
Low (18:00-03:59)	77.57%	69.65%	78.75%	74.58%
Standard (04:00-08:59)	4.94%	4.47%	4.58%	5.87%
Medium (09:00-13:59)	5.97%	14.06%	5.26%	9.50%
High (14:00-17:59)	11.52%	11.82%	11.41%	10.06%

Trials of Time-of-Use (ToU) tariffs with PiV Innovators have also shown successful shifting of charging demand away from peak periods (e.g. Hardman *et al*., 2018). The UMC scheme investigated in this trial was analogous to a ‘static’ ToU tariff whereby the time bands and savings were fixed in terms of their timing across the day (see Deliverable D7.1). Managed charging schemes may also come in the form of ‘dynamic’ ToU tariffs whereby energy prices vary minute-by-minute, hour-to-hour or day-to-day to reflect real-world fluctuations in wholesale electricity prices[18]. A trial of one form of Dynamic ToU, undertaken by Octopus Energy (2018), found significant reductions in peak electricity consumption across 28% of all customers, and across 47% of PiV drivers. While more complex than a static ToU, this suggests some dynamic ToU tariffs may also be effective at shifting PiV charging demand. However, the Octopus Energy trial was with PiV Innovators and individuals likely to be highly informed on energy management issues, therefore, the findings cannot necessarily be directly applied to the Mainstream Consumer population. In addition, details of the sample are not provided. Further research into Mainstream Consumer responses to Dynamic ToU tariffs is advised. It is not known, for example, how the Mainstream Consumer participants in these trials would have responded to a dynamic ToU tariff whereby energy prices varied more frequently than hour-to-hour and day-to-day.

Participants in the UMC group could choose to start the charge immediately, or to set a scheduled charge start time. In the case of the latter option, participants could either set new parameters after each plug-in, or use their default settings. The amount of Savings Points earned was not linked to the method by which they initiated charge sessions; it was simply related to the tariff band they charged in and the amount of charge that was delivered. Hence, participants could plug-in at the start of the Low tariff band, initiate the charge using ‘Charge Now’ and receive the same number of points as if they had plugged in earlier and scheduled

[18] These types of tariffs could take several forms, and may offer different constraints and benefits to consumers.

the charge to start in the Low tariff band. The proportion of UMC home charge events which were initiated using each of the driver input methods is shown in Table 9.

Table 9: Proportion of UMC home charge events by driver input method (BEV N = 973, PHEV N = 1,347)

Driver Input	BEV	PHEV
Charge Now	34%	36%
Defaults	61%	59%
New Settings	5%	6%
Total	100%	100%

Setting new parameters following plug-in was the least common option chosen by participants. The majority of UMC home charges were undertaken using the default settings, and around a third used 'Charge Now'. Clearly, this has implications for the design of future UMC-type systems (such as ToU tariffs) as it shows that both an ability to set defaults and an ability to start a charge straight away (rather than schedule a start time) are important features for Mainstream Consumers. In particular, the findings demonstrate the power of defaults; a concept embedded in behavioural science which shows a strong tendency for people to choose default or pre-set options because they are easiest (Service *et al.*, 2014). Defaults actively chosen by consumers can also be important for ensuring that their minimum needs are met. Whilst not directly studied here, the importance of defaults may also have implications for the design of dynamic ToU tariffs. Dynamic ToU tariffs are likely to require a greater level of engagement by consumers since energy prices vary more frequently than with a static ToU tariff; the high usage of the default function found in this study suggests that having an ability to set defaults in dynamic ToU tariffs (e.g. limit settings) may also be worthwhile to help minimise the level of effort required by consumers when adopting these types of Managed Charging schemes. However, the precise design of such a default function needs consideration, for example, it may be more appropriate to base them on prices rather than specific times of day.

The design of a Managed Charging system and consumer interface is fundamental for determining the ways in which consumers will interact with it. The system and interface used in these trials was built to fulfil the objectives of the research. While it was designed to simulate a 'market-ready' Managed Charging system, it could not be rolled out to real-world consumers. Future systems are likely to vary in their design, including the appearance of the user interfaces, and the functions they offer to consumers. Suppliers of future Managed Charging systems are recommended to undertake regular engagement with consumers to ensure system designs are as efficient and user friendly as possible. Nevertheless, the system trialed in this project enabled clear conclusions to be drawn about the broad types of features which Mainstream Consumers value. The results showed clearly that the default function was used for the majority of UMC events, and very few events were initiated by users inputting new parameters at the start of a charge session. The process of specifying inputs and setting defaults in the trial system was designed to be as simple as possible; however, alternative approaches in future systems that offer an alternative user interface may result in different behavioural patterns than observed here.

Figure 14 shows the proportion of UMC home charge events by charge start time for each driver input method. The peaks in charge start times remain consistent across the driver input methods, showing that even when using the Charge Now function, participants were charging in the Low tariff band for the majority of the time. However, as expected, events initiated using 'Charge Now' were also more common in the earlier parts of the day (between 8am-6pm). These times were in the Standard, Medium and High tariff bands (see section 2.2.1) and so will have netted fewer points (as a function of SOC added) than charges in the Low tariff band. Nevertheless the 'Charge Now' function gave participants flexibility to initiate impromptu charges at times outside of their normal schedule. The double peak in the PHEV Charging Trial appears to be in part due to alternative driver input methods. A large proportion of events where PHEV drivers chose new preferences after plugging in started in the earlier peak, between 7-8pm. Conversely, the later peak between 9-10pm was dominated by events which were initiated using the default settings. This may indicate that some PHEV drivers had regular defaults for later in the evening, but occasionally chose an earlier start time by modifying the settings in the app after plugging in.

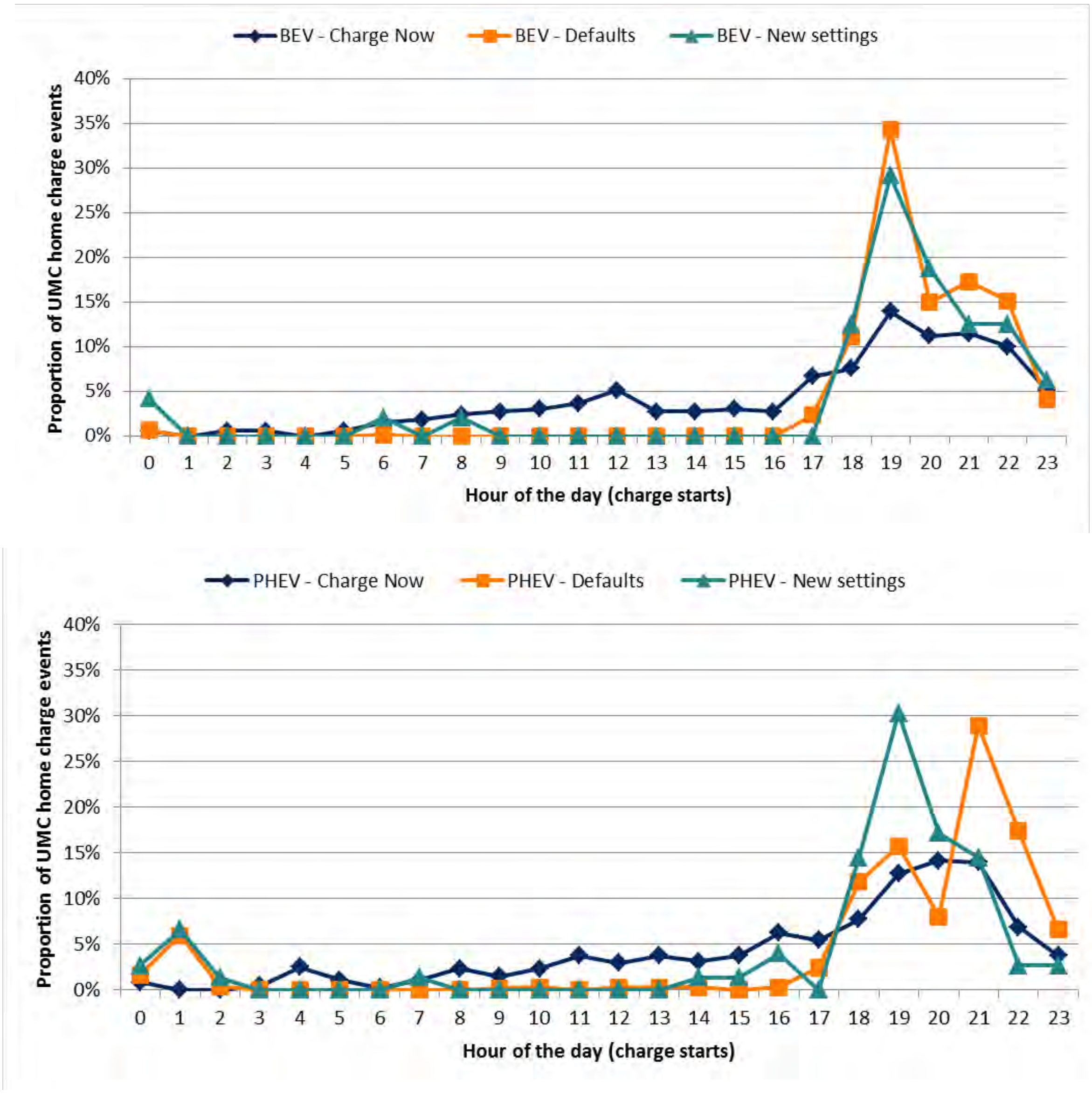


Figure 14: Proportion of UMC home charge events by charge start hour for each driver input method (BEV N = 973, PHEV N = 1,347) (Top – BEV, Bottom – PHEV)

Examination of the Desired Charge Times requested by participants also confirms a high level of engagement with the UMC scheme. For over 90% of charges where a schedule was set (either using defaults or by specifying new settings), the Desired Charge Start Time requested by users was between 5pm and midnight; these are shown in Figure 15.

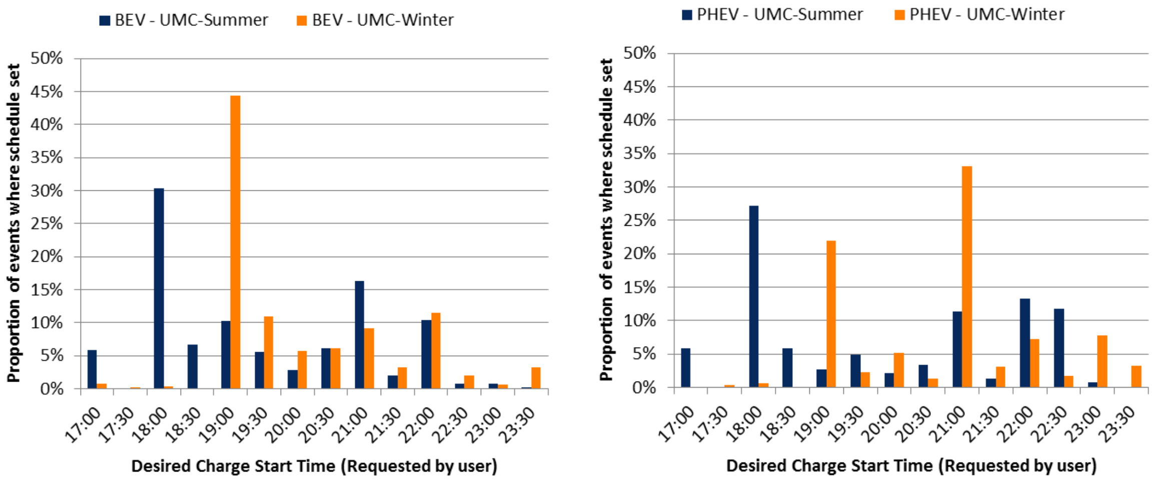


Figure 15: Proportion of UMC charge events by Desired Charge Start Times (5pm-midnight only) (Left – BEV, Right – PHEV)

A small percentage of Desired Charge Start Times was requested at 5pm (~5%), before the start of the Low Tariff period, and only in the UMC-Summer group. Even for these small number of events, the majority of the charging would still have taken place in the Low Tariff period. For BEV drivers, the most common Desired Charge Start Times were at 6pm for UMC-Summer participants and 7pm for UMC-Winter participants; in line with the start of the Low tariff bands. Similar patterns were observed for PHEV drivers; except there was also a large share of Desired Charge Start Times at 9pm. This fits with the 9pm peak in charge start times observed for the PHEV drivers, compared with the 7pm peak for BEV drivers (see Figure 13). The reason for the difference in peak charge start times between BEV and PHEV drivers is unknown; analysis of the times at which PHEV and BEV drivers arrived at home at the end of their journeys shows few differences, with peaks for both vehicle types between 5pm-6pm (see Figure 10). Possibly, the slightly later peak in plug-in times for the PHEV drivers (see Figure 9) suggests they may have felt a reduced urgency to plug-in and commence charging compared with the BEV drivers, who had longer charging times due to the larger batteries in the BEVs.

Taken together, the following conclusions can be drawn from these data:

- Participants in the User-Managed Charging (UMC) groups engaged with the UMC scheme, broadly requesting Charge Start times in line with the Low tariff bands.
- As a result, the distribution of charge start times was significantly different between the Control and UMC groups; UMC shifted charging into later in the evening (the Low tariff band) relative to unmanaged conditions; this effect was observed for both weekday and weekend charge events.
- The majority of charges were initiated using the Default settings. Around a third of the time, participants initiated charge events using the ‘Charge Now’ feature. A greater proportion of charge events outside of the Low tariff bands were initiated in this way.

- Future design of UMC-type schemes should include functions which allow users to set defaults, and which allow them to initiate a charge straight away.

3.5 Mainstream Consumer home charging behaviour in response to Supplier-Managed Charging

This section summarises the charging behaviours of participants in the SMC group to understand the impact of Supplier-Managed Charging on charging profiles. A total of 40 participants in the BEV Charging Trial and 39 in the PHEV Charging Trial experienced Supplier-Managed Charging. For the purposes of comparison the charging profiles for the SMC group are plotted alongside those observed in the Control (section 3.3) and UMC groups (section 3.4).

Figure 16 shows the proportion of home charge events by plug-in time for Control, UMC and SMC participants in each trial.

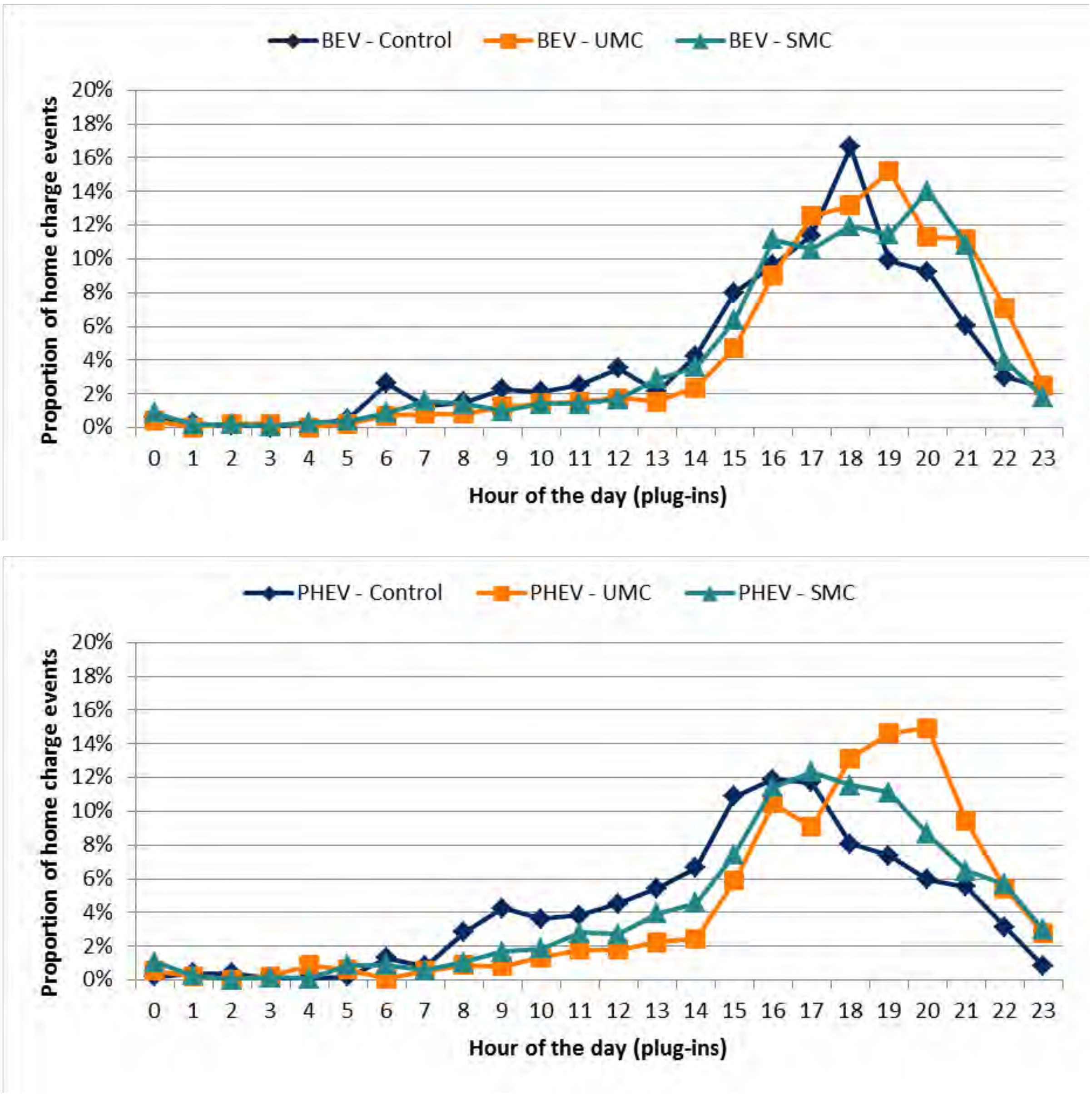


Figure 16: Proportion of home charge events by plug-in hour for Control, UMC and SMC participants (BEV N = 2,777, PHEV N = 3,589) (Top – BEV, Bottom – PHEV)

This shows that the majority of SMC plug-in events occurred in the late afternoon and early evening (3pm-9pm), similar to the plug-in events in the Control and UMC groups. As observed with UMC, there were statistically significant differences in the distribution of plug-in times between the SMC and Control groups on weekdays and weekends. The majority of plug-in times occurred later in the evening for SMC participants compared with Control group participants (8pm-9pm for BEV participants and 5pm-6pm for PHEV participants).

As found with the UMC group, there was no systematic difference in the times at which journeys ended at home between Control, UMC and SMC groups, in either the BEV or PHEV Charging Trial (see Figure 17).

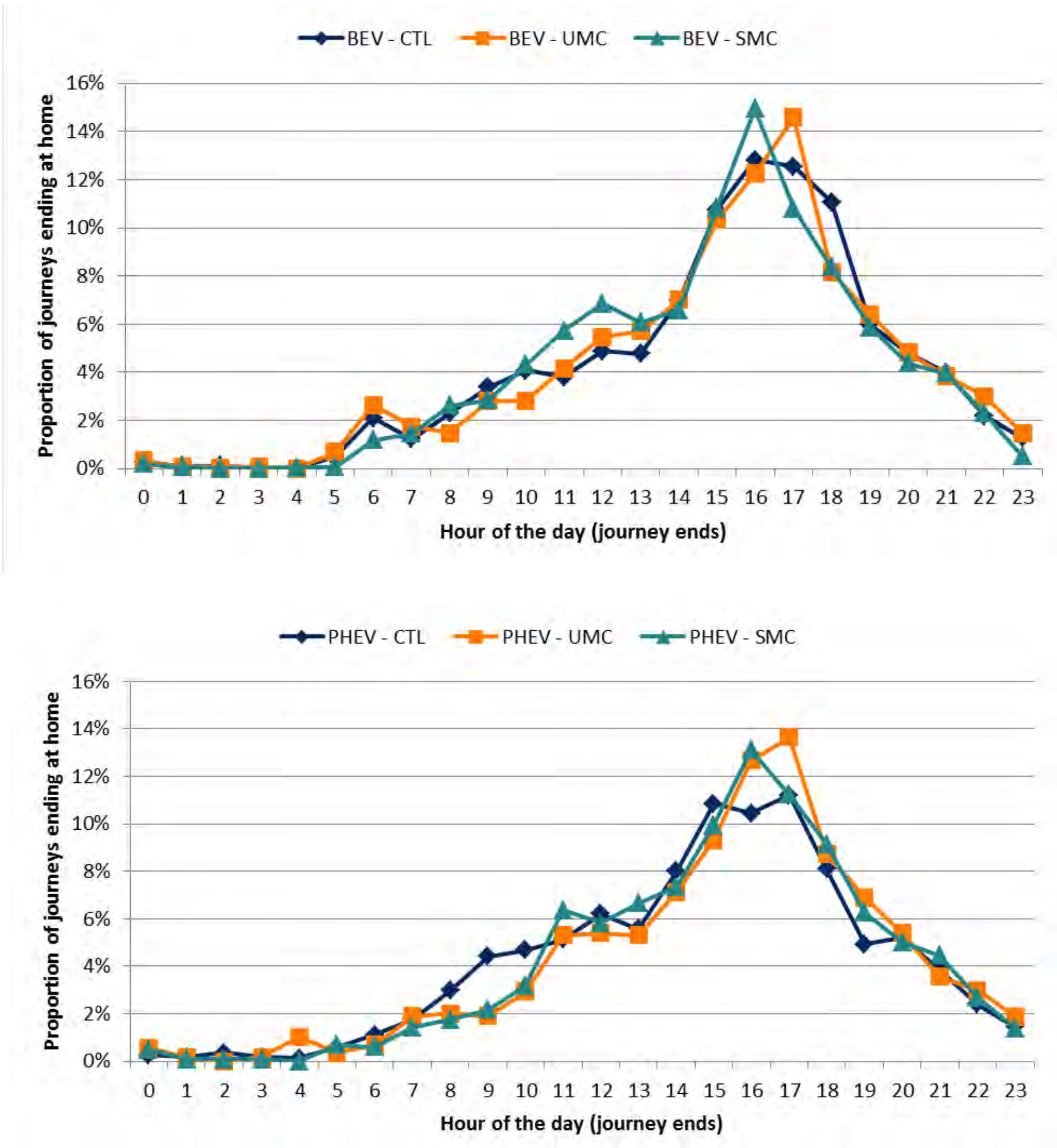


Figure 17: Proportion of Control, UMC and SMC group journeys ending at home (BEV N = 7,278, PHEV N = 7,041) by journey end hour (BEV – top, PHEV – bottom)

In the SMC group, peaks in journey end times can be observed between 4pm-5pm, but as shown in Figure 16, the peaks in plug-ins were later in the evening suggesting that there was a tendency for at least some participants in the SMC group to delay plugging in their vehicles after arriving at home, as was observed with the UMC group. Possibly, the very act of participation in a Managed Charging scheme prompted participants to consider their charging requirements (and therefore, when they plugged the vehicle in) more than those participating in an unmanaged charging scheme.

In the SMC groups, charging either began immediately (if participants chose to 'Charge Now' or it was scheduled on the basis of 'Desired SOC' and 'Departure Time' inputs (either default inputs or new inputs) (see section 2.2.2). Using these inputs, the system defined:

- a 'Charging Requirement'; the number of hours of charge needed to charge the battery from the current SOC (obtained via the vehicle telematics system) to the Desired SOC (input from the app), and:
- a 'Time Window'; the amount of time available for charging from the current time to the required Departure Time (input from the app).

The Charging Requirement in the SMC group was delivered at the end of the Time Window, minus a one-hour buffer. For example, if the Charging Requirement was five hours, and the Time Window was 10 hours (8pm to 6am), the system delivered the five hours of required charge between midnight and 5am, allowing a one-hour buffer before the Time Window ended at 6am. This configuration is important to consider when interpreting the charge start time profiles in the SMC group; the purpose was to simulate SMC from the user perspective, but it is not necessarily representative of actual charging patterns that would occur in an SMC system.

The effectiveness of the MC schemes at shifting charging demand away from the evening peak period is illustrated in Figure 18. This shows that Managed Charging reduced the proportion of home charge events starting between 4pm-7pm by at least a factor of two; from more than a third in unmanaged charging conditions (Control group) to around 16% in UMC and 12% in SMC.

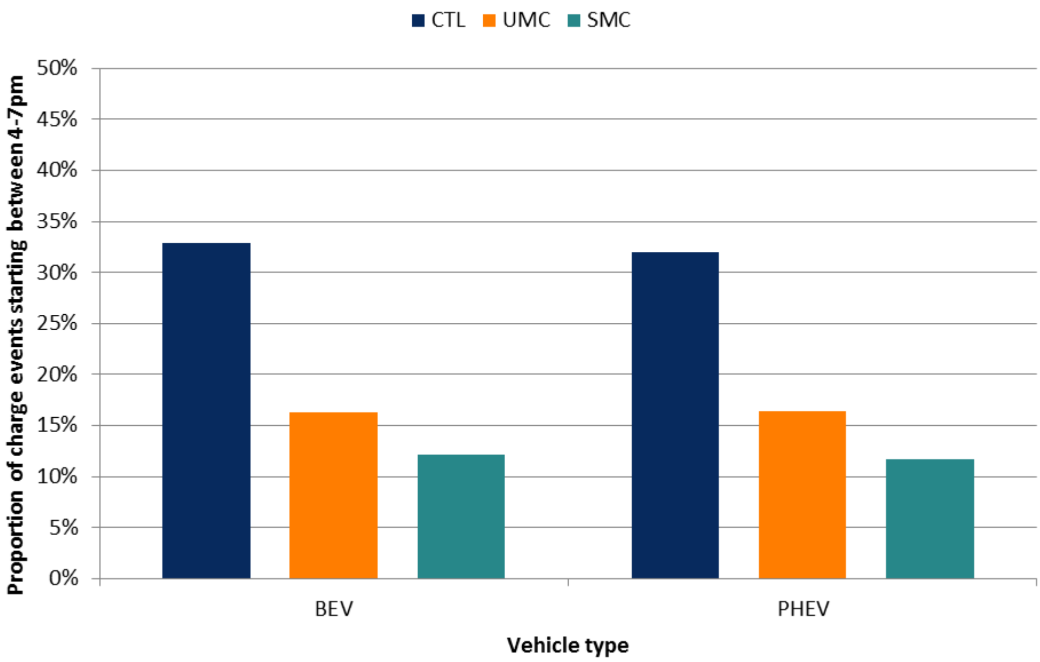


Figure 18: Proportion of all home charge events which started between 4-7pm by experimental group (BEV N = 3,788, PHEV N = 5,026)

Figure 19 shows the proportion of home charge events by charge start time for Control, UMC and SMC participants in each trial. In the BEV trial, charge start times for the SMC group were statistically significantly, and substantially, later than for the Control group, showing that SMC was very successful in shifting the timing of BEV charging demand. In the PHEV trial, there was a similar statistically significant reduction in charges starting during the late afternoon and early evening periods; however, a clearer peak can be observed in the overnight period (1am-6am) compared with the BEV trial. This was due to the way the SMC system was configured for the purposes of the trial, as described above. The PHEV could be fully charged from empty at home in about 2-2.5 hours compared with about 10.5 hours from empty for the BEV; this was due to the smaller battery capacity (8.7kWh vs. 35.8kWh of nominal capacity). Therefore, if participants, for example, set a Desired SOC of 100%, and a Departure Time in the early morning around 7am-8am (as is typical for commuters) then the system will have started the charge around 3-4 hours before that. The pronounced peak in PHEV charge start times is supported by the fact that a greater proportion of PHEV charge events (38%) began with an SOC of 10% or less compared with BEV charge events (2.5%). In other words, the BEVs had a much broader spread of starting SOC, and therefore a broader spread of charge start times in the SMC condition.

Figure 19: Proportion of home charge events by charge start hour for Control, UMC and SMC participants (BEV N = 3,788, PHEV N = 5,026) (Top – BEV, Bottom – PHEV)

Examination of the Desired Departure Times requested by participants is suggestive of this pattern. For just under 75% of charges where a schedule was set (either using defaults or by specifying new settings), the Desired Departure Time requested by users was between 5:30am and 08:30am; see Figure 20.

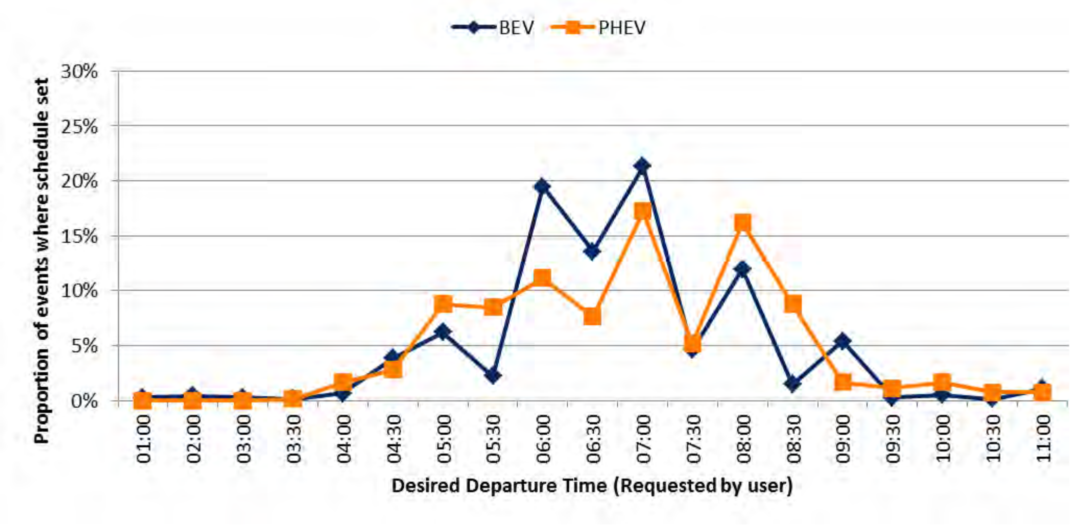
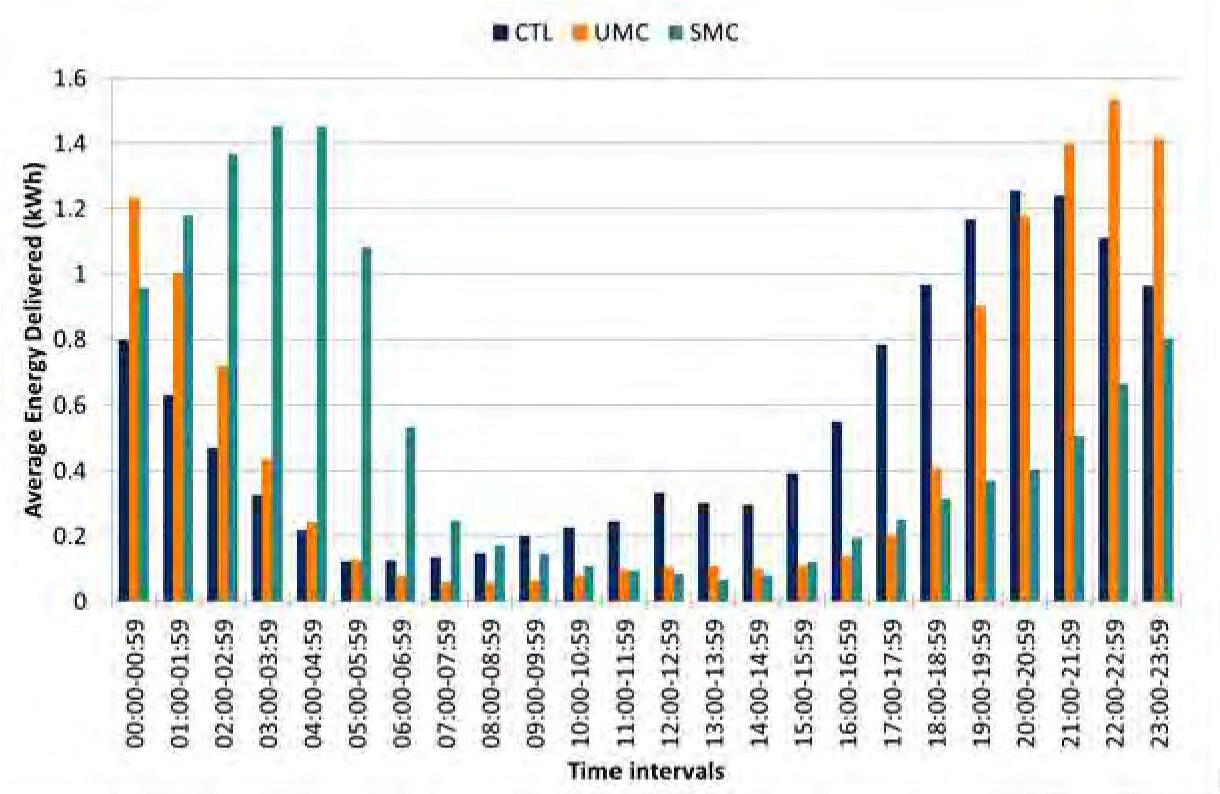


Figure 20: Proportion of SMC charge events by Desired Departure Times (1am-11am only) (BEV N = 712, PHEV N = 909)

The charging behaviours of control group, UMC and SMC participants are further illustrated in Figure 21, which presents charging data in terms of average energy delivered (kWh) per participant[19] for each experimental group. These data support the patterns seen in the profile of charge start times, with the two managed charging schemes shifting peak energy demand to later in the evening (in the UMC group) and into the overnight/early morning period (in the SMC group).

[19] For the purpsoes of this calculation, a static charging rate over the duration of each charge event was assumed.



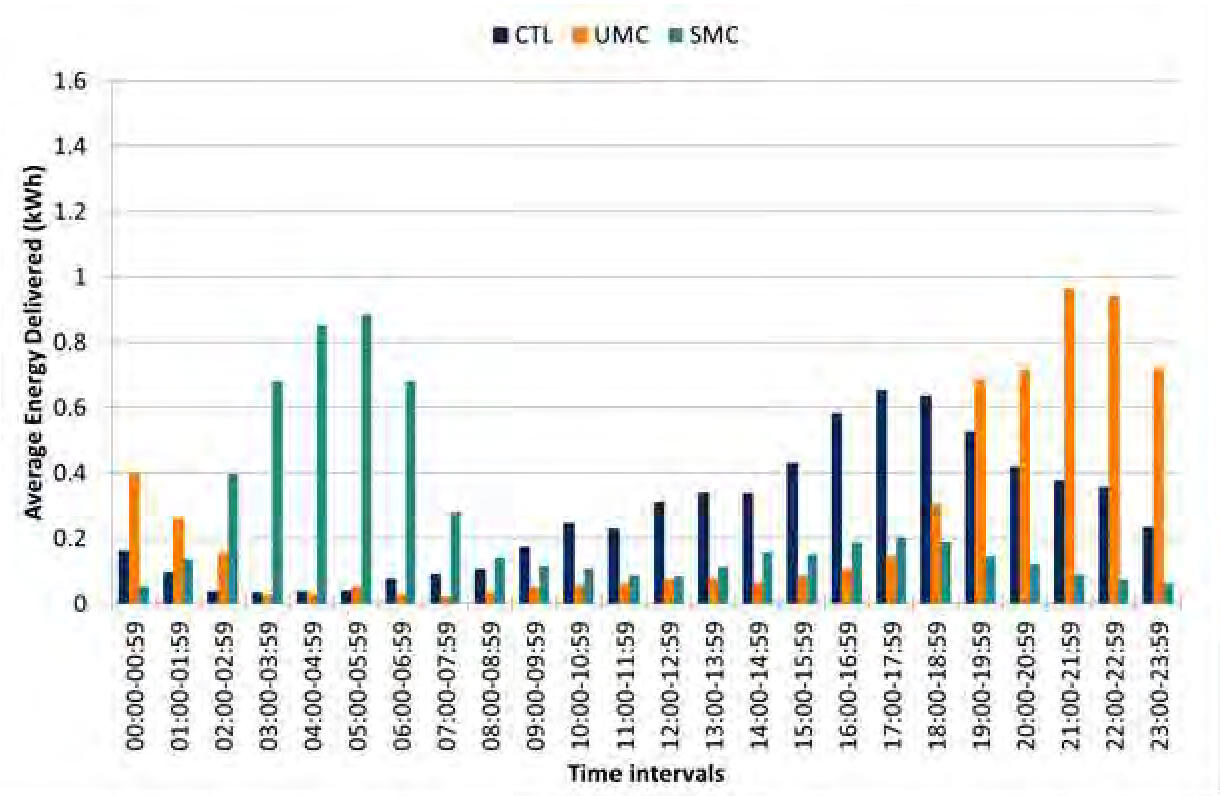


Figure 21: Average energy delivered per participant per hour of the day for Control, UMC and SMC participants (BEV N = 3,662, PHEV N = 4,875) (Top – BEV, Bottom – PHEV)

In the SMC groups participants could specify their Desired SOC (%) in increments of 5% from 10-100%. The proportion of SMC charge events by Desired SOC is shown in Figure 22. For BEV trial participants, more than 50% of events had a Desired SOC of 100%. A Desired SOC of 90%

was also set for 21% of events initiated by the defaults, and 14% of events initiated by new settings. On the other hand, 92% of PHEV charges had a 100% Desired SOC set as the default, along with 72% of charges initiated with new settings. This shows that for most charge events where a schedule was set in SMC, PHEV drivers requested a full charge. BEV drivers appeared to offer more flexibility, with over 40% of events requesting less than 100% SOC.

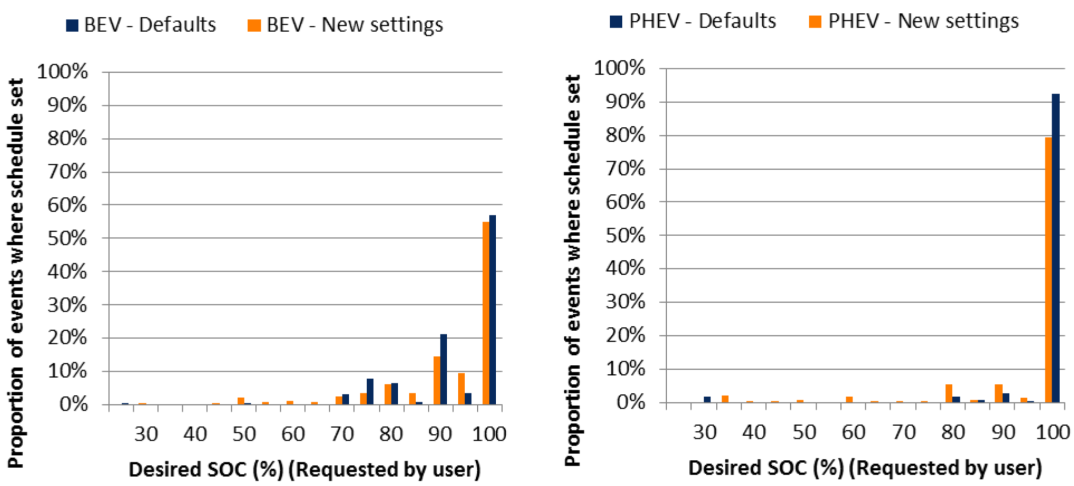
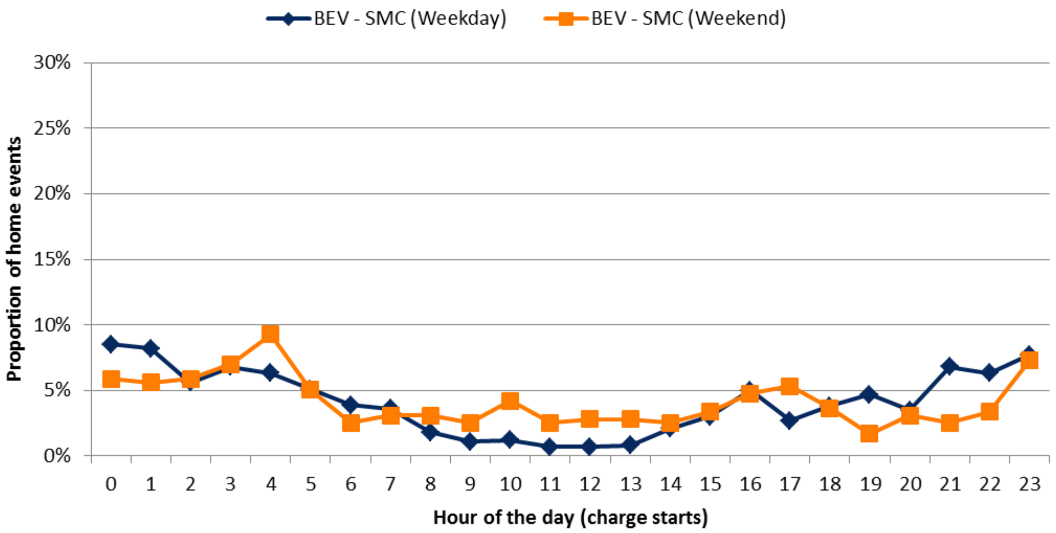


Figure 22: Proportion of SMC charge events by Desired SOC (BEV N = 760, PHEV N = 969) (Left – BEV, Right – PHEV)

This is likely due to the difference in battery size and electric range between these vehicles. The VW Golf GTE (PHEV) had a maximum range of 50km (30 miles) and so a charge of less than 100% may not have been perceived as worthwhile by drivers, especially by the PHEV drivers in this study who travelled further, on average, than the BEV drivers. The real-world range of approximately 125 miles in the VW e-Golf (Worldwide Harmonised Light Vehicle Test Procedure [WLTP], September 2018) on the other hand may have been sufficient to enable drivers to be more flexible in how much charge they needed for their next journey. This has important implications for policy; not only are longer range BEVs likely to be more appealing to Mainstream Consumers (see Deliverable D5.2) but they also have the potential to offer greater flexibility for spreading charging demand, and may even increase uptake of SMC systems, since the risk of not having enough charge is significantly reduced.

Separate charge start time profiles for weekday and weekend charges in the SMC group are shown in Figure 23.



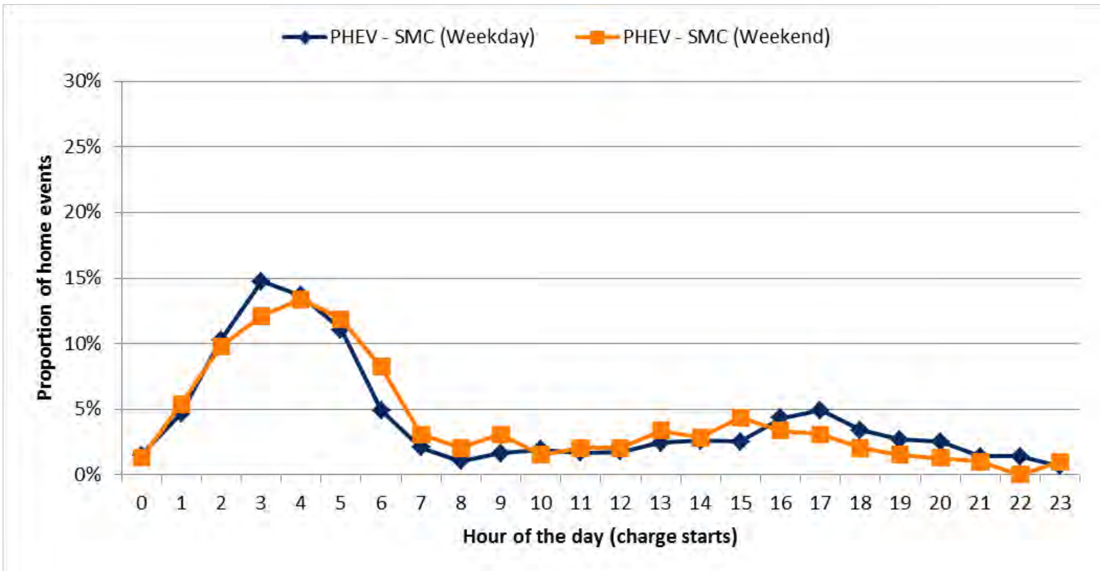
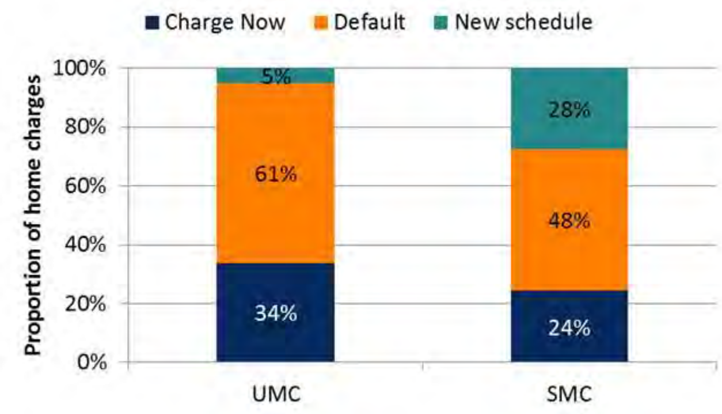


Figure 23: Proportion of home charge events by charge start hour for SMC participants on weekdays and weekends (BEV N = 1,355, PHEV N = 1,732) (Top – BEV, Bottom – PHEV)

Statistically significant differences were identified in SMC charge start times between weekdays and weekends, however – as shown in Figure 23 – the broad pattern of charging profiles on weekdays and weekends was similar. This suggests that SMC was successful in shifting charging away from the late afternoon/early evening into the overnight period irrespective of day of the week.

The proportion of UMC and SMC home charge events which were initiated using each of the driver input methods is shown in Figure 24.

BEV Charging Trial



PHEV Charging Trial

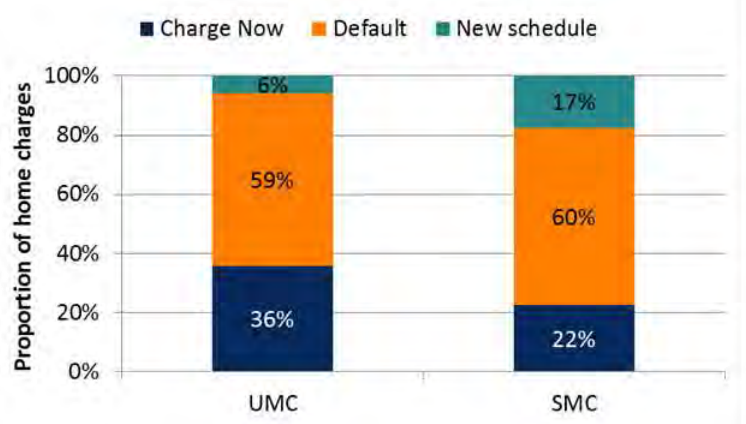


Figure 24: Proportion of UMC (N = 2,320) and SMC (N = 2,255) home charge events by driver input method

The proportion of charges initiated by each of the driver input methods was found to be statistically significantly different between the UMC and SMC groups, in both the BEV and PHEV trials. Setting new parameters following plug-in was more common in the SMC group than the UMC group, representing 28% of BEV charges and 17% of PHEV charges. The difference between BEV and PHEV trials is likely due to the PHEV drivers having a greater tendency to request and maintain a Desired SOC of 100% (see Figure 22), and BEV drivers having a greater need to manage their charging requirements. The difference between UMC and SMC groups is likely to be due to the characteristics of the two systems. In SMC, charging requirements were dependent on the current SOC of the car and participants' needs for their next journey (i.e. Desired SOC and Departure Time). In contrast, UMC participants simply chose a Charge Start and Charge Stop time; so unless participants had an atypical need to use the vehicle during their normal charging window (e.g by using 'Charge Now') there was no real reason to stray from the defaults. Hence, it is logical to observe a greater share of charge events in SMC where new charging preferences were entered, compared with UMC.

Similar to UMC, the largest share of SMC home charges were undertaken using the default settings. Around a quarter used 'Charge Now'. The prevalent usage of this option suggests SMC systems should also be designed with override functions (i.e. an ability to 'Charge Now'), default functions, and the option to choose new settings for each new charge.

Figure 25 shows the proportion of SMC home charge events by charge start time for each driver input method. This shows a clear trend for events initiated using Charge Now in the late afternoon and early evening period (similar to the time of day when SMC drivers plugged their vehicles in; see Figure 16). As with UMC, this suggests that the ‘Charge Now’ function gave SMC participants flexibility to initiate impromptu charges at times outside of their normal schedule.

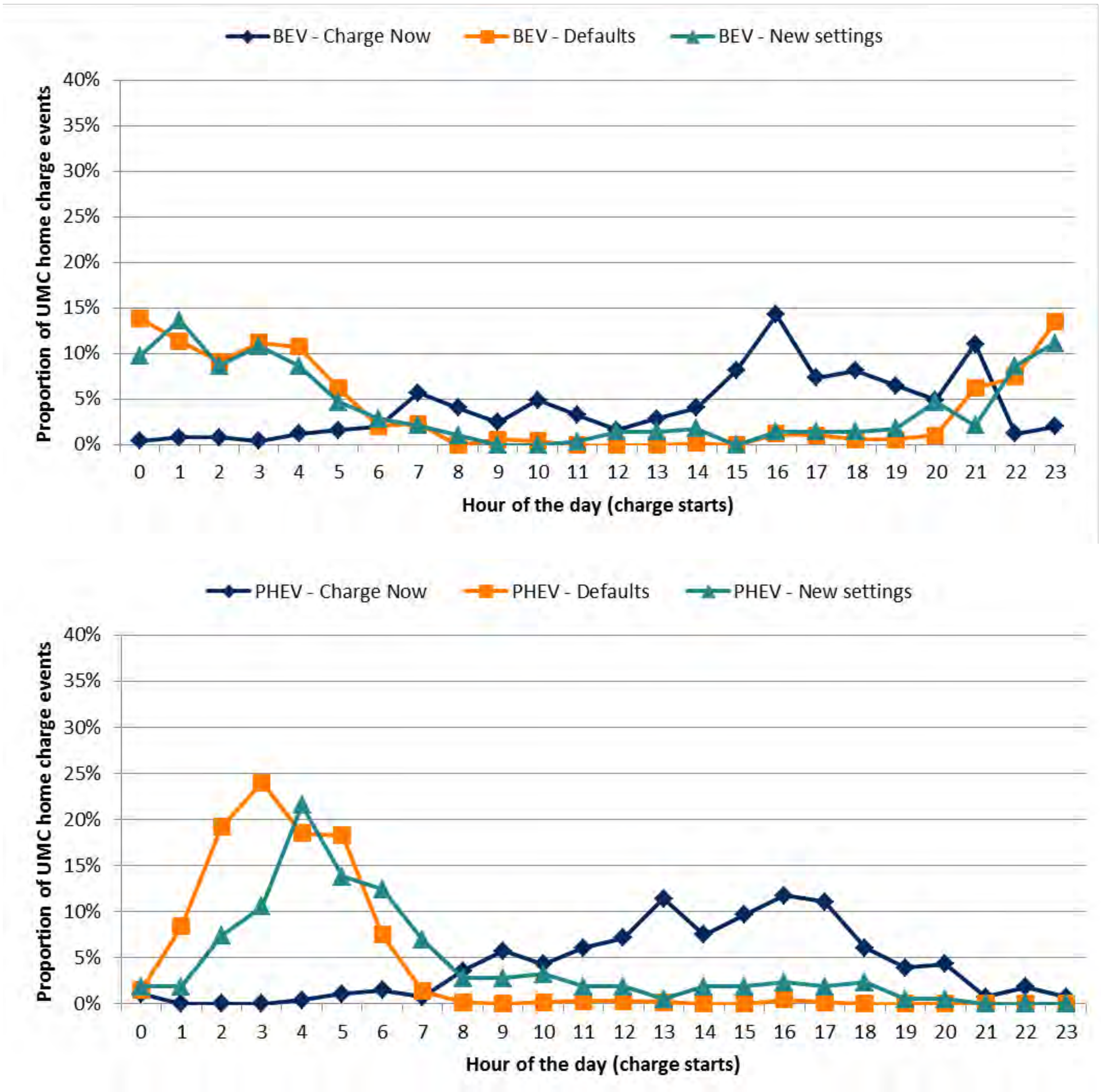


Figure 25: Proportion of SMC home charge events by charge start time for each driver input method (BEV N = 1,005, PHEV N = 1,250) (Top – BEV, Bottom – PHEV)

Taken together these findings suggest the following conclusions:

- Participants in the Supplier-Managed Charging (SMC) groups engaged with the SMC scheme.
- The majority of charges were initiated using the Default settings. Most of the time users requested Departure Times in the morning period (peaking between 5.30am-8.30am), and a Desired SOC of 100% (although more events with lower Desired SOC were observed in the BEV Charging Trial than the PHEV Charging Trial).
- As a result, SMC was highly successful in shifting charging away from starting in the late afternoon/early evening into the overnight period relative to both BEV and PHEV

unmanaged conditions, and also relative to UMC. This effect was observed for both weekday and weekend charge events.

- Around a quarter of charge events were initiated using the 'Charge Now' feature, and these typically occurred in the late afternoon/early evening in line with the most common times at which SMC participants plugged their vehicles in at home.
- Future design of SMC-type Managed Charging schemes should include a range of functions which allow users to set defaults, apply new settings at the start of each charge, and initiate a charge straight away[20].

3.6 Mainstream Consumer attitudes towards Managed Charging

The data discussed in this report so far have demonstrated that the UMC and SMC forms of Managed Charging investigated in this trial were effective at shifting charging behaviour. This section summarises attitudinal data from the Time Point 2 (TP2) questionnaire, and data from the choice experiment, to understand what Mainstream Consumers thought about Managed Charging; this is useful for understanding the propensity for adoption of MC schemes by Mainstream Consumers.

3.6.1 Satisfaction with Managed Charging schemes experience in the trial

Participants were asked to indicate how satisfied or unsatisfied they were with the charging scheme they experienced in the trial.

There were no statistically significant differences in reported satisfaction with the charging scheme between the three groups, in either the BEV Charging Trial or PHEV Charging Trial. The vast majority of participants in the UMC and SMC groups reported being either very satisfied, satisfied or neither satisfied nor unsatisfied; this suggests that overall perceptions of the MC schemes were generally positive or neutral. Satisfaction with a real-world MC scheme may differ. Consumer satisfaction may be influenced by the extent to which they feel electricity and fuel cost savings are worthwhile. Nevertheless, Savings Points earned in this trial had some external validity since they were redeemable against a cash lump sum at the end of the trial and so the ratings of satisfaction serve as a useful proxy.

3.6.2 Self-reported likelihood to choose Managed Charging

In the TP2 questionnaires, participants in each group were asked to indicate how likely or unlikely they would be to choose the charging scheme they experienced if they had a BEV or PHEV; at this point in the questionnaire they were not given explanations of the alternative types of MC scheme. The results suggest that the experience of using UMC in the BEV trial had a positive influence on the likelihood of future adoption of a UMC-based scheme. In the BEV trial, the UMC group were statistically significantly more likely to choose the scheme they experienced than the SMC group and the Control group. Around 60% of the UMC group indicated they would be either likely or very likely to choose UMC if they owned a BEV, and around 50% if they owned a PHEV.

[20] Other types of functions could also be considered, such as the ability to reschedule/reset mid-way through a charge, although this was not tested in the current study.

In the PHEV Charging Trial, a similar trend was observed; however, the differences in likelihood ratings between groups were not found to be statistically significantly.

When given a choice between the three different types of charging scheme (Unmanaged, UMC or SMC), the majority of BEV Trial participants in both the Control and UMC groups reported that UMC would be their preferred option in future (see Figure 26).

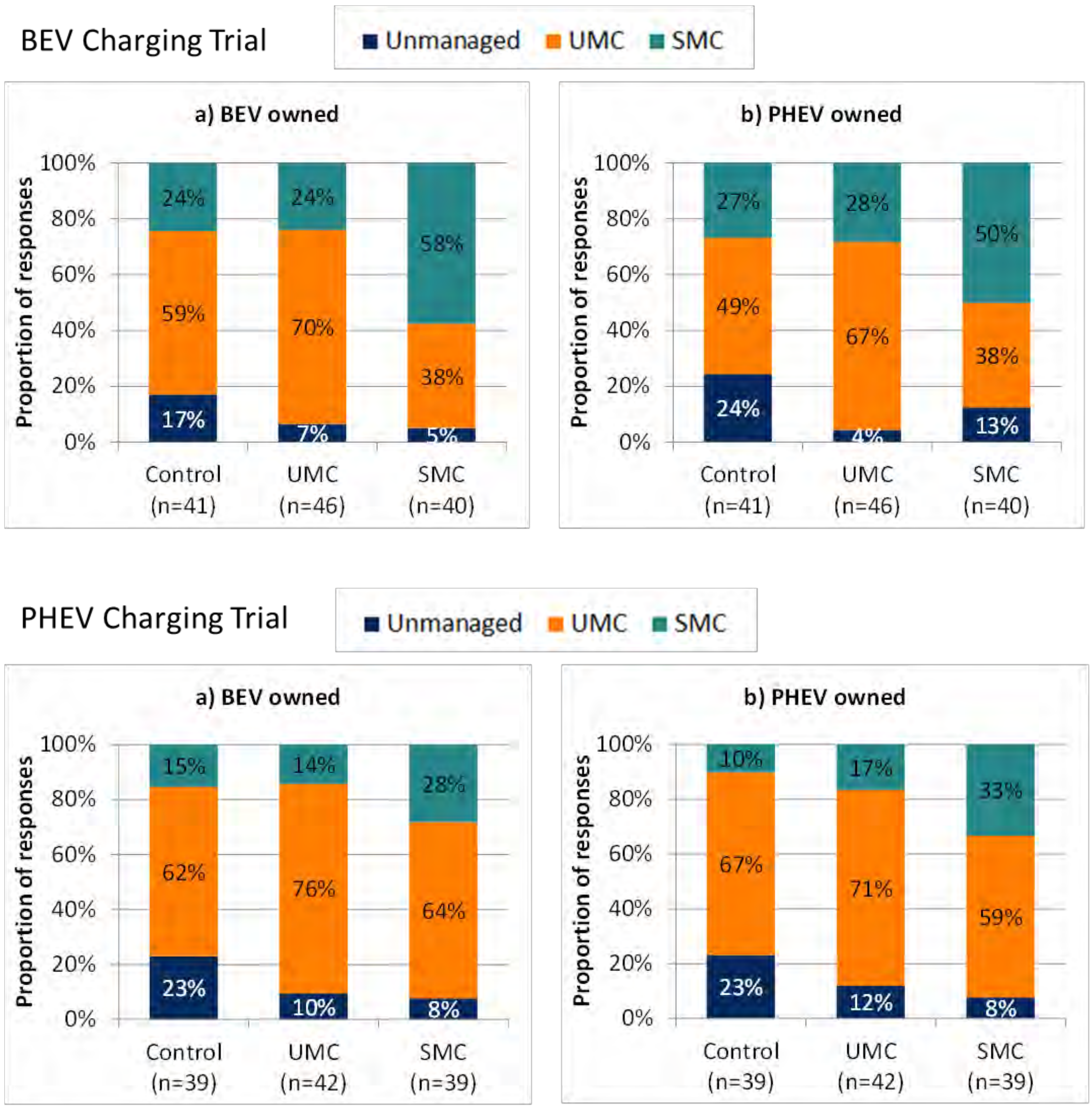


Figure 26: Proportion of participants who reported they would choose Unmanaged, UMC or SMC by experimental group (N = 247)

In contrast, BEV drivers in the SMC group were more likely to pick SMC in future. In the PHEV Charging Trial, UMC was the preferred option for the majority of participants in all three experimental groups (see Figure 26 – Bottom). However, a trend of increased preference for SMC by those who experienced SMC in the trial can still be observed. These findings suggest that participants' experience of the SMC scheme during the trial may have influenced their choice, particularly for the BEV drivers. It is also noteworthy that the majority of the Control group chose UMC; 59% of BEV drivers and 62% of PHEV drivers. This supports the findings from the choice experiment which suggest an underlying preference for Managed Charging over unmanaged charging (see section 3.6.3), but also that direct experience with SMC may be required to encourage the majority of consumers to adopt that particular variant of managed charging. Possibly this may be due to the increased complexity with SMC schemes, and the lack of comparable energy tariffs available in the market today. This has important implications for policy as it suggests that if the government and industry wish consumers to be on SMC schemes rather than UMC schemes, then innovative ways to encourage uptake of SMC schemes may be required. Insights from behaviour change literature are likely to be valuable here. It also has commercial implications for energy suppliers interested in developing SMC tariffs for consumers such that without initial incentive, consumers are more likely to choose UMC schemes over SMC, but once consumers experience SMC they are likely to remain with it. It is possible that as MC becomes more mainstream, underlying preferences may naturally shift from UMC to SMC.

In summary, these data suggest that:

- Mainstream Consumers with no previous experience of managed charging prefer the idea of UMC compared with SMC or no managed charging at all.
- Mainstream Consumers who *have* had experience with managed charging also tend to prefer UMC over SMC, with the exception of BEV drivers who have direct experience of SMC who instead are more likely to choose SMC in future.

3.6.3 Share of participants predicted to choose Managed Charging in future

The coefficients derived from the choice experiment were used to construct a choice model that predicts the share of participants who would choose each of the options in a set of SMC and UMC schemes and unmanaged charging. The construction of the choice model is outlined in the Technical Appendix.

Figure 27 shows the share of BEV trial participants that were predicted to choose SMC and UMC schemes that are illustrative of future offerings. The attribute values selected for these illustrative schemes are based on an initial analysis of trial charging data in the CVEI Demand Aggregator Framework (D7.3)[21].

[21] Annual savings of £130/year and a peak cost of 10p/kWh above unmanaged charging, as well as an SMC override function that results in loss of financial reward for that charge event, and rapid charging available within 10 minutes of home.

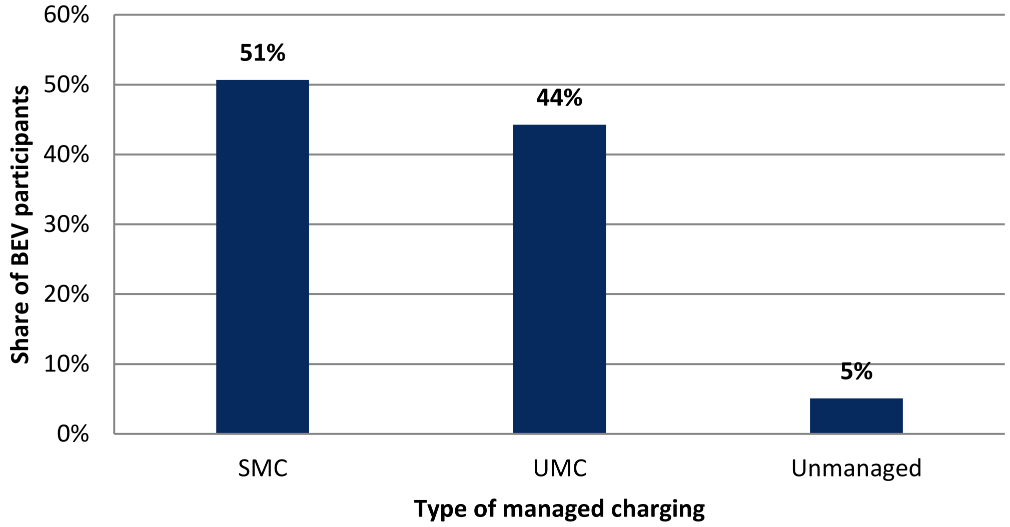


Figure 27: Share of BEV trial participants predicted to choose illustrative SMC and UMC schemes

In this example, MC appears very popular, with 95% of participants predicted to choose a MC scheme, which is in line with participant responses shown in Figure 26. However, the choice model shows a slight preference for SMC over UMC for the BEV participants, whereas most participants chose UMC as their preferred option when asked directly. It is likely that the primary reason for this discrepancy is that the illustrative choice modelled here included rapid public chargepoints within 10 minutes of participants' homes. As shown later in section 3.6.4.4, nearby rapid chargepoints shift the balance of preference in favour of SMC. Without nearby rapid charging, the share predicted to choose the illustrative SMC scheme tested in this study drops to 26% and UMC increases to 64%. This is more closely aligned with the participant preferences shown in Figure 26. The apparent large impact of rapid public charging on the choice between SMC and UMC warrants further investigation in future research.

Figure 28 shows an equivalent example choice prediction for the PHEV trial participants. The majority of participants choosing a MC scheme over unmanaged charging was slightly lower than among BEV participants, but still a very large majority at 86%. In contrast to the BEV participants, slightly more PHEV participants chose UMC than SMC, despite also having public charging within 10 minutes of home. We speculate that this can be accounted for by two factors. First, the presence of nearby chargepoints may have less value to a PHEV user than a BEV user as an insurance against not having sufficient charge, if an unexpected need to leave earlier than planned arises; a PHEV's ICE capability provides an alternative form of insurance. Second, PHEV participants were told that the nearby public chargepoints could provide only 7kW, as this was the maximum possible for the model used in the trial, and thus provides less utility than the 50kW+ rapid public charging available to the BEV participants. As a consequence, nearby public charging appears to increase overall utility of SMC to a lesser extent for PHEV drivers than BEVs.

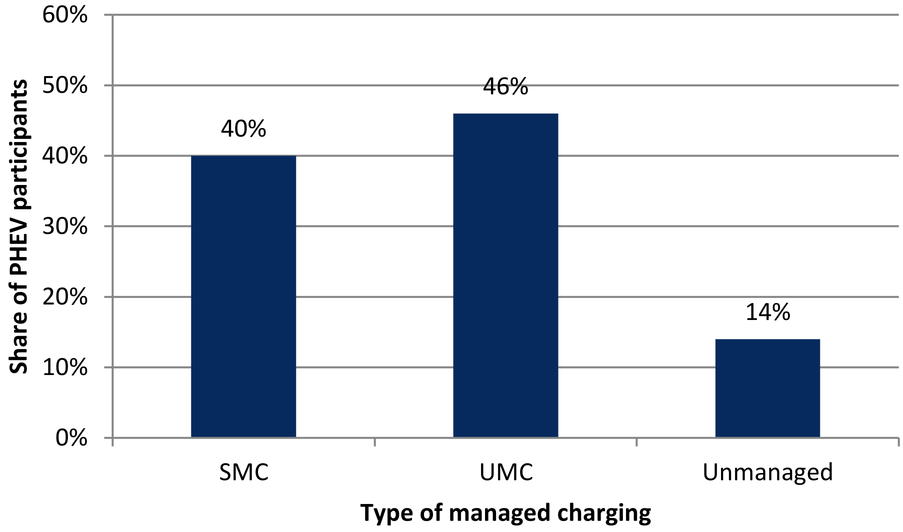


Figure 28: Share of PHEV trial participants predicted to choose illustrative SMC and UMC schemes[22]

Whilst the examples shown in Figure 27 and Figure 28 suggest that uptake of MC amongst PiV drivers is likely to be very high, it must be noted that the results of the choice model were obtained under choice experiment conditions that are not necessarily representative of choice processes under real world market conditions. For example, consumers in the real world may perceive there is a risk that the managed charging scheme will not be faultless, particularly if real world managed charging systems have greater failure rates than the systems used in the trial. In addition, participants may display a level of inertia in switching away from unmanaged charging, which at present they use by default. Choosing to even consider whether to switch to a managed scheme will in reality require effort, which some consumers may be unwilling to put in unless savings are greater. Inertia is already observed in consumers' unwillingness to switch electricity or gas supplier, despite cheaper suppliers with similar levels of service often being available. This inertia could be used advantageously by introducing policies which impose managed charging as the default mode, without an outright ban on unmanaged charging.

3.6.4 Influence of Managed Charging scheme attributes on participant choice

The example choice shares shown in Section 3.6.3 are for Managed Charging schemes with a specific set of attributes representative of what may be available in future. However, since the results of the choice experiment reflect the relative weighting participants place in each of these attributes, they reveal how sensitive their choice of preferred scheme are to changing attribute values.

[22] For both UMC and SMC: annual savings £40/year, peak cost 10p/kWh above unmanaged charging; 7kW public charge point within 10 minutes of home; changing SMC settings results in loss of financial reward for that charge event.

3.6.4.1 Annual cost savings

Figure 29 illustrates how participant choice was affected by the expected annual cost savings in an SMC scheme; the sensitivity of choice to UMC annual savings is similar since it shares the same choice coefficient. The choices of BEV trial participants were found to be more sensitive to this attribute than those of PHEV trial participants. This suggests that electricity cost is less of a concern to PHEV drivers, which may be because it contributes a smaller amount to the overall running costs of PHEVs compared with BEVs. This is supported by telematics data from these trials which shows PHEV drivers, on average, consumed 9.0 kWh/100km from charging compared with 19.1 kWh/100km for BEV participants.

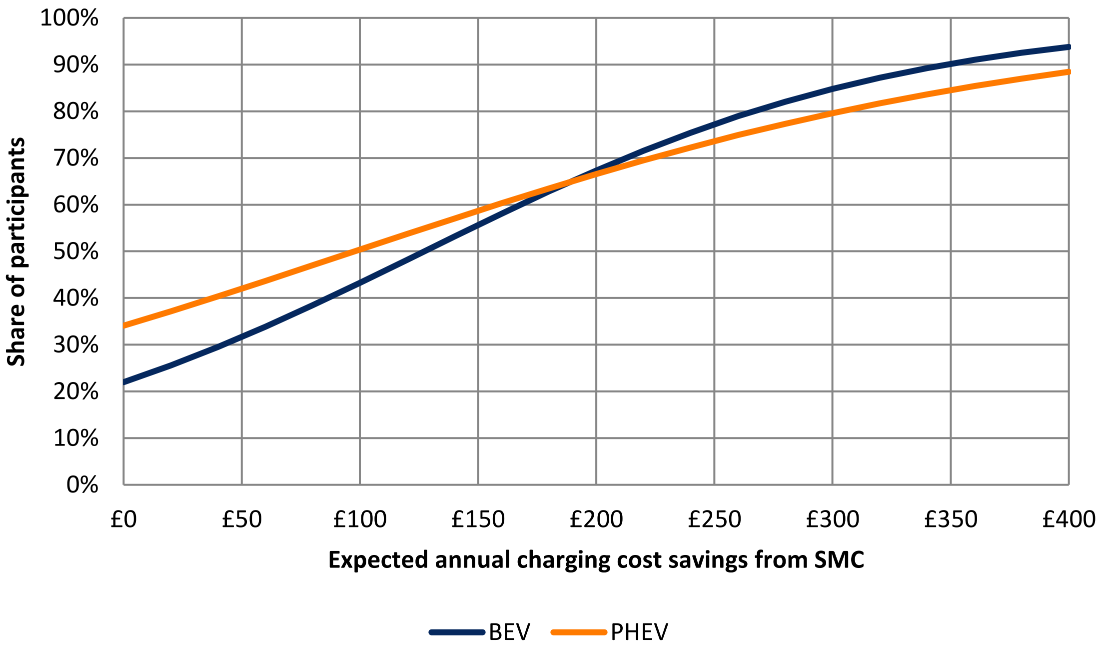


Figure 29: Share of BEV and PHEV trial participants predicted to choose SMC, at different levels of expected annual charging cost savings (all other attribute values are held constant at illustrative reference values)

3.6.4.2 Cost of charging in peak times

The likelihood of participants choosing SMC or UMC was found to decrease if the cost of charging during the tariff peak was increased. Figure 30 shows that willingness-to-pay (WTP, described in 2.4.4) for MC became more negative if the peak cost of charging relative to unmanaged charging was high, for both MC types and among both BEV and PHEV participants. This suggests that participants perceived there is a risk they may occasionally need to charge during peak times, and thus if peak cost is high they required greater compensation through higher annual cost savings to maintain the same share choosing that MC option. In general, the required level of compensation was higher for SMC than UMC, presumably because participants perceived less control over their ability to avoid peak electricity costs. Guaranteeing a certain share of the expected savings could be a way for SMC providers to address this perceived risk, although it is suggested that providers at least make a portion of the savings dependent on user behaviour to incentivise the user to provide flexibility.

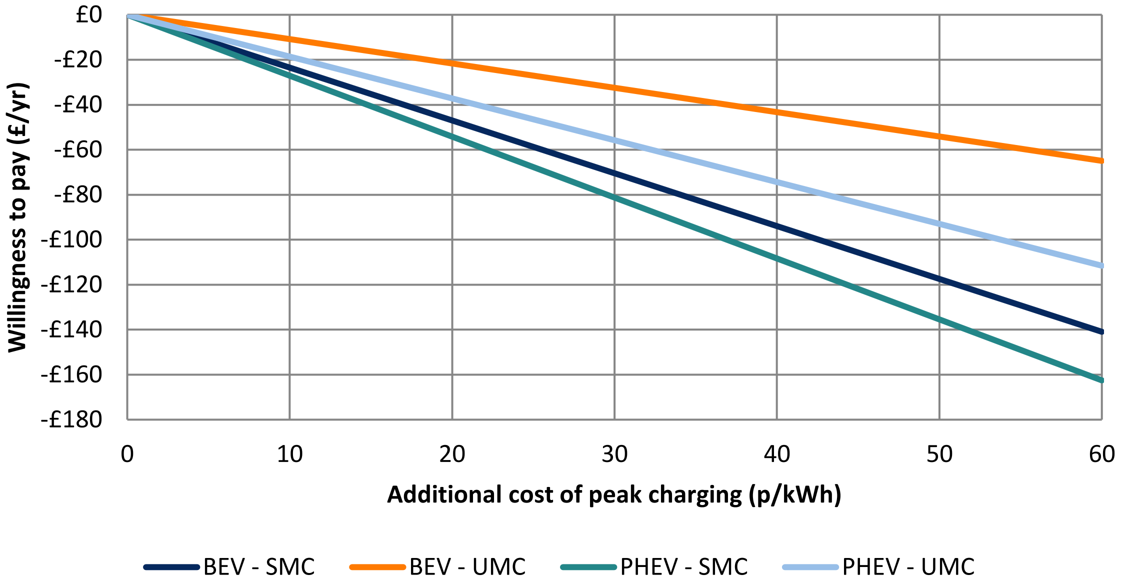


Figure 30: Participants' WTP for additional cost of peak charging relative to unmanaged charging

3.6.4.3 Override functions

Participants were also found to have a high WTP for the ability to override their settings in SMC options (see Figure 31). For both BEV and PHEV participants, an override function where users have full flexibility to change their settings after being set has approximately double the value of an override where changing settings results in loss of financial reward for that charge event. In general, BEV participants placed greater value in override capability, presumably because PHEV drivers have the option of driving under ICE power if the car is needed earlier than initially specified at the plug-in time. Consequently, they have less of a need to override their original charging settings. However, the fact that the WTP is non-zero and positive, still suggests that PHEV participants show a desire to run their cars on electric power rather than ICE. PHEV participants, for example, showed an average frequency of charging of 0.82 charges per day, which was greater than the BEV participants at 0.64 charges per day. It may also be that there is a basic level of WTP for a feature that offers "just in case" flexibility.

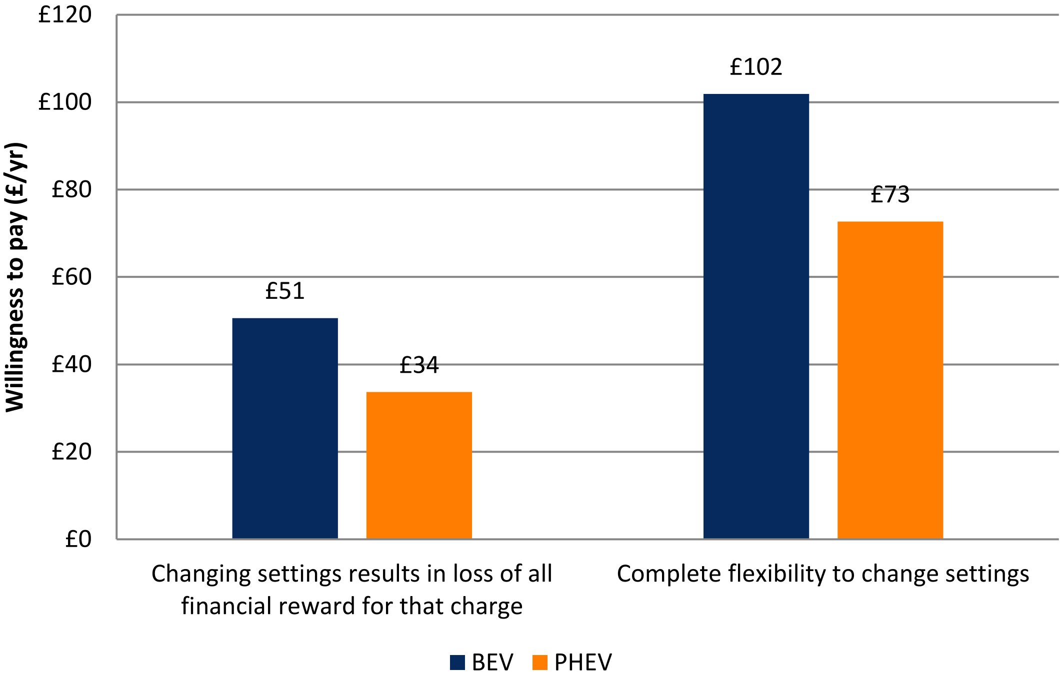


Figure 31: Participants' WTP for override function in SMC schemes

The offer of an override function would provide suppliers with a cost effective way of increasing uptake of SMC in future; indeed it might be argued that any SMC offer should have an override function. Offering an override function where participants lose the financial reward for each event in which they change settings would be unlikely to incur any net cost for the charging supplier because the financial penalty is born by the user. However, this would lead to an increase in uptake of SMC, equivalent to increasing participant cost savings by £34/year and £51/year for the PHEV and BEV participants, respectively. Offering full flexibility to override settings without financial penalty to the user would increase uptake further, but this would shift the penalty onto the supplier and so whether this is cost effective depends on how often participants choose to change their settings.

3.6.4.4 Availability of public charging

Participants were also found to attach value to there being nearby 50kW+ rapid (BEV participants) or 7kW (PHEV participants) public charging when considering a MC option. Since MC involves delaying charging to some extent, there is an increased risk that if the car is needed earlier than expected, in which case the state of charge may be lower than required. Like the override function, an alternative charging option provides a back-up in case this occurs. Figure 32 shows the additional WTP for SMC and UMC options at different proximities of public charging to home.

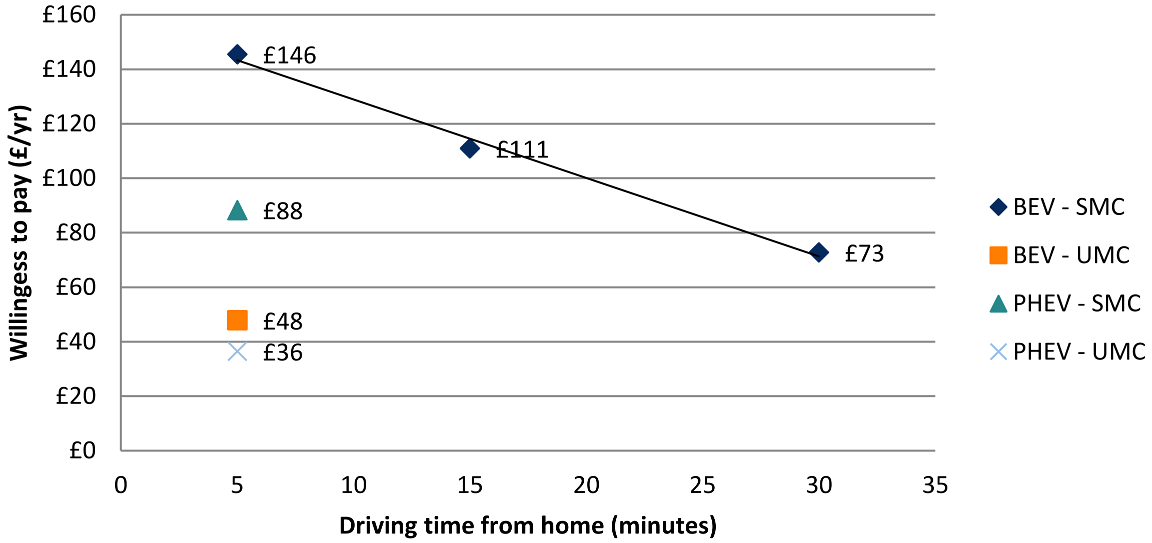


Figure 32: Participants' WTP for SMC and UMC schemes with different proximities of rapid charge points to home, relative to no access to nearby rapid (BEV) or 7kW public (PHEV) chargepoints

At a proximity of 5 minutes driving time from home, both sets of participants show an increased WTP for SMC and UMC, suggesting that building a dense public charging network would encourage more consumers to adopt managed charging, although the cost-effectiveness of this option would need to be assessed. At this level of proximity, additional WTP for SMC was found to be greater than that of UMC for both sets of participants. As observed for the peak charging cost, participants appear to associate greater risk with SMC and so value a back-up option more than for UMC. BEV participants appear to place greater value in nearby public chargepoints, but this is unsurprising since the chargepoint in question was stated as a 50kW+ rapid chargepoint, as opposed to a 7kW public chargepoint for the PHEV participants. The reason for this distinction is that nearly all PHEVs are incompatible with rapid chargepoints, and those that are charge at considerably less than the maximum charge rate due to their smaller batteries. Furthermore, PHEVs are less dependent on a back-up charging option since they can run on fuel power if necessary.

At proximities of 15 and 30 minutes driving time from home, no additional WTP for either managed charging scheme was identified for the PHEV participants, presumably because they were willing to accept running on fuel power rather than make at least a 15 minute detour to charge (at the relatively slow rate of 7kW). This was also observed for the BEV UMC participants. For SMC charging however, the BEV participants continue to attach some value even when the chargepoint required significant travel time (i.e. 30 minutes) to reach, and a linear relationship with travel time was observed. This may have been due to a perception of less certainty over SOC in the event of unexpected early departure with SMC, and, therefore, greater need for a back-up charging option.

While the choice experiment tested value placed in public charging proximity, availability of the nearest charge point was not explicitly tested. Charge points which are frequently in use by other drivers are likely to be valued less than ones which are always vacant when needed. Therefore, although charging network coverage is an important aspect to encourage Managed Charging adoption, ensuring that the network includes enough charge points that users perceive certainty of access is also critical.

3.6.4.5 Accuracy of savings estimates and anticipatory charging

For SMC options, the choice experiment also tested how the accuracy of the annual savings estimate, and the availability of anticipatory charging[23], influenced choice. In neither case were statistically significant choice coefficients identified, suggesting that neither attribute influenced choice. For the accuracy of savings estimate, participants were presented with an upper and lower bound which were equal distance from the estimate. It is likely that the risk of lower savings was offset by the opportunity of higher savings. The trial data show that most SMC participants set their desired state of charge above 90% (see Figure 22 in section 3.5), and so would not have received much benefit from anticipatory charging.

3.6.5 Underlying attitudes towards UMC and SMC

The choice experiment was primarily used to evaluate how participants trade off different attributes of Managed Charging when choosing between Managed Charging offers, and thus to build a model to predict this choice. However, the choice experiment can also be used to explore participants' underlying attitudes towards Managed Charging via the Alternative Specific Constants (ASCs) that were derived for both UMC and SMC (for further information on the ASCs, see the Technical Appendix). These in part reflect the value of unobserved factors not directly tested as an attribute in the choice experiment. For example, this could include the perceived risk associated with allowing someone else to manage a user's charging, concerns surrounding increased battery degradation, or perceived societal benefit of integrating charging with the grid.

The ASCs also accounts for the fact that the options in the choice experiment consist of different attributes. For example, the SMC scheme in the choice experiment has an override function attribute while the other options do not, and so the ASCs correct for the fact that user-managed and unmanaged charging already have this function despite not being explicitly stated. The portion of each ASC which represents the value of the unobserved factors must therefore be isolated, and this is achieved by equating the observed attributes of the SMC and UMC schemes with the unmanaged scheme. A detailed explanation of this process is outlined in the Technical Appendix.

Figure 33 shows participants' willingness-to-pay (WTP) for the unobserved aspects of UMC and SMC in both the BEV and PHEV trials (for a definition of WTP, see section 2.4.4).

[23] A refinement on SMC where users could gain additional savings by charging beyond their desired state of charge if cheap electricity was available now, but it was anticipated that electricity costs would be higher in the immediate future.

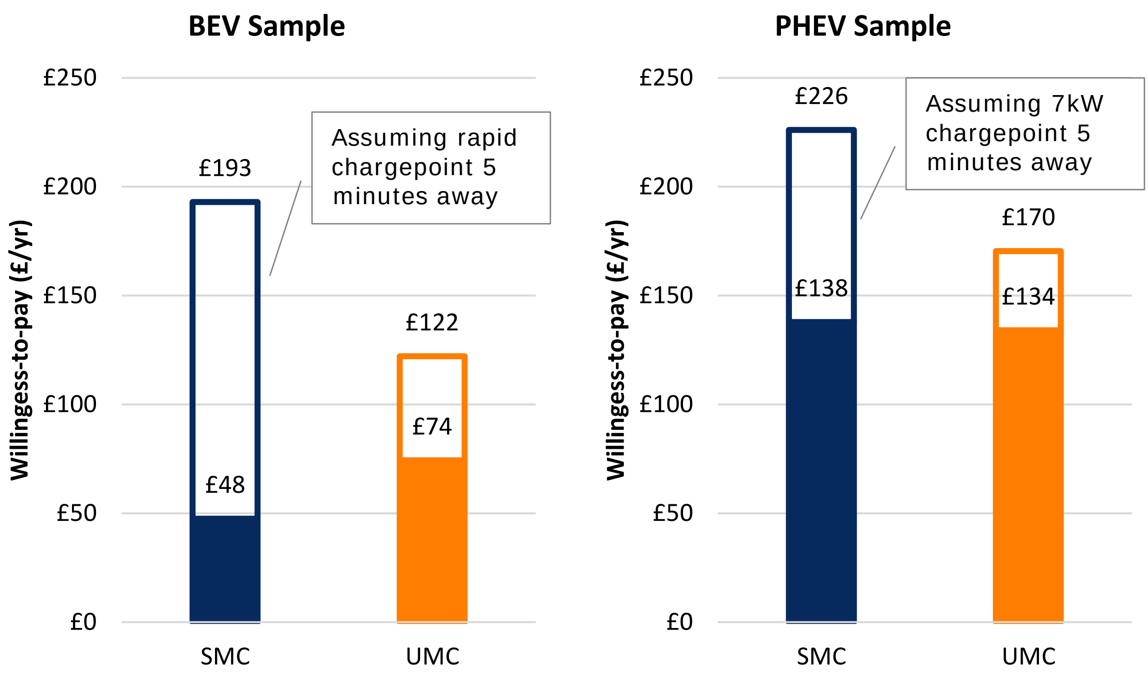


Figure 33: Willingness-to-pay for the 'unobserved factors' of SMC and UMC, for the BEV and PHEV trial samples (Transparent bar with solid border shows the WTP if nearest public chargepoint is within five minutes of home; solid bar is WTP if there is no nearby public chargepoint)

This is the WTP for each of the schemes if the observable attributes are set equal to what they are in unmanaged charging (for example, no annual savings, no additional cost of peak charging and full flexibility to override SMC settings). This is representative of participants' underlying attitudes towards each general type of scheme. In each case, two results are shown: the WTP for the unobserved factors of Managed Charging when there is no nearby public charging infrastructure (solid bars), and WTP for Managed Charging when public charging is only a five minute drive away (transparent bars)[24]. In all cases the WTP is positive, and hence participants have overall positive attitudes towards UMC and towards SMC.

As a result, the choice model predicts that even without any annual savings, more participants would choose to use SMC or UMC over unmanaged charging[25]. In addition, the choice model suggests that a large share of participants would in fact be willing to pay for either form of Managed Charging without any financial benefit in return, although incentives are still likely to be necessary to shape charging behaviour to preferred times of day.

The results suggest that PHEV drivers have a more positive underlying attitude towards Managed Charging than BEV drivers. This is potentially because PHEV drivers are less reliant

[24] This is willingness-to-pay for Managed Charging when all attributes are, as far as possible, set equal to unmanaged charging. Proximity of public charging has no impact on unmanaged charging, and so it is not possible to equate this attribute to unmanaged charging. Willingness-to-pay has therefore been shown for cases both with and without nearby public charging. For more details see the Technical Appendix.

[25] However, the choice experiment only tested participant choice between positive annual savings of £12 and £500, and so strictly the ASCs are only valid between these bounds.

on charging, since they can use the petrol engine if necessary, and so perceive less of a risk with Managed Charging.

With no nearby rapid chargepoints to act as a back-up, BEV trial participants showed a more positive attitude towards UMC. However, with rapid charging only five minutes away, their underlying attitudes towards SMC were more positive than towards UMC, perhaps because the risks associated with delegating control of charging to a third party were perceived as lower in this case. For the PHEV trial participants, underlying attitudes towards UMC and SMC were quite similar, particularly when there was no nearby 7kW public charging. Since a back-up charging option is less important for PHEV drivers, and the usefulness of 7kW charging is clearly less than 50kW+ rapid charging, the impact on attitudes when 7kW public charging is only five minutes away from home shifted attitudes in favour of SMC to a lesser extent than for the BEV sample.

3.6.6 Summary

In summary, analysis of the questionnaire and choice experiment data showed:

- The majority of participants in the UMC and SMC groups reported being either satisfied or very satisfied with the MC scheme they had experienced in the trial.
- Willingness-to-pay for the unobserved aspects of Managed Charging were positive, showing overall positive attitudes towards UMC and SMC schemes. The choice model predicted that even without any annual savings, even without any annual savings, more participants would choose to use SMC or UMC over unmanaged charging.
- In the BEV Charging Trial, the UMC group reported being more likely to choose the charging scheme they experienced (UMC) than the SMC or Control groups. When given the choice between charging schemes, the majority of the Control group also chose UMC supporting the finding of an overall preference for Managed Charging.
- In contrast, BEV drivers who experienced SMC in the trial were more likely to pick SMC in future. Taken together these findings suggest that consumers tend to choose what they are most familiar with, but the overall preference for Managed Charging over unmanaged charging and the slight advantage with UMC of it being analogous to some energy tariffs in the market today (e.g. Economy 7) suggests that greater effort or incentive may be required to encourage adoption of SMC. For example, experience with SMC seems important for adoption by BEV drivers.
- In addition to offering higher charging cost savings, options explored in this study that were found to boost uptake of managed charging are lower peak electricity pricing, a dense public charging network, and offering supplier managed charging with an override function, allowing users to change their settings once input. The latter two provide a back-up in case the car is needed earlier than expected when initially plugged-in. These were found to be more valuable to BEV drivers than PHEV drivers, who are less exposed to this risk as they can still operate their vehicle if the battery is not charged.
- For an illustrative future MC scenario, around 95% of BEV drivers were predicted to choose MC, with a slight preference for SMC over UMC (when nearby rapid charging is available). For this example, the share of PHEV drivers predicted to choose MC was lower at 85%, likely due to the lower annual savings estimated for PHEVs.

3.7 Charging away from home

All participants charged at home, but not all of them charged away from home (see section 3.2). Around 76% of BEV drivers and 58% of PHEV drivers charged away from home during the trial; this section summarises those charge events.

A total of 1,764 away-from-home charging events were captured from 96 BEV drivers and 70 PHEV drivers. Sorting these participants from most to least charges away from home shows that the majority of these charges were undertaken by a small minority of each sample (see Figure 34).

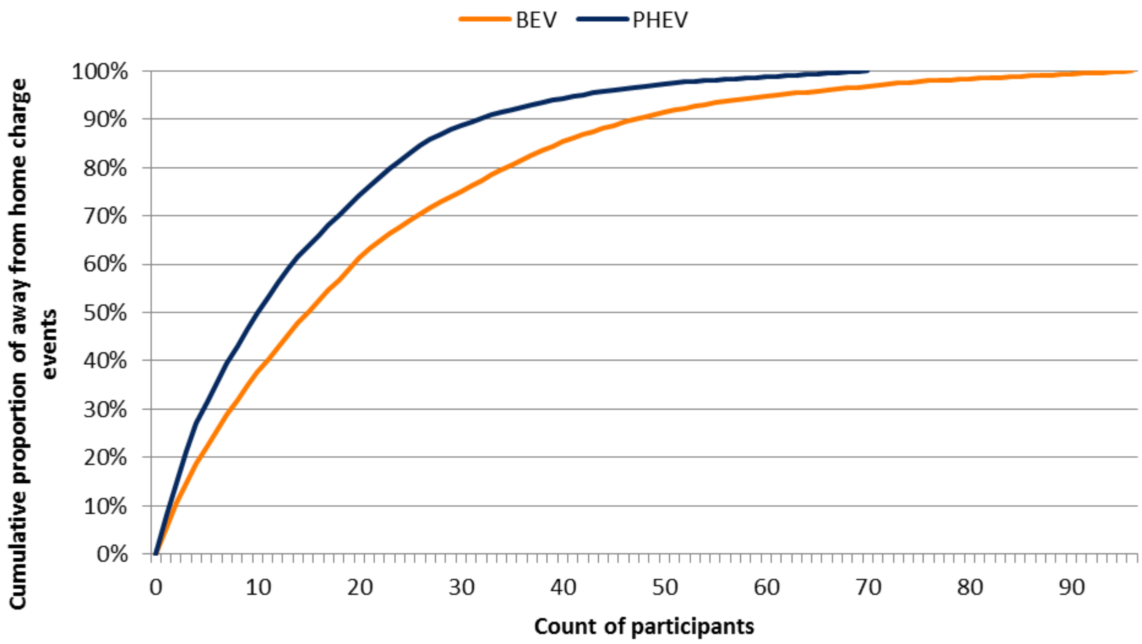


Figure 34: Cumulative proportion of charge events away from home by count of participants (BEV N = 984, PHEV N = 780)

Around 15% of the BEV and PHEV sample accounted for over 50% of charges away from home, and just under 50% of the sample accounted for over 90% of charges away from home. The highest number of charges away from home undertaken by a single participant was 53 in the BEV Charging Trial and 62 in the PHEV Charging Trial; representing about once per day across the 8-week trial.

Figure 35 shows the proportion of away-from-home charge events by charge start time for BEV and PHEV participants. As a reference point, home charge start times for the Control group are also shown; the UMC or SMC charges were not included in this comparison since charges away from home were not subject to Managed Charging.

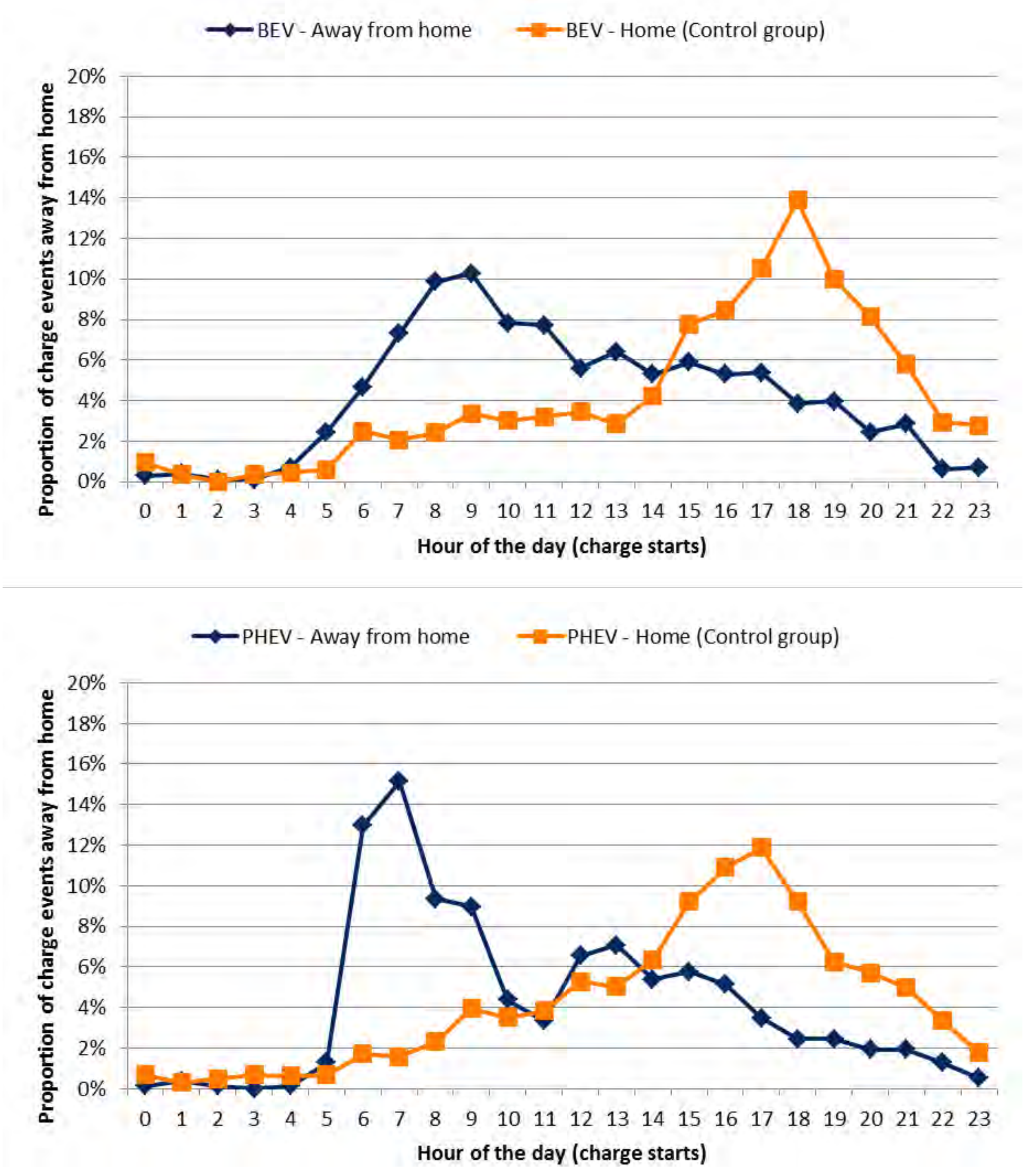


Figure 35: Proportion of away from home charge events by charge start hour (BEV N = 984, PHEV N = 780) (Control group home charge events shown as reference) (Top – BEV, Bottom – PHEV)

There was a statistically significant difference in the distribution of charge start times between home and away charge events. A clear pattern can be seen with charge events away from home starting in the morning and peaking between 7am-8am for PHEV drivers and 8am-10am for BEV drivers. A distinct contrast can be seen with the Control group home charges, where peaks were observed between 5pm-6pm for PHEVs and between 6pm-7pm for BEVs. Since charges away from home were accounted for by a small minority of the sample (as discussed above), the differences in overall away-from-home charge profiles between BEV and PHEV drivers are likely governed by differences in the behaviours of the sub-set of individuals who regularly charged away from home. Since the BEV and PHEV trials recruited different samples of Mainstream Consumers, the charging profiles in the two trials should not be directly compared.

Separate weekday and weekend away-from-home charges by charge start time are shown in Figure 36.

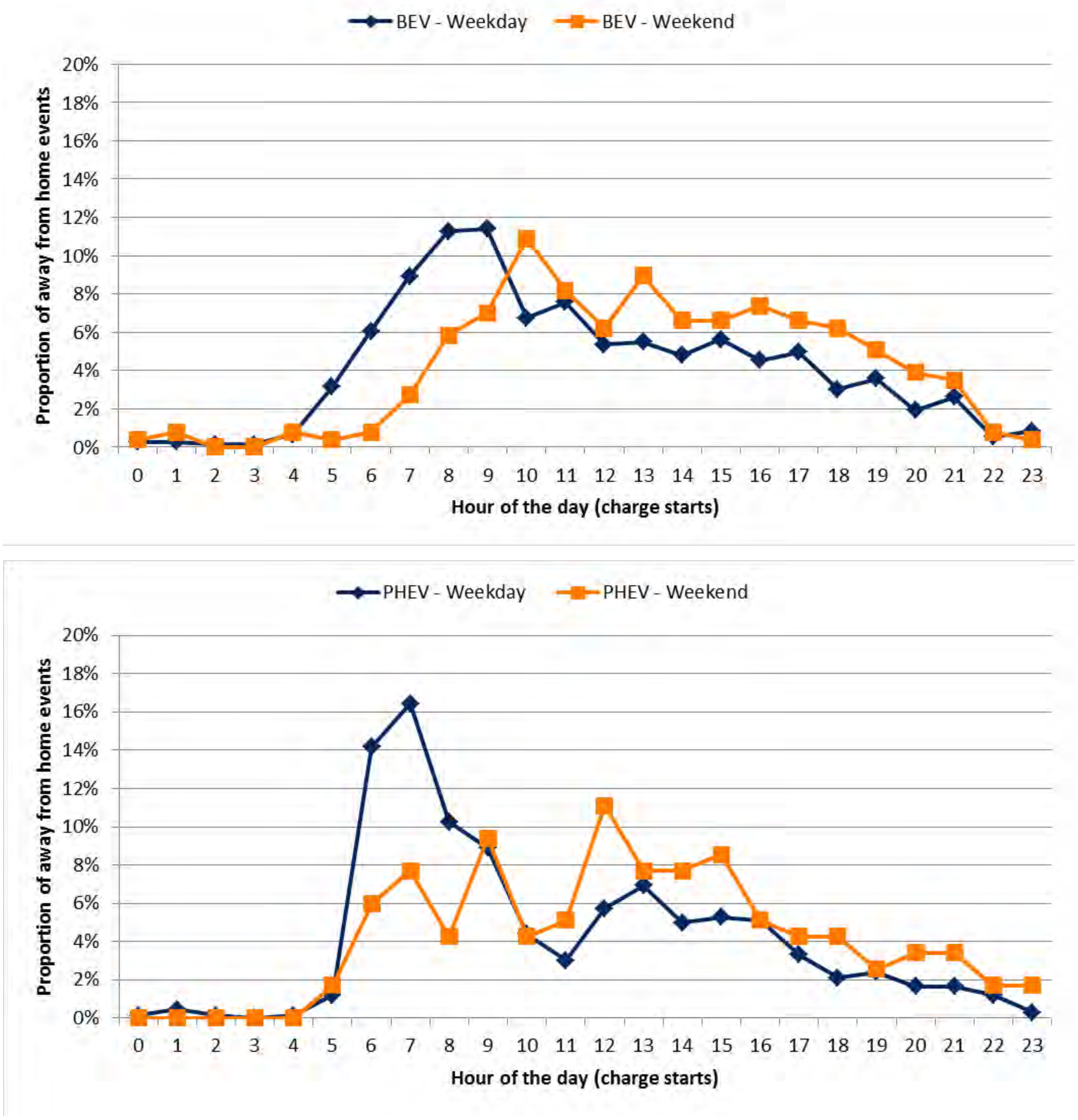


Figure 36: Proportion of weekday and weekend away from home charge events by charge start hour (BEV N = 984, PHEV N = 780) (Top – BEV, Bottom – PHEV)

There is an earlier morning peak on weekdays compared with weekends, and is more pronounced in the PHEV trial. Weekend away-from-home charge start times were more spread throughout the day; with peaks between 10am-11am and 1pm-2pm for BEV drivers, and between 9am-10am and 12pm-1pm for PHEV drivers (although it should be noted that the sample of weekend away-from-home charge events was small – see section 3.2). These differences are indicative of activity patterns at the weekend differing from those on a typical weekday (as discussed in section 3.3).

On weekdays, the peaks in the morning suggest a sub-set of Mainstream Consumers were plugging their vehicles in upon arrival at a destination away from home. This is supported by journey telemetry which showed a peak in journeys ending away from home between 7am-9am.

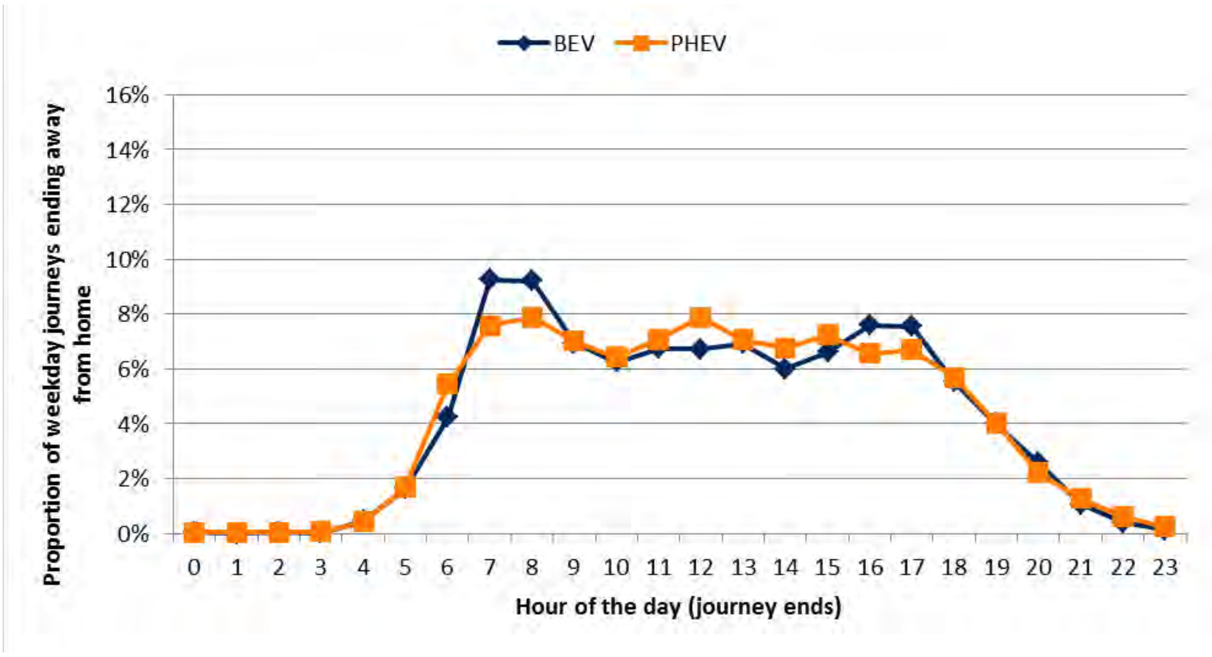


Figure 37: Proportion of journeys ending away from home on weekdays (N = 25,646) by journey end hour

The precise characteristics of the away-from-home charge locations could not be determined from these data[26], but some insights were gained through assessment of the self-report questionnaire data.

Figure 38 shows the proportion of participants who reported charging at various locations away from home. For both BEV and PHEV drivers, the most frequent charging away from home was reported to be at participants' places of work or education. This was the case for the drivers who charged away from home most often (i.e. the 15% of BEV and PHEV drivers who accounted for over 50% of charges).

While these data only represent a small sub-set of the overall sample, they show support for the hypothesis that the pattern of charging away from home in the morning can, at least in part, be explained by drivers plugging in upon arrival at their place of work or education.

[26] This was due to the anonymisation process required to ensure participants' personal information was protected; this process is fully explained in the Technical Appendix.

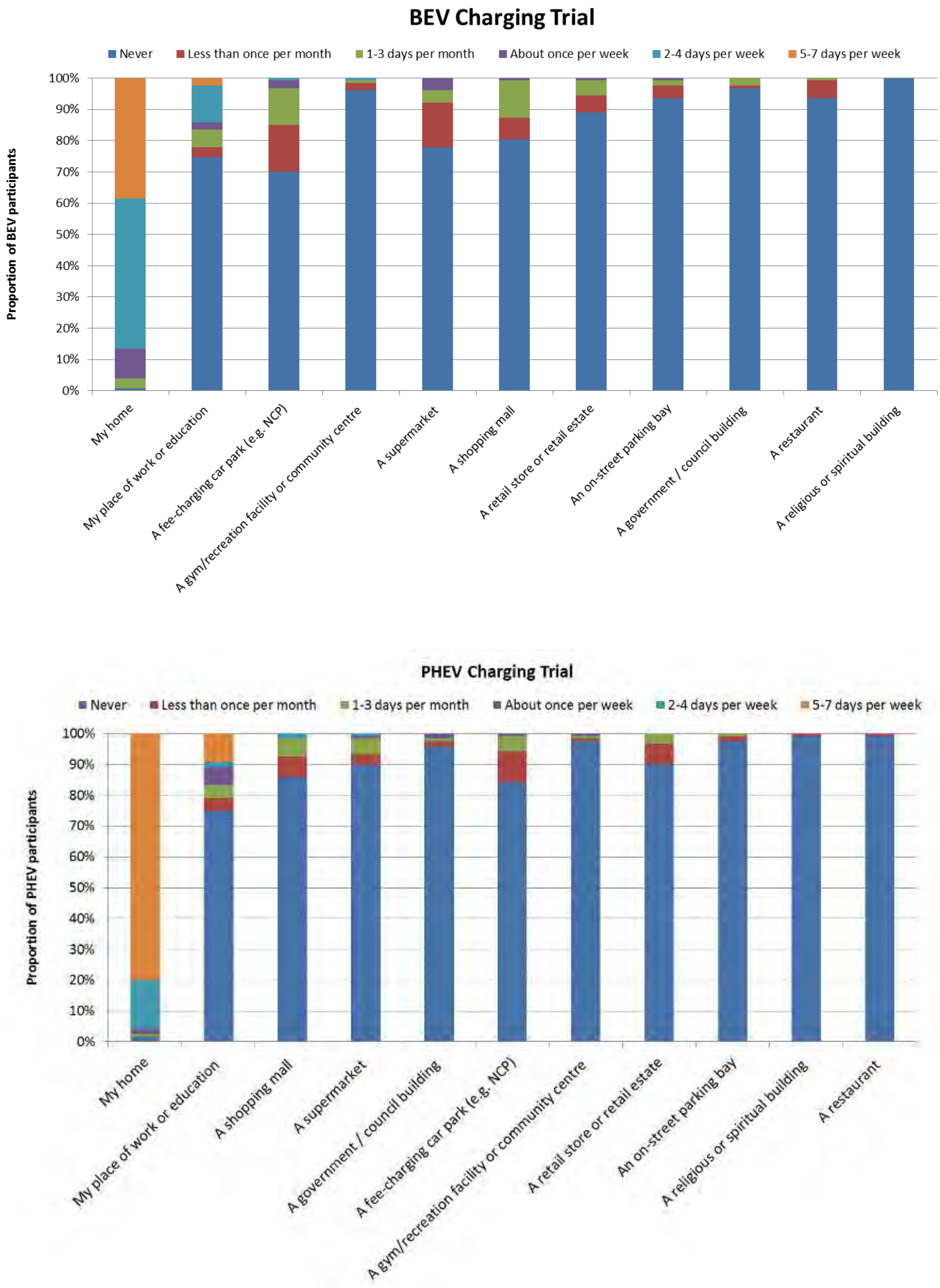


Figure 38: Self-reported frequency of charging at home and away from home (N = 248) (Top – BEV, Bottom – PHEV)

Overall, the following conclusions can be drawn from these data:

- A sub-set of the overall Mainstream Consumer sample regularly charged away from home; around 15% of sample accounted for over 50% of charges away from home, and just under 50% accounted for over 90% of charges away from home.

- There was a clear trend of most charge events away from home starting in the morning; peaking between 7am-8am for PHEV drivers and 8am-10am for BEV drivers.
- The precise location of charges away from home cannot be determined; but self-report data suggests that the place of work or education was the most common location at which drivers frequently charged away from home.

3.8 Research limitations

These Consumer Charging Trials were the first large-scale real-world trials which collected empirical PiV charging data from Mainstream Consumers with both BEVs and PHEVs. The study used a Randomised Controlled Trial (RCT) design in which Mainstream Consumer samples were given direct experience of using either a BEV or a PHEV for a period of eight weeks, yielding several key benefits: (1) it avoided PiV Innovators sample bias by recruiting Mainstream Consumer samples; (2) it ensured a sufficiently long experience with the PiVs to capture representative usage and charging behaviour; (3) it used Control groups in each trial to record the charging behaviours of Mainstream Consumer participants in unconstrained conditions, along with two Managed Charging groups to understand the relative impacts of MC schemes on charging behaviour; and (4) it minimised bias by randomly assigning participants to one of the three groups in each trial. For these reasons the data collected from these trials provides high-validity information on Mainstream Consumer PiV charging behaviours and responses to MC in the UK.

Nevertheless there were a number of limitations with the study which should be considered when interpreting the results.

As with all research with volunteer participants, the samples in the BEV and PHEV trials were inevitably biased in the sense that they were drawn from the sub-population of Mainstream Consumers who are willing to participate in research on PiV charging. While not having the same degree of enthusiasm for PiVs as Innovators, the samples may well have had a degree of bias in the direction of interest or perhaps curiosity about PiVs.

The eligibility requirements for the trial led to over- or underrepresentation of some specific groups in the population. Households with two or more cars were overrepresented in the samples; 75% of BEV participants and 80% of PHEV participants reported having two or more vehicles, compared with 35% of households in the wider population. Both samples underrepresented households with an annual income of less than £30,000, overrepresented married individuals, and underrepresented single or separated/divorced individuals. The proportion of the sample who reported high annual mileage (more than 15,000 miles) in the BEV Trial was similar to that in the NTS data, but overrepresented in the PHEV Trial. These various sample biases were likely due to the recruitment criteria for the trials. The high mileage drivers who were included in the sample were all private vehicle drivers; company car drivers, who typically have very high annual mileage, were excluded from the study for insurance reasons.

Accordingly the findings may not generalise to the entire UK car user population. In particular, households with two or more vehicles may have greater flexibility in their use of a BEV or PHEV if their other vehicle is conventionally powered. Further, the energy requirements (and therefore the charging behaviours) of drivers who travel less than 5,000 miles per annum, and company car drivers who have relatively high annual mileage, are likely to differ from the private consumers recruited for this study. In addition, the trials were limited to one model of BEV (the VW e-Golf with a 35.8kWh battery) and one model of PHEV (the VW Golf GTE with an 8.7kWh battery). Using a single model of PiV in each trial increased the validity of the charging data collected during the trials since individual charging profiles could be reliably combined across the trial samples without risk of bias due to alternative vehicle models with varying battery sizes. However, the use of only single models of BEV and PHEV do limit the generalisability of the findings to other models of PiV which may have different battery capacities. Indeed, a recent trial with PiV Innovators has reported diversity in charging behaviour associated with varying battery size, as would be expected (Electric Nation, 2018). Since vehicles with larger batteries typically have longer All-Electric Range (AER), it is possible there will be a reduced need to plug-in regularly and less need to administer a full charge; however, data are required to confirm this hypothesis.

The Consumer Charging Trials sought to replace participants' own vehicles with the trial vehicles for their everyday driving over the eight-week period. For practical reasons, it was not possible to store every participant's own vehicle for the duration of the trial. As such, participants were only requested to leave their vehicles with the research team under certain circumstances, if they did not have sufficient parking space to accommodate an extra vehicle, or if the household had more drivers than vehicles. Physically replacing their personal vehicles with the trial vehicles in these circumstances ensured that the trial did not alter household vehicle use dynamics. In addition, participants were encouraged to use the trial vehicle for their everyday travel needs. The journey and charge data suggest that all participants engaged with the trials regardless of whether they kept or stored their own vehicle. Nevertheless, it is possible that in a few circumstances in the BEV Charging Trial where journeys were on the edge of perceived AER, participants who kept their own vehicles may have chosen to use them instead of the BEV. This does not apply to the PHEV Charging Trial where range anxiety was not an issue.

Participants were permitted to allow up to one additional driver in their household to drive the trial vehicles; no more than one additional driver was permitted due to trial insurance restrictions. Telematics data was collected for all journeys and charges in all vehicles; however, classification of the data according to the specific driver in each household was not possible. Journey and charge data was therefore classed per participant, even if particular uses of the vehicle were completed by the 'additional drivers'. This means that there is a gap in knowledge of the impact of PiVs on the ways in which different household members use different vehicles in the household, and how MC requirements may differ between multi-car and multi-user households.

Charging data were collected from more than 10,000 charge events, providing a detailed understanding of Mainstream Consumer charging behaviours. The majority of charge events recorded during the trials took place at home on weekdays (around 64%). Data were also collected from charge events away from home, although these types of charge were less common during the trials, so data are available for a smaller number of events. In particular, there were only 257 BEV charges and 117 PHEV charges on weekends away from home. This limits the ability to draw robust conclusions about charging away from home on weekends, especially when comparing between experimental groups. As such, further data is required to fully understand the impact of MC schemes on charging behaviours away from home.

Choices made in the choice experiment are not necessarily representative of market behaviour in the real world, because the conditions under which choices are made in a choice experiment differ from those in which a choice is made in reality, when, for instance, real money is to be spent, or saved.

Consumers tend to be more price-sensitive when considering their own money, and under choice experiment conditions participants are being forced to choose between the options. In a real-world environment, consumers by default presently charge using unmanaged charging and so must first decide whether to even consider a Managed Charging option. Making this decision requires effort which adds disutility and thus may depress the uptake of Managed Charging. A similar effect is observed in the electricity and gas supply market, where consumers have a strong tendency to remain on a more expensive tariff despite cheaper options being available from other suppliers. Since Managed Charging is not yet an established product offering, there is no real world market data to explore the extent to which this consumer inertia affects uptake of Managed Charging. This is unlikely to be available for several years.

A further limitation of the choice experiment was that the sample size was relatively small. Whilst it was large enough to derive choice coefficients from the whole BEV and whole PHEV samples, it was not possible to derive separate coefficients for the Control, UMC, or SMC groups in each trial.

3.9 Suggested further research

This study was the first in which a choice experiment on Managed Charging was carried out with Mainstream Consumer participants who had had experience of Managed Charging. Consequently, the relative importance of the attributes selected was unknown during the choice experiment design stage. If this choice experiment was repeated, the outputs of this study would enable a more efficient design. It is also recommended that this choice experiment is repeated with a larger sample to investigate clusters of choice behaviour, and thus the extent to which this behaviour varies amongst participants. It may also be worthwhile to test choice sets where participants receive no savings or even have to pay for UMC or SMC to confirm whether the WTP of the unobserved factors of SMC and UMC remain positive.

In addition to these considerations, the findings from the Consumer Charging Trials suggest several areas for further inquiry, as detailed in Table 10.

Table 10: Suggestions for further inquiry arising from the findings of the Consumer Charging Trials

Research question	Description
What requirements do multi-car and multi-user households have for Managed Charging?	These trials were not able to segregate vehicle usage and charging data between different drivers in each household. In multi-car households, replacement of one vehicle with a PiV may change the household vehicle usage dynamics. In multi-user households who share the use of a PiV, or in households with multiple PiVs, there may be different requirements for MC schemes than single user/single PiV households. Research is required to understand the charging profiles of multi-user and multi-PiV households, how MC requirements differ between different types of household and what types of MC schemes are most effective for shifting demand in these households.
What are the most effective trigger points for encouraging adoption of Managed Charging schemes?	The Consumer Charging Trials investigated the effectiveness of using financial incentives with two types of MC scheme to shift charging behaviour. The incentives or mechanisms required to facilitate adoption of MC were not explored in depth. Future research could address how to encourage users to switch from traditional energy supply arrangements onto MC schemes, and understanding when the most effective 'trigger points' are for making the switch (for instance, at moments such as purchasing a PiV or moving house, where prior habits are known to be more easily broken). In addition, investigation of consumer attitudes towards alternative 'default' MC schemes would also be valuable; for example, one option would be for an SMC-type scheme to be the default arrangement for consumers, requiring them to 'opt out' rather than 'opt in'.
What types of Managed Charging schemes are suitable for consumers who own PiVs without off-street parking?	A large proportion of the UK population live in housing without access to private off-street parking, meaning installation of a home chargepoint is problematic. Some solutions have been proposed for this problem, for example, increasing charging infrastructure in the workplace, and installing resident charging infrastructure in street lamp-posts. Research is required to understand what types of MC scheme are suitable for these types of Mainstream Consumers who are likely to have different needs, usage patterns and logistical arrangements.

Research question	Description
To what extent can charging infrastructure at work or in public places reduce PiV charging demand in the evening peak?	A potential impact of increased charging infrastructure in public places or at office locations is a reduction in consumers' charging requirements at home. The data from this trial showed that, in unconstrained conditions, most Mainstream Consumer home charges occurred in the later afternoon and early evening weekday peak when the majority of the population are returning home from work. If consumers are able to charge at work or in public places earlier in the day, this may reduce overall charging demand in peak periods. An increase in charging infrastructure away from home could, therefore, complement home-based MC schemes by facilitating further shifts in demand away from peak periods. Further, the role of MC schemes at work or other locations away-from-home must also be considered. To understand the propensity for away-from-home charging to shift demand, detailed analysis is required of the sequences between Mainstream Consumer journeys and charges, to quantify the opportunity for charges in between different types of journeys. This analysis should also include assessment of the cost-benefit implications of providing additional charging infrastructure away from home.
PHEV usage patterns – when and why do drivers operate PHEVs on petrol vs. electric vs. hybrid power modes? What can be done to increase electric mileage?	PHEVs have been described as a "gateway vehicle". This implies their adoption by Mainstream Consumers serves to familiarise them with the nuances of owning a plug-in vehicle, and in turn increases the likelihood of future adoption of a fully-electric, zero-emission (at the tailpipe) BEV. The Consumer Uptake Trial showed that Mainstream Consumers are more likely to adopt PHEVs than BEVs in the next five years. To understand their potential impacts on the energy system in more depth, analysis of PHEV usage patterns is required to establish the factors which determine when PHEVs are driven on electric, ICE, or hybrid modes, and what can be done to increase the proportion of PHEV mileage undertaken on electric power.
Understanding the motivations behind Mainstream Consumer charging behaviours and interactions with Managed Charging	This project obtained a highly detailed set of quantitative data to understand Mainstream Consumer journey and charge patterns, along with their attitudes towards PiVs and managed charging generally. It was not possible to collect accompanying qualitative data to help to understand *why* participants behaved in particular ways during the trial – for example, why they sometimes used default charge settings, or why they sometimes choose to initiate a charge immediately following plug-in. Future exploration of the motivations behind Mainstream Consumer charging behaviours would enable a more detailed analysis of the circumstances that might influence future PiV charging demand. This could also explore the reasons why there was an overall preference for Managed Charging over no Managed Charging. This would likely require a mixed-methods research approach.

Research question	Description
What is the most effective consumer rewards system for encouraging engagement with Managed Charging?	The managed charging systems examined in this project utilised a Savings Points system whereby participants earned points for engaging with UMC or SMC, and then converting those points to a cash amount (with a fixed maximum value) at the end of the trial experience. Various examples of points-based and cash-based consumer reward systems exist in real-world propositions; for example, Nectar and Clubcard points models whereby consumers earn points for spending money in particular stores, or cashback systems whereby consumers receive money for switching to a particular high-street bank. Investigation of the most effective type of consumer reward system for encouraging adoption of, and engagement with, managed charging would inform energy suppliers, network operators, vehicle OEMs, and other third-party organisations how best to design their future consumer propositions.
To what extent do Mainstream Consumers have concerns about the impact of Managed Charging on battery health?	A potential barrier to acceptance of managed charging might be consumers' perceptions of the impact of managed charging on the long-term health of vehicle batteries. However, information about mainstream consumer perceptions of battery health impacts and issues was not obtained in this study. Future qualitative research with consumers could be undertaken to explore the extent to which consumers worry about damaging the vehicle battery, and how such concerns might impact perceptions of managed charging systems.

4 Conclusions

The key conclusions from the Consumer Charging Trials are as follows:

- In unmanaged charging conditions, participants usually charged at home in the late afternoon/early evening (3-8pm). At home, weekday charge start times in the control group peaked between 5-6pm for PHEV participants, and between 6-7pm for BEV participants. At weekends the peak in charge start events is less pronounced, with a greater share of charge start events starting earlier in the day.
- Compared with unmanaged charging, the proportion of home charge events starting between 4-7pm was more than halved in the UMC and SMC groups. The greatest reduction was observed in the SMC group. The majority of charging was shifted to later in the evening (UMC) or overnight (SMC). This effect was observed for both weekday and weekend charging.
- Managed Charging is more appealing than unmanaged charging to the majority of Mainstream Consumers who have had experience living with a PiV, even when they have not had any direct experience of Managed Charging .
- In general, after receiving information about both MC schemes at the end of the trial, participants indicated that UMC schemes have higher appeal than SMC. However, BEV drivers who have had direct experience of SMC were more likely to prefer an SMC scheme. While dependent on the wider context of the consumer offering, this suggests that experience with SMC may be important for adoption of that type of MC scheme.
- Participants in both MC conditions initiated the majority of charges using the Default settings suggesting that engagement with MC can be encouraged by making it as easy as possible for consumers. Setting new parameters following plug-in was more common in the SMC group than the UMC group; it is possible that users engage more with an SMC scheme than UMC because of the nature of the system (e.g. setting Desired SOC and Departure Time versus simply setting a charge start time).
- The key attributes which contribute to an attractive MC scheme for consumers include high annual cost savings, low peak electricity costs, and nearby public charging. Features which make SMC in particular more attractive include an override function where users can change settings for a charge event after they have been input (even if in doing so they lose all financial benefit for that event), and availability of a public charge point within five minutes drive of the users' homes (to act as a back-up in case their car is needed earlier than expected). This was particularly true for BEV drivers who, unlike PHEVs, do not have the back-up option to drive under fuel power if their batteries are not charged.
- Most charge events away from home started in the morning; peaking between 7-8am for PHEV drivers and 8-10am for BEV drivers. This contrasts with the control group home charges (which were also in unmanaged conditions), where peaks were observed between 5-6pm for PHEVs and between 6-7pm for BEVs. Self-report questionnaire data suggests that a large proportion of these morning charges away from home were at participants' places of work or education. Weekday charge events away from home were more likely to start overnight or in the early morning, compared with weekend charge events.

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Deliverable D5.3 - Consumer Charging Trials Report: Mainstream consumers’ attitudes and behaviours under Managed Charging schemes for BEVs and PHEVs

Other titles from this subject area

PPR918	Deliverable D5.3: Consumer Charging Trials: Technical Appendix. TR1006_D5.3_A
PPR899	Deliverable D5.2: Consumer Uptake Trial: Summary Report. TR1006_D5.2
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PROJECT REPORT

Consumers, Vehicles and Energy Integration
Project PPR918

Deliverable D5.3 - Consumer Charging Trials Report: Technical Appendix

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Disclaimer

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Abbreviations

AC	Alternating Current
ACEA	European Automobile Manufacturers' Association
AER	All Electric Range
ALARP	As Low As Reasonably Practicable
ANOVA	Analysis Of Variance
API	Application Programming Interface
BACS	Bankers' Automated Clearing System
BEAMA	British Electrotechnical and Allied Manufacturers' Association
BEV	Battery Electric Vehicle
BIK	Benefit-in-Kind
BIT	Behavioural Insights Team
CAN	Controller Area Network
CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Standardization
CLASS	Customer Load Active System Services
CNG	Compressed Natural Gas
CPAT	Commercial Policy and Accounting Tool
CPMS	Chargepoint Management System
CSM	Charge Station Manager
CTL	Control group
CVEI	Consumers, Vehicles and Energy Integration project
DC	Direct Current
Defra	Department for Environment Food and Rural Affairs
DfT	Department for Transport
DM	Demand Management
DNO	Distribution Network Operator
DSR	Demand Side Response
DUoS	Distribution Use of System
DVLA	Driver and Vehicle Licensing Agency
ECCo	Electric Car Consumer
EE	Element Energy
EOBD	European On-Board Diagnostics

ESME	Energy System Modelling Environment
ESOS	Energy Savings Opportunity Scheme
EV	Electric Vehicle (including all plug-in vehicles)
EVSE	Electric Vehicle Supply Equipment
ETI	Energy Technologies Institute
FCV	Fuel Cell Vehicle
FIPS	Federal Information Processing Standard
FTP	File Transfer Protocol
GB	Great Britain
GEE	Generalised Estimating Equations
GPS	Global Positioning System
HAZID	Hazard Identification
HEV	Hybrid Electric Vehicle
IC-CPD	In-Cable Control and Protective Device
ICE	Internal Combustion Engine
ID	Identification
IEC	International Electrotechnical Commission
IEE	Institution of Electrical Engineers
IMS	Integrated Management System
IPIP	International Personality Item Pool
IQR	Interquartile Range
ISO	International Organization for Standardization
KPH	Kilometres per Hour
LD	Light Duty
LPG	Liquified Petroleum Gas
MC	Managed Charging
MCAR	Managed Charging Availability Ratio
MCB	Miniature Circuit Breaker
MDSI	Multi-Dimensional Driving Style Inventory
MCPT	Macro Charging Point Tool
MHDT	Macro Hydrogen Distribution Tool
NICEIC	National Inspection Council for Electrical Installation Contracting
NEDC	New European Driving Cycle
NMC	Unmanaged Charging

NTS	National Travel Survey
OBD	On-Board Diagnosis
OCPP	Open Chargepoint Protocol
OEM	Original Equipment Manufacturer
ONS	Office for National Statistics
OSGR	Ordnance Survey Grid Reference
PHEV	Plug-in Hybrid Electric Vehicle
PIA	Privacy Impact Assessment
PiV	Plug-in Vehicle
PM	Project Manager
RCD	Residual Current Device
RCT	Randomised Controlled Trial
RE-EV	Range-Extended Electric Vehicle
RFQ	Request for Quotation
RPM	Revolutions Per Minute
SMC	Supplier-Managed Charging
SMMT	Society of Motor Manufacturers and Traders
SMS	Short Message Service
SOC	State of Charge
SOH	State of Health
SQL	Structured Query Language
SQS	Simple Queue Service
SToU	Static Time of Use
TCO	Total Cost of Ownership
TNUoS	Transmission Network Use of System
TOU	Time of Use
TP1	Time Point 1
TP2	Time Point 2
TRL	Transport Research Laboratory
UF	Utility Factors
UK	United Kingdom
ULEV	Ultra-Low Emission Vehicle
UMC	User-Managed Charging
VAT	Value Added Tax

VDC	Vehicle Data Collector
VGL	Volkswagen Group Leasing
VKT	Vehicle Kilometres Travelled
VW	Volkswagen
VWFS	Volkswagen Financial Services
WP	Work Package
WTP	Willingness-to-pay

Glossary

Item	Description
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 future scenarios to help understand what ‘good looks like’ for mass market deployment and use of ULEVs. The framework comprises various analytical tools relating to vehicle adoption and the energy system which are used to help inform the quantitative assessment as well as a set of supporting qualitative assessment metrics.
Attitudes (affective)	The emotions and feelings evoked by owning and using a vehicle.
Attitudes (instrumental)	Attitudes towards factors relating to general practical or functional attributes of driving a vehicle.
Attitudes (symbolic meaning)	What the vehicle says about its owner/driver in terms of social status, social conscience and personal values.
Battery Electric Vehicle (BEV)	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.
Consumer segments: 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.
Consumer segments: Early adopters	Those who adopt after Innovators, and only after awareness, knowledge, and positive attitudes have diffused to them from Innovators. Times to adoption are between one and two standard deviations before the mean time to adopt.
Consumer segments: Mainstream consumer	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. Includes everyone except innovators.
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.
Managed charging	This refers to the management (by users or systems) 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.

Norms (injunctive)	Perceptions of what other group members (e.g. family group, friendship group) approve or disapprove of.
Norms (descriptive, or behavioural)	Perceptions of what other group members you associate with actually do.
Norms (personal)	Perceived obligations to act in a way consistent with personal views and previous behaviour.
Norms (provincial)	The same as injunctive norms but more specifically referring to other people who live under similar conditions such as in the same locality.
Norms (social)	Informal understandings that influence the behaviour of members of a group, or wider society.
Plug-in Hybrid Electric Vehicle (PHEV)	A vehicle that is equipped so that it may be powered both by an external electricity source and by liquid fuel.
Range-extended Electric Vehicle (RE-EV)	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 you see yourself and how one perceives others see them.
Ultra Low Emission Vehicle (ULEV)	A vehicle that emits less than 75gCO_2/km.

Appendix A Detailed method

This Appendix provides a full description of the method employed for the Consumer Charging Trials. A summary of the method is provided in the accompanying Summary Report.

A.1 Overview of experimental design

Two separate trials were conducted:

- a PHEV Consumer Charging Trial to investigate the charging behaviours, attitudes and responses of mainstream consumers living with a PHEV, and;
- a BEV Consumer Charging Trial to investigate the charging behaviours, attitudes and responses of mainstream consumers living with a BEV.

Participants were recruited for the two trials from the 50-mile radii surrounding the head offices of TRL (Crowthorne, Berkshire) and Cenex (Loughborough).

Each trial adopted a between-participants Randomised Controlled Trial (RCT) design, in which participants were randomly allocated to one of three groups:

1. a User-Managed Charging (UMC) group, in which participants were incentivised to actively shift their charging to periods of generally favourable supply-demand balance, through a banded tariff structure;
2. a Supplier-Managed Charging (SMC) group, in which participants were encouraged to relinquish control of their charging to a simulated energy supplier in exchange for consequent savings on overall charging cost, or;
3. a Control Group, in which participants were free to charge their vehicles as they wished, in unmanaged charging conditions.

The UMC and SMC groups were further divided into “Winter” and “Summer” sub-groups; the Savings Points system differed between these two sub-groups allowing for examination of the effect of two alternative reward levels. The control group was not split into “Summer” and “Winter” sub-groups like the UMC and SMC groups, because all participants in the control group experienced the same reward structure. The reward points system is explained in full in section A.8.

The target location of participants across all the trial groups is shown in Table 1.

Table 1: Target allocation of participants across experimental groups and sub-groups

Group	BEV Charging Trial			PHEV Charging Trial		
	Summer	Winter	Total	Summer	Winter	Total
Control	n/a	n/a	**40**	n/a	n/a	**40**
Supplier-Managed Charging (SMC)	20	20	**40**	20	20	**40**
User-Managed Charging (UMC)	20	20	**40**	20	20	**40**
Totals			**120**			**120**

Participants took part in one of four trial blocks which ran consecutively from November 2017 to September 2018. Participants were spread approximately evenly across Control, UMC and SMC groups within each block. To broadly align with the real-world seasons, the Winter sub-groups took part during Block 1 and 2 (approximately November-April) and the Summer sub-groups took part during Block 3 and 4 (approximately May-Sept).

Participants were given access to a smartphone app which linked with their home chargepoint and the trial vehicle. For control group participants, this provided a simple interface which showed them the status of their home chargepoint (i.e. not connected, connected, charging) and the current SOC of their vehicle (0-100%). For the UMC and SMC participants, the app provided a mechanism for participants to engage with the Managed Charging scheme. In the case of UMC participants, the User App allowed them to either choose to start charging immediately, or to choose the time at which their vehicle started (and stopped, if they wished) charging. In the case of the SMC participants, the User App allowed them to choose to start the charge immediately, or to set their desired SOC and the departure time at which they needed the vehicle next and allow the supplier to manage the charge for them. Further details about the User App are provided in section A.10.

Participants in both trials were given a plug-in vehicle for a period of 8 weeks to use for their normal day-to-day journeys. Participants in the PHEV Consumer Charging Trial were given a VW Golf GTE hatchback 1.4 TSI 5dr (either 2016 or 2017 model); participants in the BEV Consumer Charging Trial were given a VW e-Golf hatchback 5dr (2017 model) (see section A.5.1). The trials sought to replace participants' own vehicles with the trial vehicles for their everyday driving over the 8-week period. For practical reasons, it was not possible to replace and store every participant's own vehicle for the duration of the trial. Instead, participants retained their own personal vehicles in most cases, except for circumstances where they were asked to leave their vehicles with the research team:

1. Where the number of drivers exceeded the number of vehicles in the household.
2. Where there was insufficient off-street parking to accommodate an additional vehicle.

This resulted in a total of 98 participants storing their personal vehicle with the research team (approximately 40% of the sample).

Incentives for taking part were given in the form of compensation for their time (via Amazon vouchers) and reward points for engaging in particular charging behaviours (depending on which experimental group they were in). The total value of the reward package was £250 per participant. In addition to the fixed compensation and incentives, participants were entered into a prize draw for a chance to win £2,500.

Participants were asked to complete a series of questionnaires during the trial:

- **Recruitment Filter Surveys**: screening questionnaires administered during the recruitment process
- **Pre-trial questionnaire:** administered following receipt of participant's consent to take part
- **Time Point 1 questionnaire**: administered before the trial vehicle was collected
- **Time Point 2 questionnaire**: administered after the return of the trial vehicle

Data from a vehicle telematics dongle connected to the OBD-II port and data from the chargepoint in participants' homes were collected during trial. These data provided information on how participants used and charged the vehicles. In addition, usage and preference data was obtained from the chargepoint management system.

An overview of the methodology for the two Consumer Charging Trials is illustrated below.

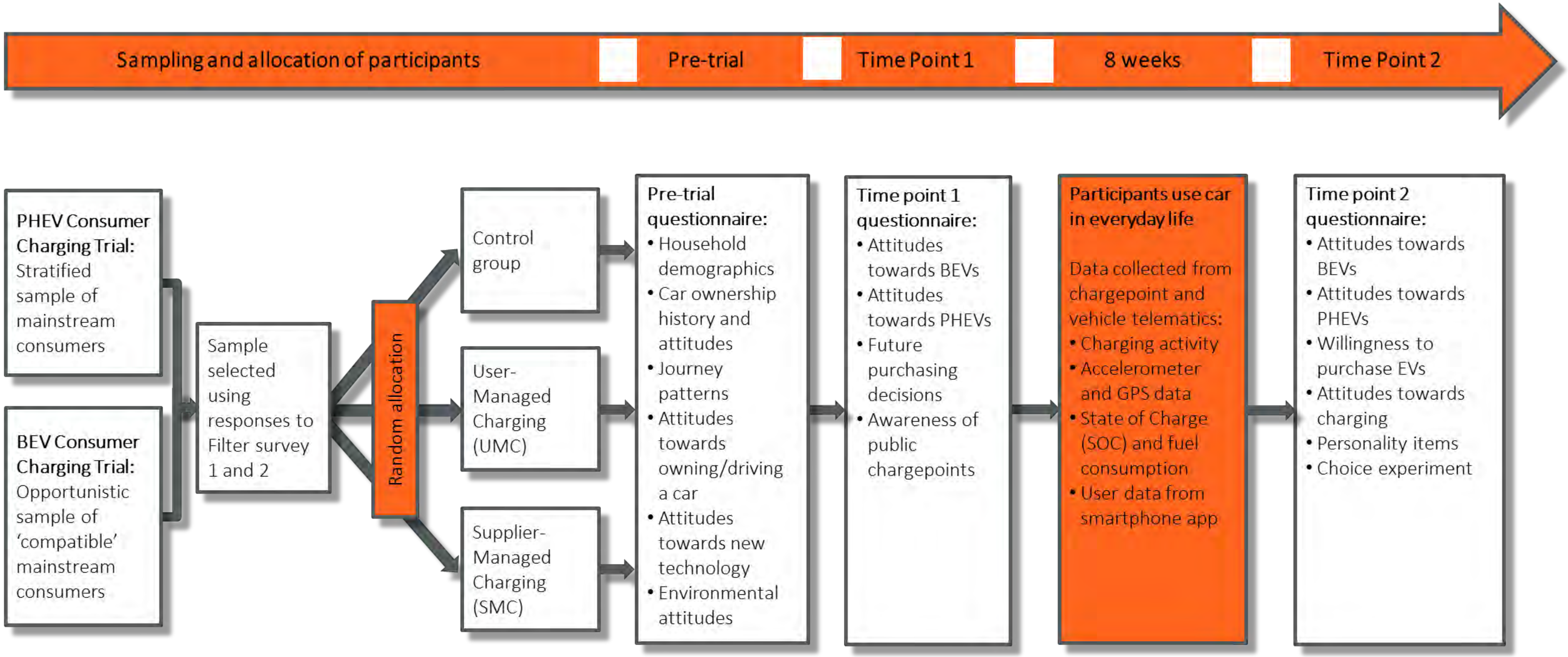

Figure 1: Overview of methodology for Consumer Charging Trials

A.2 Research questions

The research questions addressed by the Consumer Charging Trials, and the sources of data used to answer the questions, are shown in Table 2.

Table 2: Research questions and data sources

Consumer Charging Trials research questions	How will the research questions be addressed?			
	Questionnaires	Choice Experiment	Telematics/ chargepoint data	App data
1. What is the charging behaviour of mainstream consumers when not participating in a Managed Charging scheme?			✓	
2. How does the charging behaviour of mainstream consumers when participating in a Managed Charging scheme compare with their behaviour when they are not?			✓	
3. How does the charging behaviour of mainstream consumers when participating in a Supplier-Managed Charging scheme compare with their behaviour when participating in a User-Managed Charging scheme?			✓	
4. What are the diurnal, weekly and seasonal time profiles of charging when participating (or not) in a given Managed Charging scheme?			✓	
5. What are the between-participant variabilities in Mainstream Consumer charging behaviour when participating (or not) in a given Managed Charging scheme?			✓	
6. How does charging behaviour vary with time over the first eight weeks of using and charging a PiV, whether participating in a Managed Charging scheme or not?			✓	
7. How do mainstream consumers interact with specific features of User- and Supplier-Managed Charging?				✓
8. What preferences do mainstream consumers have between Supplier-Managed Charging, User-Managed Charging, and no Managed Charging?	✓	✓		
9. What factors influence preferences between Supplier-Managed Charging, User-Managed Charging, and no Managed Charging?	✓	✓		
10. What are the impacts of different User-Managed Charging tariffs and Supplier-Managed Charging schemes on a Consumer's likelihood to participate in these arrangements?		✓		
11. What are the impacts of different User-Managed Charging tariffs and Supplier-Managed Charging schemes on the likelihood of car buyers choosing a PHEV/BEV over other powertrains?	✓			

A.3 Participant sample

The trials aimed to recruit a total of 240 mainstream consumer participants (120 participants for the BEV Consumer Charging Trial and 120 for the BEV Consumer Charging Trial).

Mainstream consumers were defined as all of those whose adoption of technology has been influenced by diffusion of awareness, knowledge, and positive attitudes from people who have already adopted the innovation. This includes all consumers in Rogers' (2003) Diffusion Model segments except for Innovators; that is the Early Adopter, Early Majority, Late Majority, and Laggard segments (see Figure 2).

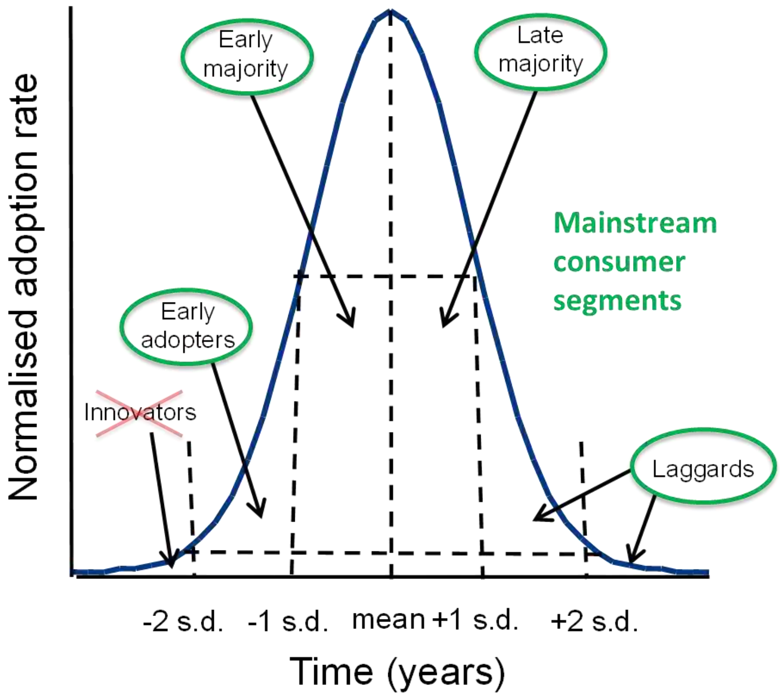

Figure 2: Segments from Rogers' (2003) Diffusion Model which are included in the 'mainstream consumer' population

Innovators were excluded at the recruitment phase. Innovators were defined behaviourally as individuals who currently have, or have had regular driving experience with a plug-in vehicle in the last 5 years, and those who were currently considering acquiring a plug-in vehicle in the next six months. In addition to this, employees of TRL, Cenex, and the ETI were also excluded from the sample due to the possibility that they might have a particular interest in PiVs by virtue of their employment.

All participants were recruited from within a 50-mile radius of TRL (RG40 3GA) and Cenex (LE11 3QF). There was an approximate 50/50 split between the two trial locations.

Due to the differences in the utility of PHEVs and BEVs, the two trials utilised different sampling techniques; these are discussed in the following sections.

A.3.1 *BEV Charging Trial*

At the time of designing the trial, the current model of VW e-Golf hatchback (2016-model) had a manufacturer-reported NEDC electric range of 118 miles (the updated 2017-model eventually used in the trial had an NEDC range of 186 miles). With realistic everyday use, this stated range equated to an actual electric range of between 80 and 90 miles. Due to their limited range, BEVs such as this are only objectively suitable as substitute vehicles for a sub-set of the mainstream consumer segment; that is, those whose travel patterns are consistent with the restricted range of approximately 80 miles. The sub-set of mainstream consumers for whom the e-Golf is *subjectively* suitable (i.e. those who themselves perceive that it would meet their needs) may be even smaller.

For these reasons the travel needs of many individuals in the mainstream consumer population will not be met by the VW e-Golf, or other comparable BEVs on the market. The target sample for the BEV Consumer Charging Trial was therefore defined as 120 mainstream consumers whose vehicle needs were met by the current capabilities of BEVs available in the market at the time of the trial. This group were called "compatible mainstream consumers" – that is, mainstream consumers for whom the vast majority of return journeys are shorter than 80 miles.

Recruitment of 120 compatible mainstream consumers required an opportunistic sampling approach. This technique involved recruiting interested individuals from the target population who met the travel pattern (and other) eligibility criteria (see section A.3.3). With the opportunistic sampling approach, there was less opportunity to stratify the sample by other factors such as age, gender and location (as was done in the PHEV Consumer Charging Trial – see section A.3.2).

A.3.2 *PHEV Charging Trial*

The target sample for the PHEV Consumer Charging Trial was 120 mainstream consumers.

Unlike the BEV Charging Trial, the utility of the VW Golf GTE (PHEV) meant that the vehicle was objectively suitable for all mainstream consumers who currently drive a car, so there were no special eligibility criteria for the PHEV Charging Trial. To ensure that the PHEV Charging Trial sample was representative of the driving population in Great Britain, a stratified sampling approach based on driving licence data from the Driver and Vehicle Standards Agency (DVSA), and population and travel data from the National Travel Survey (NTS) and the Office of National Statistics (ONS) was used (see Table 3).

Table 3: Target sample matrix for the PHEV Consumer Charging Trial, stratified using DVSA, NTS and ONS data

Resident area[1]	Age group[2]	Gender		Total
		Male	Female	
Rural	19-29	1	1	**2**
	30-49	4	4	**8**
	50+	7	6	**13**
Urban	19-29	9	7	**16**
	30-49	20	18	**38**
	50+	23	19	**42**
Total		**64**	**56**	**120**

A.3.3 *Recruitment*

A filtering process was employed to select eligible participants and exclude ineligible participants; this is described below, and illustrated in Figure 3. The initial stages of the recruitment process were common to both the Consumer Uptake Trial (reported in Deliverable D5.2) and the Consumer Charging Trials.

- **Advertise**: A variety of advertisements were published via different channels to reach a wide variety of prospective participants.
- **Step 1**: Interested prospective participants completed Filter Survey 1 to register their interest, using the URL provided in the advertisements.
- **Step 2**: Prospective participants who were eligible (based on responses to Filter Survey 1) were invited to complete Filter Survey 2; a short but more detailed questionnaire to further filter prospective participants and assess suitability specifically for each trial.
- **Step 3**: Prospective participants who were eligible (based on responses to Filter Survey 2) were invited to participate in the trial. In cases where an eligible prospective participant fit into a stratified category that was already full, they were asked if they would be happy to be kept on a reserve list.

Prospective participants were not informed about the nature of the trial until Step 2 so as to avoid biasing the recruitment towards people interested in low carbon vehicles.

[1] The 2011 rural-urban classification (RUC2011) from the Office for National Statistics (ONS) was used to define the rural/urban classification:

https://www.ons.gov.uk/methodology/geography/geographicalproducts/ruralurbanclassifications/2011ruralurbanclassification

[2] 17-18 year olds were excluded to mitigate known increased crash risk associated with young and novice drivers.

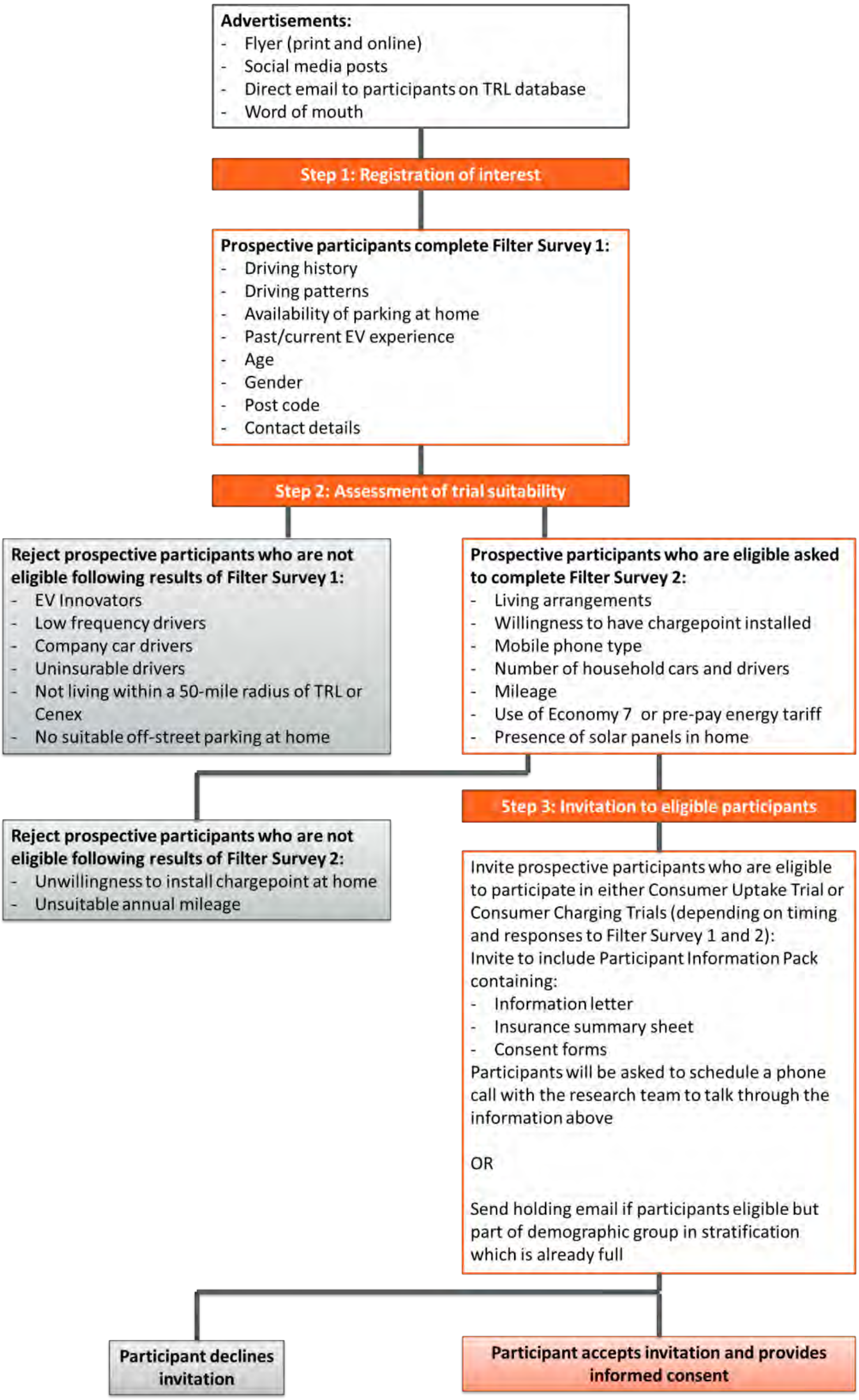

Figure 3: Overview of recruitment process up to the point of trial invitation

A.3.3.1 *Step 1: Registration of interest*

Prospective participants were asked to complete Filter Survey 1. To avoid attracting interest from PiV enthusiasts – in particular, Innovators – Filter Survey 1 contained minimal information about the design and aims of the research. The survey provided information about the incentives and the trials' contact email address, and questionnaire items covering essential information to filter out unsuitable prospective participants, including: Innovators, low frequency drivers, company car drivers and uninsurable drivers.

Eligible prospective participants were contacted by email informing them that they might be suitable and inviting them to progress to Step 2. Two reminder emails were sent to prospective participants who did not complete Step 2 in the two weeks after the initial invite email.

A.3.3.2 *Step 2: Assessment of trial suitability*

Step 2 of the process was used to further assess trial suitability using Filter Survey 2. Filter Survey 2 contained a more detailed questionnaire to obtain data on living arrangements, practicability of chargepoint installation, smartphone ownership, the number of cars and drivers within the household, annual mileage, and household energy use.

Filter Survey 2 also included an outline of both trials on the cover page to ensure prospective participants could indicate informed interest at this stage in the process. The survey also allowed prospective participants to indicate if they had a preference for participating in either trial (Consumer Uptake Trial or Consumer Charging Trials).

Completion of the Filter Survey 2 questionnaire provided the research team with sufficient information for assessing prospective participants' suitability for the Consumer Charging Trial:

- **General suitability criteria:**
    - Must live within 50 miles of the TRL or Cenex headquarters
    - Must not currently own, have previously owned or had previous regular experience driving a PiV in the last five years
    - Must not be considering acquiring a PiV in the next six months
    - Must have held a valid UK driving licence for a minimum of two years
    - Must have received no penalty points if under 25 OR no more than 3 penalty points if aged 25 and over[3]
    - Must not have had an 'at fault' insurance claim in the last three years

[3] According to data from the DVLA, the proportion of drivers with more than 3 points on their licence is 1.7%. New drivers (of whom 70% are aged 17-25 years) are impacted by the New Drivers Act which restricts them to a maximum of 6 points within the first two years of gaining a full driving licence. Introduction of the Act has been associated with a reduction in the proportion of young drivers with penalty points. Approximately 10% of new drivers commit a violation within the first two years of licenced driving; implying that around 90% of drivers under 25 will have no points on their licence. As such, the effect of these insurance conditions on the representativeness of the sample was minimal.

  - Must be a current car owner
  - Must drive regularly (at least once every two or three days)
  - Must not have a company car as their main vehicle
  - Must not require Class 2 or 3 business insurance for their vehicle (i.e. does not require business travel beyond regular commute to work and occasional trips to external locations, such as for meetings)
  - Must have access to off-street parking at a location where a chargepoint could be installed safely
  - Must be willing to have a chargepoint installed in a suitable location

- **Other information required for the purposes of sample stratification:**
  - Age group
  - Gender
  - Postcode (for urban/rural classification)
  - Living arrangements (home owner[4], living with parents etc.)
  - Number of drivers in the household
  - Number of cars registered at the household address
  - Contact details (name, email address, and contact number)

A.3.3.3 *Step 3: Invitation to participate*

Step 3 in the recruitment process involved inviting eligible prospective participants to participate in the Consumer Uptake Trial, BEV Consumer Charging Trial or PHEV Consumer Charging Trial, depending on their responses to Filter Survey 1 and 2 and the spaces within the target samples for each trial.

Once a prospective participant had been allocated to the Consumer Charging Trials, they were sent an invitation to participate by email. As part of the invitation to participate, prospective participants were sent a Participant Information Pack containing:

- An information letter providing a description of the trial
- A description of the key terms and conditions of the vehicle insurance policy
- The consent form and a link to a webpage where the consent form can be completed online

[4] Home owners were preferred over tenants where multiple potential participants were available within sampling categories to ensure they were able to consent to chargepoint installation.

A.3.3.4 *Exclusion points*

In line with ethical practice, participants were free to withdraw from the trial at any time without giving a reason. There were also circumstances where participants were deemed unsuitable by the research team, these included:

- **Uninsurable drivers**
    - All drivers were requested to provide permission for TRL to electronically access their DVLA records to ensure that their licence was valid and met trial insurance requirements in terms of penalty points, violations and time held. Participants who did not meet the insurance criteria were unable to continue in the trial. No drivers failed the DVLA checks.
- **Household unsuitable for installation of chargepoint**
    - Prior to installation of the chargepoint, they checked the property was suitable for safe installation of the chargepoint. Where no safe or suitable installation was possible the participant was unable to continue in the trial. The number of participants who completed each step in the trial process is shown in Figure 4; this includes a record of the number of installations which were not completed successfully, and why.
- **Unsafe or illegal driving**
    - Vehicle familiarisation drives with a TRL or Cenex staff member were completed at vehicle handover. The purpose of these drives was to allow the participant to become familiar with the vehicle and to check that the participant was able to control the vehicle safely. There were no cases where the participant was withdrawn after the familiarisation drive.

A.4 Trial procedures

The trial procedure was standardised to minimise any potential bias resulting from the use of two locations (TRL and Cenex). TRL ran a training workshop with all vehicle handover staff (including those from TRL and Cenex) prior to commencing the pilot[5] (and again following the pilot), which included specific training on the vehicles from VW representatives, a full safety briefing, and training on how to brief participants and manage vehicle handovers. Refresher training sessions were also conducted mid-way through the trials. This ensured that all staff involved in the trial procedure were fully briefed and informed. As a further check, a TRL researcher attended the first few trial days at Cenex to ensure consistency across the two trial locations.

The trial procedure is illustrated in Figure 4; this also shows the number of participants who were involved at each stage of the process.

[5] A pilot was run with seven participants. These participants completed an identical, but shortened trial procedure as the full trials; their trial lasted for one week rather than eight weeks. This enabled a full practice run to ensure all aspects of the trial procedure were fully tested before commencing with the trials for real.

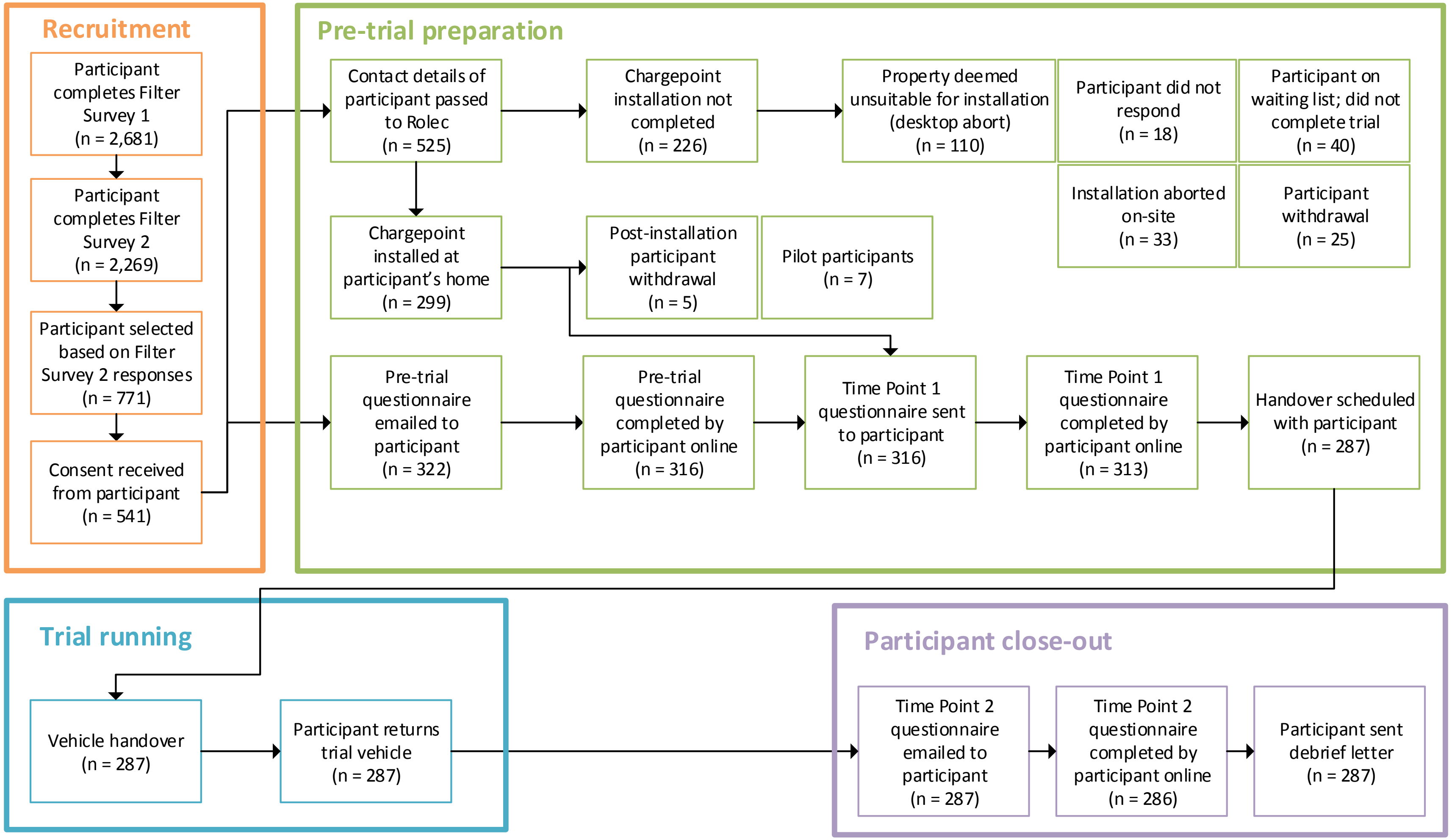

Figure 4: Trial procedure

The following sections provide a more detailed description of each stage of the trial procedure.

A.4.1 *Pre-trial preparation phase*

A.4.1.1 *Installation of chargepoints*

Mode 3 chargepoints were installed by experienced professional contractors, trained by and working on behalf of the manufacturer of the chargepoint. Installations were only completed after a participant survey and/or site inspection had taken place with the participant to make sure their property was suitable. Around 140 households were deemed unsuitable for installation following this survey (see Figure 4).

The reasons for this included:

- Isolation switch required
- Household already at maximum demand
- No spare ways on consumer board
- Groundworks required
- Landlord only gave permission for installation in garage and garage consumer board incompatible
- Main fuse needed to be upgraded
- Old style fuse board not compatible

All installations were also preceded by a dynamic on-site risk assessment. These assessments were carried out with the participant to inspect the area of works and to identify any unreported hazards in order to ensure that:

a) all hazards were captured sufficiently

b) suitable control measures were identified that mitigated the risks and were agreeable with the participant

c) suitable control measures were implemented where possible (e.g. participant moving household items to allow safe access to the fuse box and sufficient work space for the engineer to use their equipment safely)

In addition, an abort arrangement was setup with criteria to determine when it was not safe to undertake installation. The abort arrangement was an agreed process between ChargedEV, Rolec and TRL to carry out certain steps when one or more of the predefined abort criteria were met. Those steps included:

1. Engineer informs householder of requirement for abort and reason(s) why and participant signs a form which outlines why the install was aborted
2. Engineer informs ChargedEV office staff of abort and reason(s) why
3. Information cascaded down to TRL who accept or reject abort decision based on the information provided by ChargedEV

At the end of the trial, participants were given the option of keeping the chargepoint, or having it removed and any rectification work required undertaken, at no cost to them. Seven participants chose to have the chargepoint removed; the remainder of the sample chose to keep the chargepoint.

A.4.1.2 *Scheduling vehicle handovers*

Once confirmation had been received from Rolec that the chargepoint had been successfully installed at a participant's home, the participant was contacted by the research team in order to schedule vehicle handovers.

As described in section A.1, the full sample of 248 participants was achieved by splitting the trial schedule into 4 'blocks' (see Table 4).

Table 4: Trial blocks

Block	Dates when block was scheduled	Number of participants completed in block
1	22/11/17 to 23/02/18	55
2	12/02/18 to 17/05/18	71
3	16/04/18 to 19/07/18	62
4	05/06/18 to 07/09/18	60
Total		**248**

Participants took part within each block over a period of 8 weeks, with the exception of Block 1 in which participants were given a total of 9 weeks with the vehicle. This was because Block 1 ran over the Christmas period and so the block was extended by one week to counter any 'atypical' data collected during Christmas week (25th – 31st December 2017).

The block structure was used to facilitate the sequencing of vehicles to participants at each location, and to ensure there was sufficient time contingency (at least 2 days) between when a vehicle was returned by one participant and when it had to go out to the next participant.

A.4.1.3 *Pre-trial and TP1 questionnaires*

Once participants' vehicle handovers had been scheduled, they were sent links to the Pre-Trial Questionnaire (PTQ) to complete in their own time, but before they collected the vehicle. Once the completed PTQ had been received by the research team, participants were sent the Time Point 1 (TP1) questionnaire, for completion in the week preceding their first handover. As part of the handover procedure, the research team checked that both questionnaires had been completed prior to participants taking away the vehicle. The questionnaires are discussed in more detail in section A.11.

A.4.2 *Trial running phase*

A.4.2.1 *Vehicle handovers*

This section describes the standardised vehicle handover process which was used.

Vehicle handover

1. Participants arrived at trial headquarters (TRL or Cenex) at the date and time specified and were met by a researcher.

2. If participants were storing their personal vehicles with the research team for the duration of the trial, they were directed to a secure parking space[6]. A researcher then accompanied the participant on a walk-around of their personal vehicle to ensure that the existing condition of the vehicle, including any damage, was noted. If necessary, photos of the vehicle were taken and saved in the secure project area. The mileage of the vehicle was also recorded. The participant signed a form confirming the current condition of their vehicle. A key tag with the vehicle details was attached to the participant's key, and the key was stored in a secure location.
3. Participants were asked to show their driving licence to verify validity, the types of vehicles that the participant could drive, and any penalty points or disqualifications. Participants were also asked to provide another form of ID to confirm their identity and address (e.g. utility bill or bank statement). If a participant wished to add an additional driver in the household to the insurance they were also required to provide the additional driver's licence and proof of address.
4. Participants undertook an eyesight test, to check their eyesight was to the standard required for safe driving.
5. All licence and eyesight checks were passed by participants; they were then subsequently given a trial briefing by the researcher. The briefing covered background information about the trial, what was expected of the participant and points regarding health and safety.
6. Participants then completed a walk-around inspection of the trial vehicle condition, including an interior inspection, with the researcher. The condition of the vehicle and any existing damage was noted on a vehicle condition form.
7. Researchers provided participants with an explanation of the vehicle controls and key features. Researchers followed a set protocol in order to ensure that information given to participants was standardised and accurate.
8. Participants were familiarised with the features and controls unique to the BEV and PHEV vehicles. They were also given a demonstration of how to access the charging port on the vehicle, locate the charging cable, how to safely plug in the charging cable at both the vehicle and chargepoint ends, and how to remove the charging cable on completion of charging. Researchers made sure that BEV and PHEV participants were familiar with the in-vehicle displays of battery SOC and range. This also included providing them with information on the AER of the vehicle and the likely impact when operating it under various driving conditions (e.g. urban driving vs. motorway driving).
9. Participants were briefed on the reward points system (see section A.8); for participants in the UMC and SMC experimental groups this also included a full demonstration and explanation of the smartphone app.

[6] 98 participants stored their personal vehicle with the research team (approximately 40% of the sample). For participants who did not store their personal vehicle with the research team, odometer readings from their vehicle were requested at the start and end of the trial with the aim of deterring participants from utilising their own vehicles during the trial period.

10. On completion of the vehicle briefing, participants were asked to take the vehicle for a short familiarisation drive, accompanied by a researcher, to ensure they understood how the vehicle operates and were comfortable driving the vehicle. The familiarisation drive also gave the researcher the opportunity to appraise the driving of the participant and assess whether it could be considered unsafe, or if any illegal manoeuvres were performed.
11. On completion of a successful familiarisation drive the participant was issued with an In-vehicle Information Pack containing key information about how the vehicle operated, how to charge it, health and safety information, and a list of key contacts, including what to do in the event of a breakdown or incident.
12. The PHEV trial vehicles were given to participants with a full tank of fuel. Both the BEV and PHEV vehicles were given out with an SOC of at least 80%. Participants were asked to return the vehicles with the same amount of fuel, and as much charge as possible.
13. On completion of all briefing and handover activities, the participant was given the opportunity to ask any questions and then sign a consent form. Researchers assigned participants to their vehicle on the trial's 'Admin Portal'[7].
14. Participants took the vehicle away for use during their normal day-to-day activities for a period of 8 weeks (9 weeks for Block 1 participants).

Return of vehicle

1. Participants returned the vehicle to TRL/Cenex at a pre-arranged time at the end of the trial period. Participants were met by a researcher who accompanied them on a walk-around of the vehicle, and interior inspection, to check the returned condition against the condition of the vehicle when it was taken away. If there was any new damage to the vehicle this was recorded and the participant was encouraged to provide an explanation. If the damage required repair, the participant was notified that they may be liable for any costs up to the agreed maximum excess.
2. The researcher recorded the mileage, fuel level and charge level of the vehicle (as applicable), and checked all original equipment (owner's manual, first aid kit, locking wheel nut, and charge cables) was still with the vehicle.
3. The researcher then unassigned participants from the vehicle on the Admin Portal.
4. Where applicable, participants were shown to their personal vehicle by a researcher who accompanied them on a walk-around of the vehicle, and interior inspection, to check the current condition against the condition of the vehicle when it was first brought in by the participant. If there was any new damage to the vehicle this was recorded and the participant notified that an investigation would be undertaken. The participant was notified that TRL would organise and cover the costs of repairing any damage.
5. The researcher logged the date and time of collection of the participant's personal vehicle along with the Participant ID.

[7] A web portal used for managing the allocation of vehicles to participants during the trial.

6. Participants were notified that the final questionnaire (Time Point 2) would be sent to them by email within one week and that upon completion they would receive their final payment.

A.4.2.2 *Vehicle safety checks and cleaning*

Between vehicles being returned by one participant and being collected by the next (in between blocks), safety checks were performed on the vehicles. Safety checks covered items such as tyre wear and condition, seatbelt functioning, lights, and oil, coolant and washer fluid level. All vehicles were also given an interior and exterior valet by a third-party valet company between each block.

A.4.3 *Participant close-out phase*

A.4.3.1 *TP2 questionnaires*

Once participants' had completed their trial and returned the vehicle they were sent a link to the Time Point 2 (TP2) questionnaire; participants were asked to complete the questionnaire within one week of returning the vehicle.

A.4.3.2 *Participant debrief*

Following return of the vehicle, the reward points which participants accumulated over the course of the trial (see section A.8) were converted to cash and paid to participants via BACS transfer.

Upon receipt of the completed TP2 questionnaires, participants were given the final compensation payment (in the form of Amazon vouchers) as well as the final “top-up” payment to bring their total reward package up to £250 (see section A.3.3). Participants were sent a debrief letter to thank them for their time and confirm what will happen to their data and when the findings of the research will be published.

A.5 Vehicle management

A.5.1 *Trial vehicle fleet*

The Consumer Charging Trials used two variants of the Volkswagen Golf; the ‘e-Golf’ BEV and ‘Golf GTE’ PHEV. The two models were identical in functional capability (other than the powertrain differences) and were (as closely as possible) matched in trim. The specifications of the PHEV and BEV models are shown in Table 5.

The vehicle fleet consisted of a total of 90 new Volkswagen Golf vehicles; 45 PHEV GTE models, and 45 BEV e-Golf models. The vehicles were leased directly from Volkswagen Group Financial Services (VGFS). The manufacturer’s warranty covered all vehicles for the duration of the trial. Vehicle maintenance and servicing was covered under the terms of the lease agreement; Volkswagen dealerships local to TRL and Cenex were used for this purpose. Servicing or maintenance was, wherever possible, scheduled between participant experiences or blocks so as to minimise disruption to the trial. The lease agreement also provided comprehensive breakdown cover and tyre replacement; participants were provided with full details of this cover (and what to do in the event of an incident) as part of the In-vehicle Information Pack.

Table 5: Vehicle manufacturer[8] reported specifications for the VW Golf PHEV and BEV models

Manufacturer reported specification	VW Golf GTE (PHEV)	VW e-Golf (BEV)
Engine	1.4 TSI (petrol)	Electric motor
Gearbox	6 speed auto DSG	Direct drive
Nominal Capacity, i.e. units to full charge (kWh)	8.7	35.8
Maximum AER (miles)[9]	31	186
Expected AER (miles)[10]	25	175
Fuel economy (combined)	156.9	n/a
Time to full charge (AC - 2.3kW) (hours)	3.75	17
Time to full charge (AC - 3.6kW) (hours)	2.25	10.5
Time to 80% charge (DC – 50kW) (hours)	n/a	0.75
Power Output (PS)	204 (combined)	136
Max torque (Nm)	350 (combined)	290
Mass - kerb weight (kg)	1615	1615 - 1687
Mass - gross weight (kg)	2040	2020
Emissions (CO_2 g/km)	38	0
Acceleration (0-100km/h)	7.6	10.4
Vmax (km/h)	222	150

A.5.2 *Vehicle storage*

TRL trial vehicles were stored at a secure vehicle storage facility near Camberley, Surrey approximately 9 miles from TRL's head office in Crowthorne, Berkshire. Cenex trial vehicles were stored in a secure multi-story car park on the campus of the University of Loughborough in Leicestershire, where Cenex are based. Participants' personal vehicles were also stored at either the Camberley storage site or the multi-story car park on the University of Loughborough campus. As part of the vehicle handover process, participants' vehicles were inspected on arrival to record any damage and log the mileage. Keys were tagged with participant and vehicle details and locked in secure storage. For some participants, vehicle storage was not necessary as their own vehicle remained at their household.

[8] Volkswagen Financial Services (Personal communication, July 2017).

[9] New European Driving Cycle (NEDC) range (July 2017). These rates were correct at the time of running the trials and as such were the values communicated to participants. Worldwide Harmonised Light Vehicle Test Procedure (WLTP) figures have since been released (September 2018). These report a maximum range of 144 miles and a real-world range of 125 miles for the VW e-Golf.

[10] Real-world range estimated by Volkswagen (July 2017).

A.6 Vehicle charging

Both the e-Golf (BEV) and the Golf GTE (PHEV) were supplied with Mode 2 and Mode 3 charging cables (see Table 6 for an explanation of the charging modes). At the vehicle handover sessions, the research team provided participants with a demonstration of how to charge the vehicles; hard-copy instructions were also provided to participants as part of the In-vehicle Information Pack.

Table 6: Explanation of charging modes[11]

Mode	Summary	Details	Safety
Mode 1	• AC charging • Non-dedicated circuit • Non-dedicated plug/socket	• Connects to an existing non-specialised circuit (e.g. a standard socket in a house) using a cable with no control equipment • Although protected by a BS 1362 fuse, RCD protection not guaranteed	• Not recommended for EV charging.
Mode 2	• AC charging • Non-dedicated circuit • Non-dedicated plug/socket • Cable-incorporated RCD	• Cable that connects the vehicle to the electrical supply incorporates an In-Cable Control and Protection Device (IC-CPD) • Provides RCD protection downstream of the unit • In residential applications Mode 2 charging power will often be limited by vehicle protocols to charging at 1.4kW to 2.3kW (6-10A) • Limited to 3kW (13A) in residential use or 7.4kW (32A) for industrial	• Regular charging should only be carried out using a dedicated EV circuit • Occasional charging from a non-dedicated circuit is acceptable
Mode 3	• AC charging • Dedicated EV charging system • Dedicated plug/socket • Control, communications and protection functions incorporated in the chargepoint with “smart” charging potential and other functions • Wide range of charging capabilities, single or three phase AC up to 50kW	• Control, communications and protection functions incorporated in the chargepoint with “smart” charging potential and other functions • Specialised system for EV charging used in residential, commercial and public charging • Always runs from a dedicated circuit • Wide range of charging capabilities, single or three phase AC up to 50kW • Commonly operates at 3.7kW (16A) or 7.4kW (32A) in residential applications but power may be significantly higher in commercial or public applications	• Designed for EV charging

[11] Adapted from ‘A Guide To Electric Vehicle Infrastructure’ (BEAMA, 2015).

Mode	Summary	Details	Safety
Mode 4	• DC charging • Dedicated EV charging system • Dedicated plug/socket • Tethered units; no separate Mode 4 cable required in vehicles • CHAdeMO or CCS (Combined Charging System) connectors and communication protocols	• Provides a DC charge to the vehicle and carries out the control functions within the chargepoint • Bypasses the charger carried on the vehicle so can utilise large and heavy equipment needed to provide particularly high charge currents • Wide range of charging capabilities from tens of kW to over 100kW	• Designed for EV charging

A.6.1 *Charging at home*

For long-term use of plug-in vehicles, Mode 3 charging (involving the use of a dedicated PiV charging station with its own circuit) is the recommended method for domestic charging. Therefore, for the purposes of these trials, a Mode 3 chargepoint was installed in participants' homes to enable them to safely charge the BEV and PHEV during the trial. These chargepoints were 3.6kW.

A.6.2 *Public charging*

Participants were given free access to the 'POLAR plus' public charging network via a membership card (key fob) provided with each vehicle. POLAR is the UK's largest public charging network and contains thousands of chargepoints across the UK, ranging from 3-pin and Type 2 sockets, to their rapid charger, 'The Ultracharger'. POLAR plus customers can also access the Charge Your Car (CYC) network of chargepoints.

Around 80% of the network's chargepoints are free to use. For other chargepoints on the POLAR network, the costs associated with charging were covered directly through a TRL account; participants were not required to pay for the use of POLAR public chargepoints in this trial. Maps showing the location of POLAR public chargepoints[12] in the areas surrounding TRL and Cenex are shown in Figure 5 and Figure 6, respectively. Participants were directed to the POLAR plus map web page during vehicle handover so that they were aware of how to find public chargepoints.

[12] https://polar-network.com/map – up to date at the time of starting the trials (November 2017).

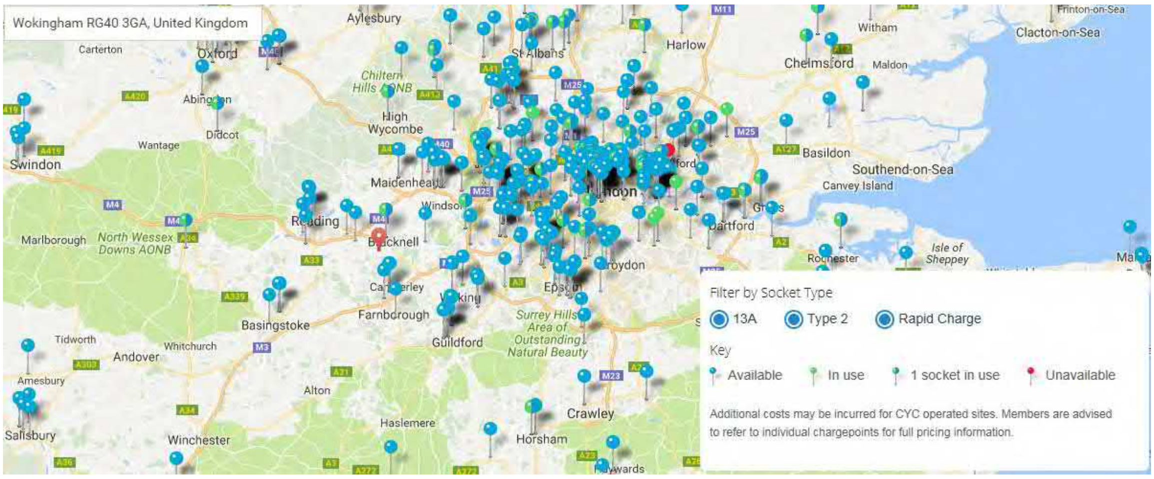

Figure 5: Public chargepoints on the Polar network in the area surrounding TRL

Figure 6: Public chargepoints on the Polar network in the area surrounding Cenex

A.7 Experimental groups

Both the PHEV Consumer Charging Trial and the BEV Consumer Charging Trial employed identical experimental conditions. The detail provided in this section therefore applies to both trials. Trial participants were randomly allocated to one of three groups; the group into which participants were allocated determined the Managed Charging schemes (experimental conditions) which they experienced during the trial (see Table 7).

Table 7: Experimental conditions

Group	Description
Control group	Participants were free to charge when they wanted, with no financial or other incentives for charging in a particular way (although they were incentivised to meet minimum weekly usage requirements). This established a baseline for energy use and charging behaviour when there were no incentives offered to the consumer, so that comparisons could be made with each of the experimental groups.

Group	Description
User-Managed Charging (UMC) group	Participants were encouraged to actively manage their charging, through the provision of a banded tariff that gave them financial incentives to charge at particular times of day[13].
Supplier-Managed Charging (SMC) group	Participants were encouraged to delegate management of their charging to the (simulated) energy supplier. Participants were provided with financial incentives for giving the supplier flexibility over precisely when their vehicle is charged, by setting their charging requirements and plugging in for as long as possible.

A.8 Trial incentives and compensation

As part of Stage 1 of the CVEI project, a literature review was conducted by the Behavioural Insights Team (BIT) to understand the validity of using different forms of incentives in behavioural research. The key findings from this literature review were used to inform the design of the trial incentives.

It is first important to distinguish between two types of incentive:

1. an incentive to participate in a research trial, and;
2. an incentive designed to influence a particular behaviour during a research trial.

The first of these will be referred to from here as 'compensation' (for participating), and the latter as an 'incentive' (to encourage engagement with the vehicle usage and charging requirements of the trial).

Fundamentally, it was important to ensure that compensation and incentives were psychologically separated so that one did not distort the effect of the other. This was achieved via two approaches:

- Taken together, the compensation and incentives were equivalent to a total offering of £250, but took two distinct forms:
  - Compensation was provided in the form of Amazon vouchers, so as to remove the likelihood that the value of the compensation is psychologically offset against expenditure on electricity bills during the trial.
  - Incentives were provided in the form of a points-based reward system, where desired behaviours were rewarded with points. Points were accumulated and redeemed against a cash lump-sum at the end of the trial (see section A.8.1).
- The compensation and the incentives were provided at different points in time:

[13] Savings available in the UMC and SMC conditions was based on PiV charging behaviour; it was not possible for participants to make additional savings by shifting other elements of their total household electricity demand. This may well be reflected in real-world MC offers, since it is perhaps easier to time-shift PiV charging demand than other elements of household electricity demand.

- Compensation was provided both at the start of the trial, before participants collected the trial vehicle and at the end of the trial;
- Participants in the UMC and SMC groups were provided with the status of their points in real-time throughout the trial, and alerted when actions resulted in points. Total points were converted to cash at the end of the trial.

The breakdown of compensation and incentives is shown in Table 8:

Table 8: Breakdown of compensation and incentives for Consumer Charging Trials

Group	Sub-group	Time at which participant received compensation				
		Pre-trial questionnaire	Time point 1 questionnaire	Conversion of reward points to cash	Time point 2 questionnaire	Final debrief "top-up" payment
Control group	N/A	£25 voucher	£25 voucher	Up to £150 cash	£50 voucher	£0-150 voucher
User-Managed Charging (UMC) group	Summer	£25 voucher	£25 voucher	Up to £20 cash	£180 voucher	£0-20 voucher
	Winter	£25 voucher	£25 voucher	Up to £125 cash	£75 voucher	£0-125 voucher
Supplier-Managed Charging (SMC) group	Summer	£25 voucher	£25 voucher	Up to £30 cash	£170 voucher	£0-30 voucher
	Winter	£25 voucher	£25 voucher	Up to £150 cash	£50 voucher	£0-150 voucher

Participants were told that they would receive up to £250 worth of reward for involvement in the trial, and they were told that this was split between Amazon vouchers for completion of the questionnaires, and points earned during the trial which would be converted to cash at the end of the trial, up to a fixed amount. As shown in the table above, this fixed amount varied depending on which group participants were in, e.g. those in the Control group were told that the points they earned would be converted to cash, up to a maximum of £150, whilst those in the SMC-Summer group were told that their points would be converted to a maximum of £30.

An important aspect of the design of the Consumer Charging Trials was consideration of seasonal variation in charging behaviour, PiV use and energy prices. Of particular importance were the distinct differences in energy prices between 'summer' and 'winter' periods. In the winter, there are much higher daily price differentials than in summer, and there are sharp transitions in prices between summer and winter. Because of this, the UMC and SMC experimental groups were divided into the "Summer" and "Winter" sub-groups (as explained in section A.1). The maximum value of the reward points that participants were able to earn differed across the four sub-groups[14] (UMC-Summer, UMC-Winter, SMC-Summer and SMC-Winter). The relative sizes of these maxima reflected the relative differences in cost savings that are expected to occur seasonally in future UMC and SMC charging offerings, as modelled in Deliverable D7.1.

There were undesirable ethical implications associated with the maximum achievable value of reward points differing between sub-groups, in that it would be unethical to limit the opportunity to receive the full reward value of £250 for some participants but not others. As such, a final "top-up" payment was made at the point of participant debrief whereby participants were given Amazon vouchers worth whatever value was required to bring their total reward package up to the value of £250. Participants were not told about the top-up payment until the end of the trial.

For example, if a participant in the UMC Winter group received:

- £25 Amazon voucher upon completion of the Pre-trial questionnaire
- £25 Amazon voucher upon completion of the Time Point 1 questionnaire
- Conversion of reward points to £100 cash upon return of the vehicle, and;
- £75 Amazon voucher upon completion of the Time Point 2 questionnaire

Then the total value of their reward package was £25 + £25 + £100 + £75 = £225. A final debrief top-up payment of £25 (given as an Amazon voucher) was therefore made to bring the total value of reward up to £250.

The method by which participants accumulated reward points in each group is explained in section A.8.1. At the end of each trial block, reward points were converted to cash using a conversion rate (C). The conversion rate was calculated by dividing the maximum cash value of points (detailed in column 5 of Table 8 above) by the highest number of points earned by a participant in a given experimental sub-group (e.g. the UMC-Winter group in the BEV trial). The conversion rate was then applied to all other participants in the same sub-group and trial block, giving them a proportionate value.

For example, if, at the end of Block 1, the maximum number of points earned by a BEV participant in the UMC Winter group was 1000, then the conversion rate (C) was calculated as:

- C = £150/1000 = 0.15 (or 1 point = £0.15)

The final top-up payment was not disclosed to participants until the end of their trial block so as to avoid negating the effect of the incentives.

In addition to the above rewards, all participants were entered into a prize draw for a chance to win £2,500. The winning name was drawn at random once all participants had completed the trial.

[14] In order to avoid participant bias, the participants were not made aware of the different sub-groups in the trial, nor were they told the name of the sub-group to which they belonged.

A.8.1 *Experimental groups and reward points logic*

As described above, incentives were provided in the form of a points-based reward system, where desired behaviours were rewarded with points. Points were accumulated and redeemed against a cash lump-sum at the end of the trial. This section describes the process for earning reward points in the control, UMC and SMC groups. In the control group, they were called ‘Participation Points’, and in the SMC and UMC groups they were called ‘Savings Points’.

A.8.1.1 *Control groups*

In the control groups, participants were not incentivised to charge in a particular way.

The incentive scheme in the Control group was linked to a minimum vehicle mileage requirement as opposed to a minimum charging requirement. This was particularly important for the PHEV Charging Trial; in this trial, it was possible that some participants would choose not to charge the PHEV by plugging it in, and instead operate the vehicle like a Hybrid Electric Vehicle (HEV) or pure petrol vehicle. Instigating a minimum charging requirement in the PHEV control group could have therefore biased the findings by deterring this behaviour. In the case of the BEV Charging Trial, driving the BEV directly linked with a requirement to charge and so this bias was not an issue, however for simplicity it was beneficial to employ the same incentive structure across the two trials.

Hence, participants in both the PHEV and BEV control groups were asked to use the vehicle for their normal day-to-day journeys, driving at least 50 miles per calendar week (Monday-Sunday). For each week during the trial in which they met the minimum mileage requirement Control group participants in the BEV and PHEV Charging Trials accumulated ‘Participation Points’. They were told at the start of the trial that they could earn a maximum of £150 for their Participation Points. Participation Points accumulated over each week in the trial period and were administered upon return of the vehicle at the end of the trial. In each week they could earn 20 Points, worth £18.75, if they drove at least 50 miles. Points were only awarded if the mileage requirement was met; partial points were not awarded. Therefore, participants who met the mileage requirement in every week of the trial earned a total of 8 x 20 = 160 Participant Points, worth £150 cash[15].

A.8.1.2 *Supplier-Managed Charging (SMC)*

In the SMC condition, participants were able to maximise the number of Savings Points they could earn by relinquishing control of their charging to the simulated energy supplier; the system then optimised the participants’ charging so as to deliver the maximum Savings Points.

Savings Points in the SMC group (SP_{smc}) were calculated retrospectively for each charging event using the following formula:

$$\mathbf{SP_{smc} = 0.5*X + 0.5*Y}$$

[15] For participants who had the vehicle longer than 8 weeks, e.g. those who took part in Block 1, the maximum cash reward for the points was still capped at £150 cash.

Thus, Savings Points (SP) consisted of two elements:

1. The actual savings to the supplier (relative to an assumed counterfactual) associated with the actual charging for that day (X)
2. The potential additional value to the supplier associated with the available window for charging, taking into account the time of day and length of the window for which the vehicle was available for charging (Y)

Savings Points were the weighted sum of the two elements, X and Y. Equal weight was given to the X and Y components; this is reflected in the 0.5 weightings shown in the equation above.

The "X" component represented the actual savings made by the supplier in a particular charge event. The "Y" component represented the average level of savings that would occur for a charge event of that type; i.e. the savings represented on a typical time-price curve.

Including only the X component would have made it more difficult for the consumer to link their Savings Points to their charging behaviour, since X varied from charging event to charging event (even where the timing and duration of the charge was the same). The additional element "Y" was therefore added; Y was equal from charge event to charge event where the timing and duration of the charge was the same. This made it easier for participants to couple their Savings Points to charging behaviours since Y was a more predictable component.

Participants were provided with information on the Savings Points earned for each charging event and cumulative Savings Points earned to date, via the App.

Variable savings based on the price of energy (X)

For Deliverable D7.1 of the CVEI project, a 'Price Series Model' was developed providing estimated hourly energy prices (p/kwh) for the year 2030. This model indicated the retail price of energy in hourly time intervals for each hour of each day for a full year. The Price Series Model detailed distinct but equally proportioned 'summer' and 'winter' periods.

For the SMC groups in this trial, two composite 9-week[16] price series were compiled from the year-long Price Series Model. For half of the participants (the SMC-Summer sub-group), energy prices from the summer period of the Price Series Model were used. For the other half (the SMC-Winter sub-group), the energy prices from the winter period of Price Series Model were used.

For each plug-in event at home, users could either choose to start the charge immediately, or they could specify when they next needed the vehicle (the Departure Time), the State of Charge (SOC) they needed by that time (the Desired SOC) and then let the supplier manage the charge for them[17]. This latter approach defined a:

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[16] The day of the week in which participants start the trial varied, so a 9-week series was chosen to ensure that prices were available for a full 8-week period, irrespective of the day on which participants started the trial in week 1.

[17] This could either be achieved by the user choosing new inputs after each plug-in, or by the user leaving the system to automatically apply the default inputs 15-minutes after each plug-in (see section A.10).

- **Time Window;** in which the vehicle was available for charging, and a;
- **Charging Requirement**; the number of hours of charge which the system had to deliver within the Time Window (dependent on the initial SOC when the vehicle was plugged in at the start of the Time Window, and the Desired SOC).

The system looked at energy prices within the associated composite Price Series Model and identified the cheapest hours within the Time Window in which to deliver the Charging Requirement.

For example, if the Time Window was 12 hours, and the Charging Requirement 5 hours, then the system selected the 5 hour-long periods with the lowest prices from the Price Series Model which fell within the 12-hour Time Window.

The Actual Charging Cost (A) was determined by the sum of the lowest prices identified from the Price Series Model. For each given charge event, the Actual Charging Cost was then compared to the Baseline Cost (B_{SMC}). The Baseline Cost was determined by the cost of charging if the Charging Requirement was delivered as soon as possible within the Time Window.

For example, if the Time Window was 12 hours, and the Charging Requirement was 5 hours, then the Baseline Cost was calculated by summing the first 5 hours of energy prices from the Price Series Model which fell at the start of the 12-hour Time Window.

Thus, the value of X was calculated using the following formula:

$$\mathbf{X = B_{SMC} - A}$$

Participants who provided greater flexibility to the system (i.e. longer Time Windows relative to the Charging Requirements), had a better chance of maximising the value of X, since there would have been more opportunity to deliver the charge in lower price periods. The level of reward for a given availability window varied day-to-day throughout the 8-week trial, based on the underlying price series.

Thus, the value of X varied depending on:

(a) the user’s charging behaviour – how much charge they required (the Charging Requirement), and the Time Window for which they made the vehicle available for charging, and;

(b) the price of energy for the relevant time period in the price series.

By passing through this variation to the user, the supplier manages its risk associated with the unpredictability of hourly electricity costs.

Since hourly electricity costs in the price series varied across the 8-weeks, participants were not easily and rigidly able to associate the value of X with their behaviours. Therefore, to increase the likelihood of participants being able to implicitly learn about how to maximise savings, an additional, more predictable, element was also included within the calculation of Savings Points; the ‘Y’ component, explained in the following section.

Fixed savings for making vehicle available to charge at optimum times of day (Y)

For the reasons explained above, Savings Points accumulated in the Supplier-Managed Charging group also incorporated an element, Y, which represented the potential additional value to the supplier associated with the available window for charging. These potential values took into account the time of day and length of the Time Window. Unlike the price series which contributed to the value of X, the value of Y was not subject to day-to-day variation. If the participant had the same Charging Requirement and made the vehicle available during the same Time Window on two different days, they received the same Y Savings Points. By including this Y component in the calculation of Savings Points, it provided an opportunity for stronger reinforcement learning through experience during the trial compared with if only the value of X was used.

Y Savings Points also acted as a reward for charging at times that had high potential value (generally low electricity price).

The potential additional values were represented in an Hourly Value Model produced for Deliverable D7.1 of this project**.** Generally, times where the wholesale costs of electricity purchased by the supplier are low result in higher potential values (which also need to account for variations in wholesale costs – an explanation of how these values were calculated is included in Deliverable D7.1). The Hourly Value Model provided the potential additional value of charging in each hourly time interval for a typical weekday and a typical weekend day during the trial.

To account for seasonal variation of potential additional value during the year, two sets of values were generated, thus giving two versions of the Hourly Value Model:

1. Hourly Value Model 1 ('summer')
2. Hourly Value Model 2 ('winter')

Participants in the SMC-Summer sub-group accumulated Y Savings Points based on Hourly Value Model 1, and participants in the SMC-Winter sub-group accumulated them based on Hourly Value Model 2.

The system summed the potential values from the Hourly Value Model within the Time Window for which the Charging Requirement could be delivered. Charging Event potential value (Y) was then calculated as follows:

> **Y** = sum of highest hourly potential additional values in Time Window as needed to deliver Charging Requirement

Thus, the greater flexibility a participant provided to the system (i.e. the bigger the Time Window relative to the Charging Requirement) at times when the potential value was high, the bigger the value of Y, and the more Savings Points participants earned. Participants who performed identical charging behaviours throughout their participation received consistent values of Y. Since the value of Y depended on the Charging Requirement, there was no perverse incentive to plug in for extended times when no substantial charge was needed.

A.8.1.3 *User-Managed Charging (UMC)*

In the User-Managed Charging (UMC) condition, participants were able to make savings by actively managing the charging of their vehicle so that their energy use was highest at times when the cost of energy is lowest, on average. Savings were delivered to the participants via the accumulation of Savings Points, as in the SMC group.

Savings Points in the UMC group (SP_{umc}) were calculated for each participant using the following formula:

$\mathbf{SP_{umc} = Z}$

where Z was a function of the savings to the supplier (relative to an assumed baseline – explained in next section) associated with the actual charging for that day.

Participants were provided with information on the Savings Points earned in each charging event and the cumulative Savings Points earned to date, via the App. They were also informed of the estimated Savings Points which would be earned upon entering their required charging start time (and stop time, if applicable), based on the Charging Requirement calculated by the system. On completion of the charging event, the actual Savings Points acquired were fed back to the participant via the App, based on the actual charge.

A function of the savings to the supplier associated with the actual charging for that day (Z)

Hourly energy prices (p/kwh) from the Price Series Model (Deliverable D7.1) were used to produce a Tariff Model. This indicated the price of charging in hourly time intervals for each hour of the day, organised into "bands", and split by weekdays and weekend days. A real-world UMC Tariff Model would likely include summer and winter tariffs to reflect the seasonal structure in prices and daily price differentials seen in the Price Series Model. To reflect this in the trials, half of the participants received a "summer" tariff with low price differentials between bands, and the other half received a "winter" tariff with high price differentials between the bands. The time bands are shown in Table 9, and the energy prices for each model are shown in Figure 7.

Table 9: UMC Tariff bands for Summer and Winter sub-groups

UMC-SUMMER TARIFF BANDS

Tariff band	Time period	Savings Points available
Low	18:00-03:59	Most
Standard	04:00-08:59	
Medium	09:00-13:59	
High	14:00-17:59	Least

UMC-WINTER TARIFF BANDS

Tariff band	Time period	Savings Points available
Low	19:00-04:59	Most
Standard	05:00-09:59	
Medium	10:00-14:59	
High	15:00-18:59	Least

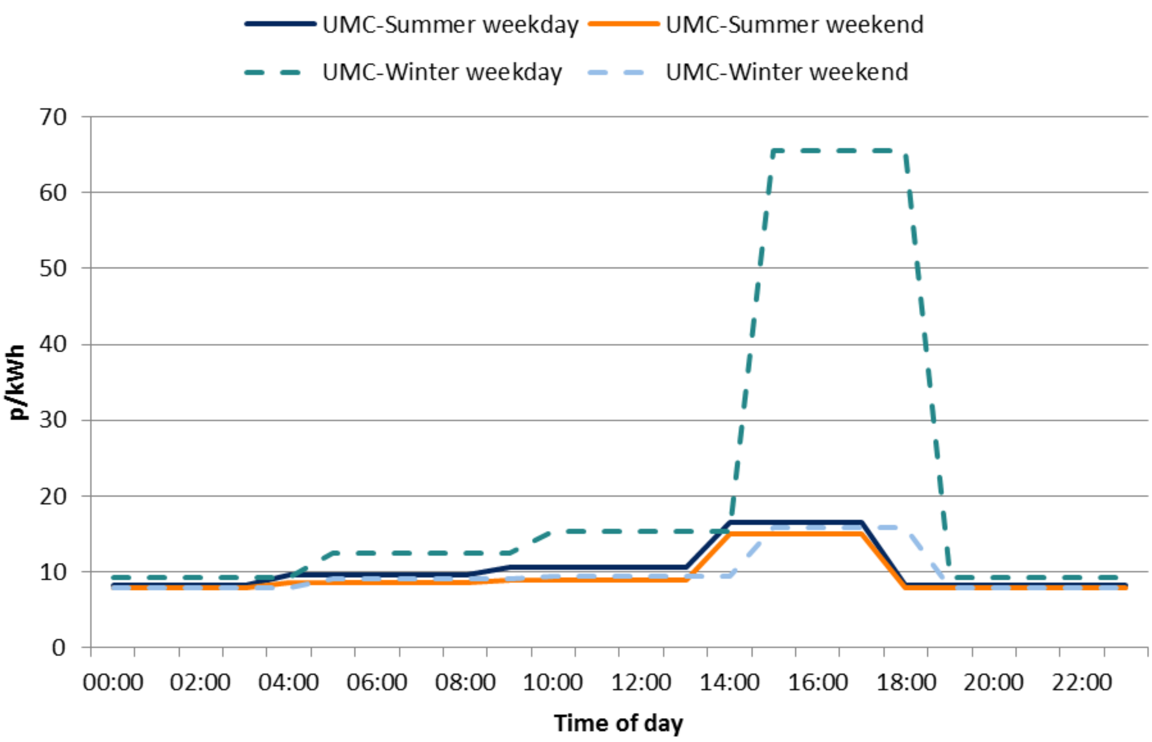

Figure 7: UMC Tariff Model block retail prices for Summer and Winter sub-groups

For each plug-in event, the users specified when they wished the charge to start (i.e. by choosing to charge immediately, or by choosing to delay charging to a specified time) and, if desired, when they wished charging to stop (i.e. by selecting a charge finish time, or selecting 'not required').

This allowed users to define a window within which they wished the vehicle to be charged, thus giving them the ability to limit their charging to, for example, one Tariff band whilst preventing charging in another Tariff band. This information, coupled with the current SOC of the vehicle (obtained via the telematics system), defined a:

- **Charge Start Time**; the time at which charging began;
- **Charge Stop Time**; the time at which charging stopped due to 100% SOC being reached, or the time at which the user requested the charge to stop, and a;
- **Charging Requirement**; the number of hours of charge required to reach 100% SOC, or the number of hours between the Charge Start Time and Charge Stop Time (whichever was smaller).

The system looked at the energy prices within the Tariff Model, starting from the Charge Start Time and ending either at a time when 100% SOC will be reached, or at the Charge Stop Time, if the user specified one.

For example, if the user plugged in at 19:00, set the Charge Start Time to 22:00, did not set a Charge Stop Time, and the Charging Requirement was 5 hours, then the system would have looked up the energy prices between 22:00 and 03:00.

Alternatively, if the user plugged in at 19:00, chose to start the charge immediately, and set a Charge Stop Time of 23:00, then the system would have looked up the energy prices between 19:00 and 23:00.

The **Actual Charging Cost (A)** was therefore determined by the sum of those prices identified from the Tariff Model. To estimate the value of savings achieved by the system for each given charge event, the Actual Charging Cost was compared to the **Baseline Cost (B_{UMC})**. The Baseline Cost was determined by the cost of charging in the High Tariff band in the Tariff Model for the given day of the week.

For example, if the Charging Requirement was 5 hours, then the Baseline Cost was calculated by summing the cost of 5 hours of charging in the High Tariff band.

Thus, the value of Z was calculated using the following formula:

$$Z = B_{UMC} - A$$

Participants who delayed their charging to times when the energy prices were low (e.g. during the Low Tariff band in the Tariff Model) received greater savings (as illustrated in Table 9).

A.9 Chargepoint Management System

The Chargepoint Management System (CPMS) was a cloud-based system which was used to manage individual home charging operations, process information from and feed information to the User Interface (smartphone app), and collect and process data from the vehicles and chargepoints. An overview of the interactions between the CPMS and other components of the wider system is shown in Figure 8.

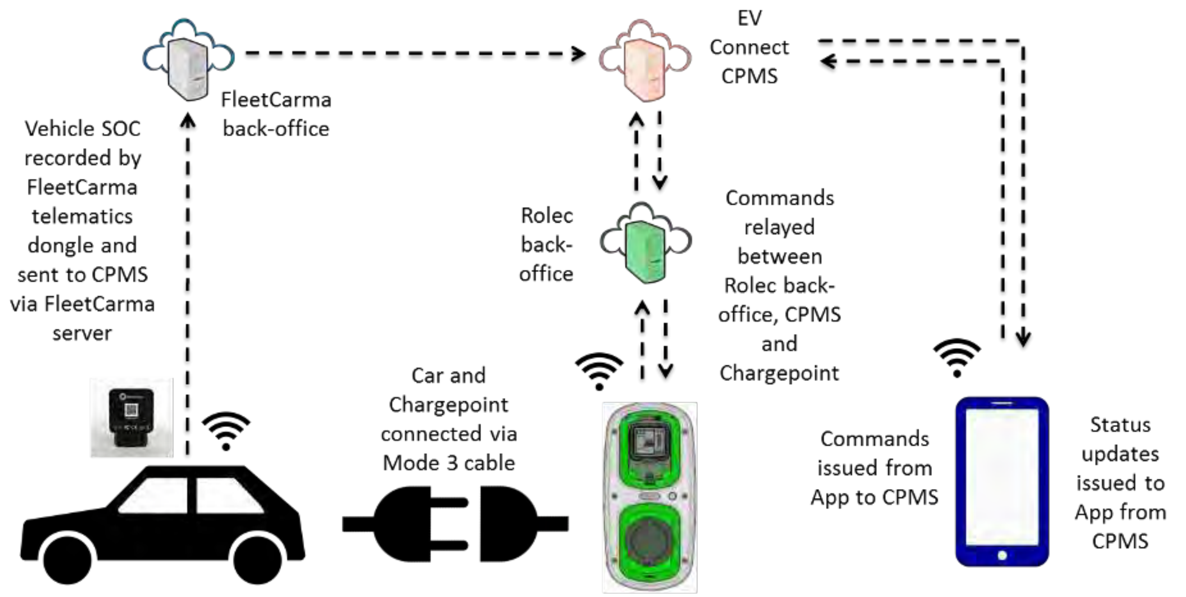

Figure 8: Overview of interactions between CPMS and other components

The CPMS was only active for home charge events. The CPMS interacted with the vehicles, the drivers who operated the vehicles, the chargepoints (via the Rolec back-office), and the smartphone app (User Interface). Specifically, it acted as intermediary between all of the components and logged all home charge interactions:

- The telematics dongle communicated SOC to the CPMS via the FleetCarma back-office.

- The Rolec chargepoint communicated location, status and other relevant information to the CPMS via the Rolec back-office.
- Vehicle SOC and charging status (i.e. connected, not connected, charging, etc) information was processed and served to the driver from the CPMS through a web-based mobile application on their smartphone enabling the driver to view charging status, and make decisions about charging their vehicle (UMC and SMC groups only).
- Decisions from the driver were processed by the CPMS, which then relayed appropriate control commands to the chargepoint via the Rolec back-office.
- Regularly updated SOC data from the vehicle telematics dongle were received by the CPMS via the FleetCarma back-office.

The FleetCarma telematics system, one of the components of the CPMS, was also active for charge events away from home; the telematics dongle collected data for all charge events (and all journeys) irrespective of location.

The CPMS sent email notifications to the user upon each plug-in at home, requesting the user's charging preferences for that particular session. If no user inputs were recorded by the CPMS within 15 minutes after plug-in, then the default values were selected. Further information about the smartphone app is provided in section A.10.

In the Control group, charging began upon plug-in at the chargepoint; the CPMS logged the start and end of the charge session, and fed SOC data (received every 5 minutes from the vehicle telematics dongle) to the app.

In the UMC group, charging either began immediately (if participants chose to 'Charge Now') or it was scheduled on the basis of 'Start Time' and 'Stop Time' inputs (either default inputs or new inputs from the user) (see section A.10.2). This information was fed into the CPMS so that the system knew when to start (and stop) charging the vehicle. If no stop time was requested by the user then the system charged the vehicle until it reached 100% or until the user ended the charge session (e.g. by plugging out).

In the SMC group, charging either began immediately (if participants chose to 'Charge Now') or it was scheduled on the basis of 'Desired SOC' and 'Departure Time' inputs (either default inputs or new inputs from the user) (see section A.10.3). Using these inputs, the CPMS defined a:

- **Charging Requirement**; the number of hours of charge needed to charge the battery from the current SOC (obtained via the Vehicle Telematics System – see right-hand side of Figure 8) to the Desired SOC (input from User App), and a;
- **Time Window**; the amount of time available for charging from the current time to the required departure time.

Using these parameters, the CPMS then generated appropriate commands to the chargepoint. The Charging Requirement in the SMC group was delivered at the end of the Time Window, minus a one-hour buffer. For example, if the Charging Requirement was 5 hours, and the Time Window was 10 hours (20:00 to 06:00), the CPMS delivered the 5 hours of required charge between 00:00 and 05:00, allowing a one-hour buffer before the Time Window ended at 06:00.

As such, the actual delivery of charge in the SMC group differed from the way in which the Savings Points were calculated for SMC participants (see section A.8.1.2). From the user experience perspective, it was important for the SMC condition to simulate the inconvenience to the user of not having full control of precisely when the charge was administered. This was achieved with the charge delivery system since it ensured that charging in the SMC group was delayed from the time of plug-in for most use cases. The one-hour buffer was provided so that users were not inconvenienced (by having lower SOC than requested) if they made a minor variation in departure time, but were inconvenienced if they chose to end the charging event and start using the vehicle more than an hour before the time they specified. Critically, this solution ensured the system was simple to implement for the purposes of the trial, and minimised the risk of system faults.

A.10 User Interface: smartphone application

Participants in all three experimental groups were provided with a web-based smartphone application for use during the trial. For the participants in the UMC and SMC groups, the app allowed them to adjust their charging preferences and engage with the managed charging scheme. A passive version of the app was also provided for participants in the Control group; this simply displayed the current vehicle status and SOC, allowing participants to monitor battery charge levels remotely.

VW operate a smartphone app called 'CarNet' which allows users of some VW vehicles (including the e-Golf and Golf GTE) to monitor vehicle status and control vehicle charging remotely. As such, to avoid conflict between the app designed for the trials and the CarNet app, access to CarNet was blocked for all participants.

Participants accessed the app through a URL provided by the research team. Full training on how to use the app was provided at vehicle handover and participants were given an App Guide to take away with them. The app was designed to be simple and easy to use. The following sections provide a full description of the interface which participants in each of the experimental groups were given.

A.10.1 *App design for Control group*

Upon login, Control group participants were presented with a static State of Charge screen showing their vehicle's current SOC and the current status of the vehicle – connected, not connected, charging, charge finished (see Figure 9). This page displayed the SOC from the last data packet received from the FleetCarma telematics system (see section A.13) and the date and time at which this data packet was received.

Figure 9: Control group SOC page

A.10.2 *App design for UMC group*

The UMC group had access to four pages within the app:

- **'SOC' page**: View latest vehicle SOC data and current status
- **'Charge' page**: Set charging preferences for current charge event
- **'Defaults' page**: Set default charging preferences for future charge events
- **'Points' page**: View Savings Points earned to date

Participants were able to navigate between the pages by clicking the relevant buttons on the horizontal bar at the top of the screen. These pages are described further in the following sections.

A.10.2.1 *'SOC' page*

The 'SOC' page showed the vehicle's current SOC and the status of the home chargepoint – charging, charge scheduled, no charge scheduled, charge finished (identical in layout to the Control group app screen shown in Figure 9). As with the Control group, this page displayed the SOC from the last data packet received from the FleetCarma telematics system and the date and time at which this data packet was received.

A.10.2.2 *'Charge' page*

Upon plug-in to their home chargepoint the buttons on the 'Charge' page of the app unlocked, allowing participants to set their charging preferences for the charge event. Participants were presented with two options:

1. Choose the Start Time and Stop Time (optional) for the charge

2. Begin the charge immediately (by pressing ‘Charge Now’)

To choose the Start Time and Stop Time for the charge, the user simply clicked on the drop-down menu which presented them with a list of times in half-hourly increments (see Figure 10 – left). In the Stop Time drop-down menu, an option to set ‘No Stop Time’ was included, in case they preferred to allow the vehicle to continue charging until the SOC was 100% (or until they manually stopped the charge by unplugging the vehicle, whichever was sooner). The Start Time and Stop Time values displayed when first opening this page (e.g. 14:00 and 14:30 in Figure 10 – left) were the user’s current Default values (see next section for explanation of the Defaults).

The drop-down menus also displayed the UMC tariff bands (Low, Standard, Medium, and High) so that users knew which band they were charging in, depending on the Start Times and Stop Times they selected. Estimated Savings Points were also displayed on this page.

When scheduling a charge session, users could also choose to save the values they entered as defaults, if they wished, by ticking the ‘Save as default’ tick box before pressing ‘Go’.

Alternatively, the user could choose to start the charge session immediately by pressing the ‘Charge Now’ button at the bottom of the page.

In the event that users changed their mind after scheduling a charge session, they were able to override the existing charging preferences by unplugging the vehicle and then reconnecting to initiate a new charge session. Upon disconnection a charge stop command was sent to the CPMS and the Savings Points were calculated and transmitted to the App.

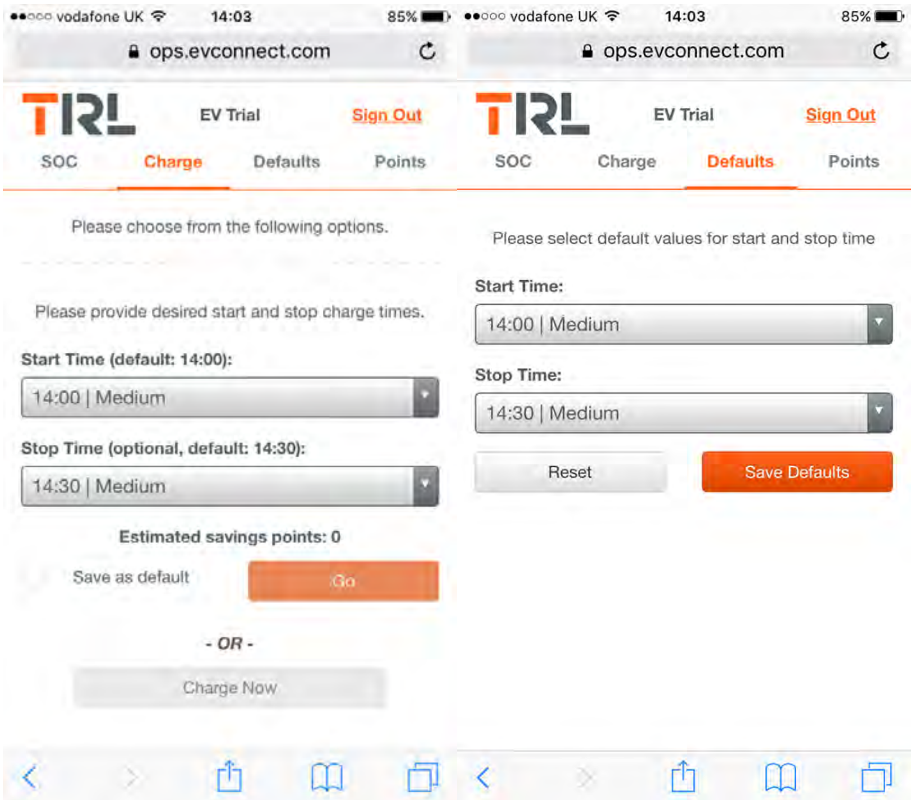

Figure 10: UMC ‘Charge’ page (left) and ‘Defaults’ page (right)

A.10.2.3 *'Defaults' page*

On the 'Defaults' page, participants could set default values for the Start Time and Stop Time (see Figure 10 – right). Default values were used by the system in the event that no user inputs were received within 15 minutes following a new plug-in. This function allowed users to set recurring charging preferences and negated the need for them to physically interact with the App at the start of every charge session.

Default values were selected using drop-down menus, identical in design to the 'Charge' page. The values could be saved by clicking the 'Save Defaults' button. Alternatively, if the user decided not to change the defaults they could either navigate to a different page (using the horizontal bar at the top of the page) or click 'Reset' which reset the values to what they were previously.

A.10.2.4 *'Points' page*

For each charge event, participants in the UMC group accumulated Savings Points, depending on when they chose to charge their vehicle (see section A.8.1). Participants were able to view the Savings Points they had earned to date on the 'Points' page (see Figure 11).

Figure 11: UMC 'Points' page

The page displayed data for all home charging events completed for the duration of the trial, and included:

- The start date and time of the charge
- The stop date and time of the charge
- The amount of SOC added to the battery (expressed as a percentage)
- The Savings Points earned for each charge event

The total number of Savings Points earned to date was displayed at the bottom of the page.

All charge events were classified as either 'Valid' or 'Invalid' by the CPMS. Events were marked as Invalid if there was no SOC increase during the charge session, if the start or end charge timestamp was missing, or if the charge stop timestamp was earlier than charge start (e.g. due to communication errors). Events were marked as Valid if all timestamps were logged correctly in sequence and if the SOC increased during the charge session. On the 'Points' page, a record of both valid and invalid events was displayed for participants; invalid events were demarcated with italic font. Invalid events did not qualify for Savings Points, and so the Savings Points displayed for such events were zero.

A.10.3 *App design for SMC group*

Participants in the SMC group also had access to four pages within the app:

- **'SOC' page**: View latest vehicle SOC data and current status
- **'Charge' page**: Set charging preferences for next charge event
- **'Defaults' page**: Set default charging preferences for future charge events
- **'Points' page**: View Savings Points earned to date

As with the UMC group, participants were able to navigate between the pages by clicking the relevant buttons on the horizontal bar at the top of the screen. These pages are described further in the following sections.

A.10.3.1 *'SOC' page*

The 'SOC' page was identical to that used in the Control and UMC versions of the app (see section A.10.1).

A.10.3.2 *'Charge' page*

Upon plug-in to their home chargepoint the buttons on the 'Charge' page of the app unlocked, allowing participants to set their charging preferences for the charge event. Participants were presented with two options:

1. Choose their Desired SOC and Departure Time
2. Charge immediately

To choose the Desired SOC and Departure Time, participants clicked on the drop-down menu which presented them with a list of values (see Figure 12 – left). The parameters had to be entered sequentially; Desired SOC had to be selected first and then Departure Time. The Desired SOC drop-down menus displayed SOC in 5% increments between 10% and 100%. The Departure Time drop-down menu displayed times in half hourly increments.

Values which were not achievable were greyed out and non-selectable. For example, only SOC values greater than the vehicles' current SOC were selectable from the Desired SOC drop-down menu. Likewise, the Departure Time drop-down menu precluded drivers from selecting a Departure Time and a Desired SOC which was not possible (e.g. 80% in 1 hour).

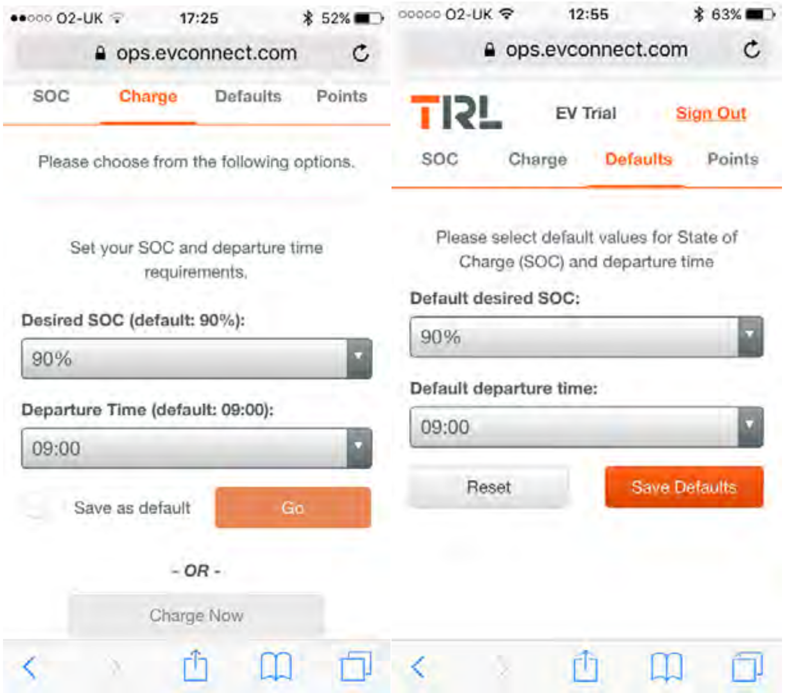

Figure 12: SMC 'Charge' page (left) and 'Defaults' page (right)

Alternatively, the user could choose to start the charge session immediately by pressing the 'Charge Now' button at the bottom of the page.

In the event that users changed their mind after scheduling a charge session, they were able to override the existing charging preferences by unplugging the vehicle; this sent a charge stop command to the CPMS and the Savings Points were calculated and transmitted to the app. Users could initiate a new charge session by plugging the vehicle in again.

A.10.3.3 *'Defaults' page*

On the Defaults page, users could set default values for the Desired SOC and Departure Time (see Figure 12 – right). Default values were used by the system in the event that no user inputs were received within 15 minutes following a new plug-in. This function allowed users to set recurring charging preferences and negated the need for them to physically interact with the app at the start of every charge session. In the event that the default values were selected but were unachievable at the time of charging (for example, if default values of 100% SOC by 07:00 were selected following a plug-in with 10% SOC at 05:00), the charge session initiated immediately.

Default values were selected using drop-down menus, identical in design to the 'Charge' page. The values could be saved by clicking the 'Save Defaults' button. Alternatively, if the user decided not to change the defaults they could either navigate to a different page (using the horizontal bar at the top of the page) or click 'Reset' which would reset the values to what they were previously.

A.10.3.4 *'Points' page*

For each charge event, participants in the SMC group accumulated Savings Points, depending on the charging parameters they set (see section A.8.1.2). Participants were able to view the Savings Points they had earned to date on the 'Points' page (see Figure 13).

Figure 13: SMC 'Points' page

The page displayed data for all home charging events completed for the duration of the trial, and included:

- The plug-in date and time
- The departure date and time
- The amount of SOC added to the battery (expressed as a percentage)
- The Savings Points earned for each charge event

The total number of Savings Points earned to date was displayed at the bottom of the page.

As with the UMC group, all SMC charge events were classified as either 'Valid' or 'Invalid' by the CPMS. Events were marked as invalid if there was no SOC increase during the charge session, if the start or end charge timestamp was missing, or if the charge stop timestamp was earlier than charge start (e.g. due to communication errors). Events were marked as valid if all timestamps were logged correctly in sequence and if the SOC increased during the charge session. On the 'Points' page, a record of both valid and invalid events was displayed for participants; invalid events were demarcated with italic font. Invalid events did not qualify for Savings Points, and so the Points displayed for such events were zero.

A.11 Questionnaires

Participants completed a number of questionnaires during the trial including a two-stage filter survey process to inform recruitment (see section A.3.3), a pre-trial questionnaire, and an attitudinal questionnaire which was repeated before and after the trial.

A summary of the content and data collected by each questionnaire is provided in Table 10.

Table 10: Breakdown of data collected by each questionnaire

Questionnaire	Data collected
Filter survey 1	**Section 1: Driving history** • Time holding a UK driving licence • Penalty points on driving licence • At fault insurance claims **Section 2: Vehicles and driving information** • Driving regularity • Car owner • Company car driver • Off-street parking • PiV ownership • Intention to adopt a PiV **Section 3: Information about you** • Age group • Gender • Contact details
Filter survey 2	**Section 1: Trial interest** • Trial interest • Living arrangements • Willingness to install a chargepoint **Section 2: Your car(s)** • Number of cars in the household • Number of licensed drivers in the household • Car type • Annual mileage • Long journey (i.e. >typical BEV range) regularity • BEV acceptability **Section 3: Domestic energy information** • Smartphone suitability • Economy 7 and pre-pay tariffs • Solar panels
Pre-trial	**Section 1: General background**

Questionnaire	Data collected
	• Educational attainment • Employment status • Household income • Relationship status • Living status **Section 2: Your household and cars** • Household membership • Cars in the household • Car types • Car purchase method • Car mileage • Main car year of purchase • Main car purchase type (e.g. new or old) • Main car purchase price • Main car purchase choice factors • Main car fuel economy • Main car purchase decision influence **Section 3: Your journeys** • Commuting • Weekday and weekend typical mileage • Journey distance • Urban/rural driving • Mode use and regularity • Current car club membership • Current mobility services user • Journey app planning user **Section 4: Owning and driving a car** • Attitudes to car ownership (car-authority identity) • Driving style (Multidimensional Driving Style Inventory) **Section 5: New technology** • Attitudes to new technology **Section 6: The environment** • Attitudes to Driving and the Environment Inventory
Time Point 1	**Section 1: Battery Electric Vehicles** • Instrumental, Symbolic and Affective attitudes towards BEVs • Self-congruity to BEVs • Willingness to adopt a BEV • Willingness to adopt a BEV by range and time to charge

Questionnaire	Data collected
	• Important factors in decision to adopt a BEV • Influence of access to long-range vehicle options on willingness to adopt • Influence of depreciation on willingness to adopt **Section 2: Plug-in Hybrid Vehicles** • [Repeat Section 1 for PHEVs] **Section 3: Next vehicle purchase** • Future car purchase intentions **Section 4: Home electricity use** • Household energy use patterns • Attitudes towards energy use **Section 5: Plug-in Vehicle charging** • Awareness of PiV public charging points
Time Point 2	**Section 1: Battery Electric Vehicles** • Instrumental, Symbolic and Affective attitudes towards BEVs • Self-congruity to BEVs • Willingness to adopt a BEV • Willingness to adopt a BEV by range • Willingness to adopt a BEV by time to charge • Important factors in decision to adopt a BEV • Influence of access to long-range vehicle options on willingness to adopt • Influence of depreciation on willingness to adopt **Section 2: Plug-in Hybrid Vehicles** • [Repeat Section 1 for PHEVs] **Section 3: Next vehicle purchase** • Future car purchase intentions • Information on PHEVs or BEVs sourced **Section 4: Experience with the Plug-in Vehicle** • Evaluation of vehicle performance • Feedback on charging experience • Future charge location predictions • Awareness of PiV public charging points **Section 5: Charging tariff**

Questionnaire	Data collected
	• Feedback on charging tariffs **Section 6: About you** • Self-identity to PiVs • Newcastle Personality Assessor **Section 7: Choice experiment** • See section A.12

The **filter survey questionnaires (Filter Survey 1 and Filter Survey 2)** were used to determine the eligibility of participants to take part in the trial.

The **Pre-trial questionnaire** was used to collect data for the segmentation and for descriptive analysis to understand how participants fit into the different consumer segments based on their willingness to adopt. It also contained questions relating to the participant's household, vehicle ownership history, travel patterns, attitudes about owning and driving a car, driving style, mobility-as-a-service, attitudes about new technology, personal travel and the environment.

The **Time Point 1 questionnaire** was used to understand participants' attitudes towards BEVs and PHEVs before experience of the vehicles. The questionnaire contained BEV and PHEV specific questions comparing them with conventional cars, affective, symbolic and instrumental attitudes towards BEVs and PHEVs, and propensity to adopt a BEV or PHEV as a main or second car.

The **Time Point 2 questionnaire** was an extended version of the Time Point 1 questionnaire aimed at understanding how attitudes changed with experience of the vehicles. In addition to all the questions in the Time Point 1 questionnaire, this contained additional questions on preferred charging locations, a personality inventory and the **choice experiment**.

A.12 Choice experiment

The choice experiment included in the Time Point 2 Questionnaire was the principal means of addressing several of the research questions concerning attitudes towards different characteristics of managed charging tariffs. Choice experiments, which employ Discrete Choice Analysis, enable the relative values consumers place in these characteristics to be quantified.

A.12.1 *Introduction to Discrete Choice Analysis*

The purpose of Discrete Choice Analysis is to simulate as far as possible the decision-making process followed by consumers in the real world. When choosing between various products or services (for example different public transport options or car powertrains), consumers are assumed to make a trade-off between the attributes of each to come to a decision. For a managed charging tariff, these attributes could include annual cost, peak electricity price, existence of override option, etc. Discrete Choice Analysis is used to quantify the different weighting consumers apply to each attribute, and thus the overall 'utility' that each alternative would provide. Mathematically, the utility, U, of a choice alternative, i, can be expressed as:

$$U_i = \sum_{j=1}^{j=T} \beta_j x_{ij} + \varepsilon_i$$

- x_{ij} is the value of the j^{th} observed attribute for choice alternative i (e.g. peak electricity cost of a user managed charging tariff).
- β_j is the choice coefficient (weighting) for the j^{th} observed attribute for choice alternative i (e.g. weighting of peak electricity cost).
- ε_i is the utility value of the unobserved factors[18] for choice alternative i.
- T is the total number of observed attributes.

A consumer will choose the alternative that offers the greatest 'utility', and so the results can be used to predict the likely uptake of each member of a choice set. Critically, the technique simulates a choice between discrete alternatives which correctly represents the real-world process consumers would go through when considering distinct charging tariffs but can choose only one (and cannot mix and match the attributes of each). The results of Discrete Choice Analysis enable the value consumers place in various charging tariff attributes to be quantified and investigated.

Discrete Choice Analysis has been in use since the 1970s and was developed by Daniel McFadden which earned him the Nobel Prize in Economics in 2000. It was first used to successfully predict demand for the San Francisco Bay Area Rapid Transit system, and has proved popular in the transport sector for predicting uptake of vehicle technologies. The US Department for Energy, for example, used discrete choice modelling to develop the Transitional Alternative Fuels and Vehicles Model which in its initial form was used to forecast fuel choice amongst vehicle buyers (Leiby & Rubin, 1997). This was subsequently extended to include hybrid and fuel cell technologies (Green, 2001), and in its latest guise forms the uptake model used in the US Department of Energy's Market Acceptance of Advanced Automotive Technologies (MA3T) Model. Models based on Discrete Choice Analysis have shown to be better predictors of technology uptake than those based on simpler methods, such as 'diffusion curves', as they account for changes in individual attributes, which do not necessarily change at similar or constant rates.

A.12.2 *Choice experiment design*

Discrete Choice Analysis requires a large dataset containing the results of consumer choices made between alternative products with known attribute values. For products which are already established in the market, this data can be gathered simply from historic market shares and the specifications of each product available. This is known as 'revealed preference' data. This has the advantage of being based on actual real-world decisions. However, for novel products where few or no examples are currently available, or they are not necessarily representative of future products, revealed preference data either does not exist or has limited variation that does not reflect the full range of possible future 'offers' to customers.

[18] Unobserved factors are the vehicle attributes not explicitly investigated through an observed attribute (x_i). This could be because they were not included in the choice experiment or because they are intangible or difficult to quantify (e.g. perceived risk associated with novel technology).

This is of particular relevance for managed charging, where product offerings remain in their infancy. Instead, a 'stated preference' choice experiment can be employed in which consumers in a survey are presented with a set of hypothetical product alternatives and asked to choose to select or 'purchase' one of them. By varying the values of the product attributes between choice sets, a large dataset of consumer choice behaviour can be generated, including combinations of attributes that may only be available in future products. This allows the contribution of each attribute towards overall utility to be derived independently. This technique has been employed in this study.

A 'stated preference' choice experiment was included in the Time Point 2 Questionnaire, to understand how participants valued different attributes of managed charging, and therefore what factors carried most weight in consumers' decisions to use such a system. The choice experiment presented each participant with 10 hypothetical choices between a supplier-managed charging tariff, a user-managed charging tariff, and unmanaged charging. In each case, they were asked which one they would choose to use to charge the BEV or PHEV they used during the Consumer Charging Trial. The attributes of the two managed charging tariffs were varied across each of the choices.

The following section outlines which attributes were included in the choice experiment.

A.12.2.1 *Selection of choice experiment attributes*

The attributes used in the choice experiment were intended to encompass the benefits and inconveniences of each of the managed charging tariffs. Some characteristics are implicit in the managed charging tariffs and since they cannot be varied, need not be included in the attribute list. For example, SMC, by definition, requires a level of external monitoring and control, whereas UMC does not. The perceived inconvenience for these inherent characteristics is quantified in the 'alternative specific constants' which, among other things, capture the value of these 'unobserved factors'. However, to ensure that these factors were fully accounted for, a detailed description of UMC and SMC was provided to participants before they completed the choice experiment.

Only the attributes of the managed charging tariffs that could realistically vary between product offerings, and which alter the consumer proposition should be included in the choice sets. The following section outlines the justification for which attributes were included in the Consumer Charging Trial choice experiment, as well as how they were presented. This is supported by a literature review of similar choice experiments featured in Appendix K of CVEI 170922-6.1 D5.1 – Part 4 – Appendices for Consumer Charging Trial.

Expected value of the annual savings/revenue

The value of financial savings is a key attribute of managed charging as it expected to be the primary motivation for selecting managed charging over unmanaged charging. This can be expressed in terms of a cash payment or net savings on the electricity bill. In the real world, consumers may prefer one of these methods of compensation over the other; however, it is assumed that under choice experiment conditions where only hypothetical money is at stake consumers will behave agnostically. This avoids having to explore two attributes relating to cost savings. Presenting this attribute as the "net annual savings in charging cost" provides the necessary flexibility.

Quoting the savings as annual is deliberate as it avoids participants having to consider a possible seasonal variation in plug-in car running costs and available savings. This is similar to how different utility tariffs are shown on price comparison websites, or how savings from residential solar PV panels are quoted, both of which show a very strong seasonal variation. In reality, suppliers may offer options to smooth any seasonal variations such as through fixed monthly direct debit payments which are commonplace for household electricity contracts today.

Annual savings included in the choice experiment were varied between £20 and £250. However, to ensure that savings lay within a realistic range for each participant, the actual savings shown to participants were scaled depending on whether they drove a PHEV or BEV, and their annual mileage. Participants with greater annual mileage would be expected to have higher annual running costs and so would realise larger annual savings through managed charging. Participants with an annual mileage greater than 15,000 miles had their value of their savings attributes scaled by a factor of 2. Similarly, PHEVs drive only a share of their mileage under electric power and so their annual electricity usage would be less than for a BEV. Consequently, the savings available to PHEVs through managed charging would be lower than for BEVs. Therefore, the annual savings attribute values shown to PHEV trial participants was scaled by 0.6. Under the new WLTP type-approval methodology[19] which is the assumed share of mileage carried out under electric power for a PHEV with 30 km of real-world electric range[20].

Accuracy in the estimate of annual savings

Uncertainty associated with the actual value of the user's net savings arises from two main sources:

- **User-side**; variability in the charging behaviour of the user
- **Supplier-side**; the tariff/rewards structure set by the electricity/charging supplier

Quantifying user-side uncertainty is challenging and is not something that users could know when choosing between managed charging tariffs. To avoid including this in the choice experiment, the net savings are defined as what would be expected if their trip patterns remain consistent. However, even if this is the case, supplier-side uncertainty may still result in the annual savings differing from the expected value.

In the Charging Trial, there are four different time-of-use tariffs for UMC: Summer-Weekday, Summer-Weekend, Winter-Weekday and Winter-Weekend. UMC itself is not limited to these tariffs and could in theory involve daily tariffs throughout the entire year. However, these tariffs are always set in advance, and so savings for the user can be predicted with a high degree of certainty (assuming their trip patterns remain consistent). With UMC, therefore, a

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[19] According to the relationship between range and share of driving under electric power used for the WLTP type-approval, featured in the Technical Report on the development of a Worldwide harmonised Light-duty driving Test Procedure (WLTP).

[20] The results of this trial found that share of mileage under electric power is wide-ranging, and in some cases is significantly lower than 0.6. However, the scaling factor used remains valid as it is only intended to make the range of annual savings values shown in the Choice Experiment more realistic for each participant.

user's savings are not affected by supplier-side variability. The risk that the grid savings do not materialise to the extent predicted when setting the time-of-use tariff is borne by the supplier.

A major difference with SMC is that the tariff and therefore the savings are unknown until after the charging event. The risk that grid benefits do not materialise can therefore be transferred to the user (at least partially). An estimate can be made for the annual cost savings based on expected demand and supply over the course of the year, but with far less certainty than for UMC. Participants' willingness to accept this risk should therefore be quantified. For the SMC choice sets, participants were presented with not only the expected annual savings, but also a possible range of variation, from 0% to ±50%. This was presented to participants in terms of absolute values in GBP rather than a percentage, based on the value of annual savings, as this was considered easier for participants to understand. The "no variability" level (0%) represents a situation where the rewards tariff is set in advance and the electricity supplier takes on the risk that the grid savings are less than expected.

Additional cost of charging during peak hours relative to unmanaged charging

It was found by Kaufmann *et al*. (2013) that consumers are less willing to accept time-of-use tariffs with large differences between peak and off-peak prices. Ideally, UMC participants would only charge during off-peak hours; however, there may be some occasions where charging during peak hours is unavoidable, for example, during days with lots of trips or where a trip is unexpected. The higher the peak price, the greater the impact on a user's overall savings and so the greater the perceived risk. Participants' willingness to accept this risk with UMC was investigated through the inclusion of a cost of peak charging attribute. The peak cost was shown relative to the cost of unmanaged charging. This approach isolates the additional expense of charging during peak hours compared with not participating in managed charging at all.

Willingness to accept higher peak charging cost was also investigated for SMC. With SMC, the price tariff structure is not necessarily known to the user as it is for UMC, and the cost of charging may only be known after each charging event. However, the cost will still vary throughout the day, and users that provide very little flexibility and do most of their charging during peak hours would therefore end up paying more than for unmanaged charging. This is equivalent to a high peak price in the UMC time-of-use tariff and would be similarly perceived as a risk by users that may be required to occasionally charge during peak hours. SMC choice sets therefore also included the average additional cost of charging during peak hours relative to unmanaged charging.

For both UMC and SMC, this additional peak cost was presented in terms of pence per kilowatt hour above the unmanaged charging electricity price. It was envisaged that some participants would be unaware of how this relates to vehicle running costs, and so an indicative additional pence per mile was also provided.

Override function

A key risk associated with managed charging is that the car is unexpectedly required before the specified departure time. Under unmanaged charging (the Control group), the car will have at least charged to some extent from the point of plugging in and is more likely to have the necessary SOC to meet the needs of the unexpected trip. However, for managed charging, there is a risk that if participants need their car earlier than expected then no or very little charging will have taken place. The ability to immediately start charging at this point would reduce the impact of this risk. For UMC, this can be achieved by simply changing the charge start time to the present time. However, for SMC, charging control is ceded to the supplier and so an override function would be necessary to return control back to the user. Financial reward is allocated against the level of flexibility that electricity suppliers are provided with to charge the car, but this flexibility is lost if users suddenly remove their vehicle from the stock of cars under the supplier's control. A financial penalty or loss-of-benefit may be put in place to discourage this action. If an override feature is in place, an example penalty could entail the user losing the entire reward available for that charging event. A softer approach could be to allow the user to adjust their charging configuration mid-charge to force immediate charging, but this will still result in a financial penalty since they will receive only the reward accrued up to that point. This forms the basis for two of the levels for this attribute in the SMC choice set. A base level of no override function at all was also included, to enable the value of an override function to be assessed. In practice, this would be the inability to change the charging configuration once it has been defined for that charging event.

Access to rapid/slow public charging

For BEVs, the risk of making unexpected trips can also be mitigated through the provision of a dense rapid charging network. If necessary, a driver can quickly top up their car with additional energy without too much delay to their journey. This applies to both forms of managed charging. Charging density was presented in the choice sets as travel time from home to reach the nearest rapid chargepoint.

For PHEVs, the VW Golf GTE model used in the trial was unable to rapid charge, and so this attribute tested the benefit gained from the availability of nearby 7kW public charging instead. The Mitsubishi Outlander is currently the only PHEV model available in the UK which is compatible with a DC rapid chargepoint, but due to its small battery capacity, it charges at a rate considerably lower than the 50kW available. No other manufacturers have announced upcoming PHEV models that are capable of rapid charging.

A base level of no chargepoint access was also included to measure the inconvenience of not having a nearby chargepoint or a BEV that is not rapid charge enabled.

Anticipatory charging function

Under the trial's SMC tariff, participants were required to define the SOC that they needed at the end of the charging event. For users that set this final SOC at <100%, if wholesale electricity prices are low (or are anticipated to be high during the next charge event), and the requested SOC is met before the specified end of the charge event, there is an opportunity to further charge the car at lower cost to the electricity supplier and therefore consumer. An *anticipatory charging function* would determine when this is possible, thus providing additional savings to the vehicle owner. The benefit of this function is dependent on the extent to which participants select a required SOC below 100% and how often both cheaper electricity is available and the SOC being met early. The latter is challenging to predict without the actual algorithm for the SMC tariff, and there may be little benefit realised for users that always select 100% SOC. Consequently, this attribute was presented as the maximum value of the additional savings from anticipatory charging, but participants were told that they should expect to receive less than this if the frequently selected a high SOC. Maximum additional savings took two levels, either 10% or 20% above the quoted annual savings, although this was presented in terms of £s to make it easier for participants to evaluate.

A.12.2.2 *Final choice experiment attribute list and design*

The attributes included in the choice experiment, as well as the possible values ('levels') seen by participants, are presented in Table 11:

Table 11: Description of each attribute in the choice experiment and levels shown

Attribute	Description	Levels
Expected annual charging cost savings	Expected net annual financial benefit for participating in each managed charging tariff (assuming consistent trip patterns).	*5 levels*, scaled based on the participant's annual mileage and vehicle used during the trial • £20 / £100 / £150 / £200 / £250 per year If annual mileage >15,000 miles then scaled by factor 2. If vehicle used was PHEV then scaled by factor 0.6.
Accuracy in the estimate of annual charging cost savings (SMC only)	Maximum deviation between the expected and actual annual savings assuming driving patterns remain consistent.	*4 levels* • ±10% / ±25% / ±50% / no variability Expressed in £s, dependent on the annual cost saving level.
Additional cost of charging during peak hours relative to unmanaged charging	Cost of charging at peak times relative to the fixed electricity price available with unmanaged charging.	*4 levels* • No additional cost / +5p/kWh / +20p/kWh / +60p/kWh An indicative cost in terms of additional p/mile is also shown: • No additional cost / +1p/mile / +5p/mile / +15p/mile
Access to rapid charging close to home (BEVs only) or 7kW public chargepoints	Proximity of public charging to home to mitigate risk of car being needed before managed charging has finished.	*4 levels* • Chargepoint within 5 / 15 / 30 minutes of home / no chargepoint available
Existence of an override function (SMC only)	Ability for user to override charging configuration if circumstances change, and associated penalty.	*3 levels* • Yes, complete flexibility to change configuration • Yes, but changing configuration results in loss of all financial reward for that charge event • No, configuration cannot be changed once set

Attribute	Description	Levels
Anticipatory charging (SMC only)	Maximum additional savings from system charging above set end SOC if prices are low and time available.	*3 levels* • Available with extra savings of 10% / 20% • Function unavailable Expressed in £s, dependent on the annual cost saving level.

The choice sets were generated with the software package Ngene by ChoiceMetrics. This used a so-called 'D-efficient' design, which aims to avoid unbalanced choice sets which occur when the utility of one choice is considerably higher than the others (for example, a case where an SMC option shows significantly greater savings than UMC, override availability and a lower peak charging cost). In this case the choice would be obvious for the vast majority of participants and little useful information would be gathered by observing their choices. Efficient design creates only choices where participants must carefully consider the full range of attributes, thereby optimizing the amount of useful information that can be drawn from the limited number of choice questions.

An example choice question is shown in Figure 14. In total, 100 choice questions were generated, and these were arranged in blocks of 10. Each participant was randomly assigned to one of the blocks, and so answered 10 choice questions. For each choice question, participants were asked to choose between a user-managed, supplier-managed or unmanaged charging option. Participants were also asked to choose between only the managed charging options. This ensured that if a participant always chose the unmanaged option in their initial choice, information on their attitude towards managed charging attributes was still collected.

	User-managed charging	*Supplier-managed charging*	*Unmanaged charging*
Net annual savings	**£50** per year	**£200 (+/- £100)** per year	*None*
Additional cost of charging during peak hours relative to unmanaged charging	No additional cost compared with the unmanaged charging rate	**60 p/kWh more** than the unmanaged charging rate (adding about 15p per mile)	*N/A*
Access to 7kW public charging close to home	Public charge point within 5 minutes of house	Public charge point within 15 minutes of house	*N/A*
Availability of an override function	*No override function necessary*	Override available, but changing settings results in loss of all financial reward for that charge event	*N/A*
Anticipatory charging	*N/A*	Yes, giving up to £40 extra saving per year	*N/A*

If you could choose between these three charging schemes, which one would you choose?

☐ ☐ ☐

If you had to choose between one of the managed charging schemes, which one would you choose?

☐ ☐

Figure 14: Example choice question featured in the choice experiment

A.13 Telematics

The trial vehicles were equipped with a telematics device ('dongle') in the form of a self-contained lightweight cellular data logger fitted to the OBD-II port (see Figure 15). The dongles were supplied and maintained by FleetCarma; a Cleantech Information and Communications Technology company based in Ontario, Canada.

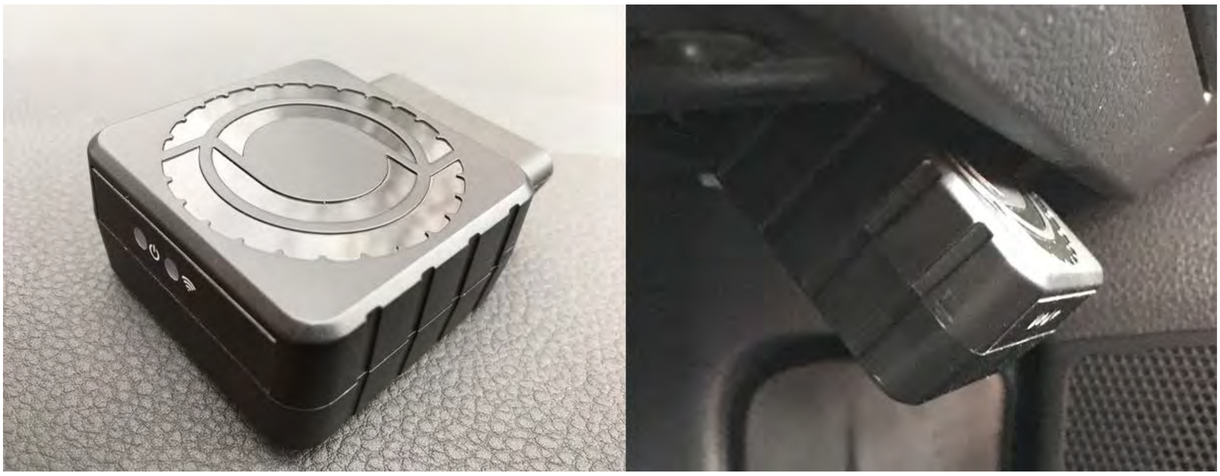


Figure 15: FleetCarma 'C2' telematics dongle (left) and in situ in vehicle (right)

The devices:

- integrated with the FleetCarma web portal to allow real-time capture of vehicle status and location;
- were compatible with all CAN bus and Legacy protocols dating back to 1996, and interface with J1979 OBD-II data;
- were powered by the vehicle battery, with low power consumption;
- automatically transmitted encoded and encrypted data via the cellular SIM card;
- had an on-board backup capacity to store data locally in the event that there was poor cellular signal or a fault with the network; stored data were transmitted automatically once network connection was restored;
- fitted quickly and easily within the vehicle without obstructing the driver or the operation of the vehicle.

The devices collected GPS coordinates, event-based data (e.g. at ignition on/off), and journey and charge data at up to 1Hz whilst the vehicles were in operation.

The data were output into raw datasets (containing the second-by-second data within each journey and charge event) and aggregated 'Journey logs' and 'Charge logs', containing summarised data for each journey and charge event (e.g. average speed during journey, and SOC at start and end of charge event). Full details of the contents of these datasets are provided in Table 12 to Table 15.

Table 12: Telematics data collected for each vehicle – Journey Logs

Data collected	Description	Sampling frequency
Trip ID	Unique ID for each journey; different journeys saved on different rows within the dataset	1 per journey
Start Date & Time	Start date and time for each journey	1 per journey
Trip Distance (mi)	Total distance of journey (ignition on to ignition off)	1 per journey
Trip Duration (hh:mm:ss)	Total duration of journey (ignition on to ignition off)	1 per journey
Starting Odometer (mi)	Odometer at start of journey	1 per journey
Ending Odometer (mi)	Odometer at end of journey	1 per journey
Fuel Consumed (gal)	Total fuel consumed during journey	1 per journey
Fuel Consumption (MPG)	Average fuel consumption in journey (this is calculated in the portal by dividing the number of miles driven by the total gallons of petrol used)	1 per journey
Electricity Consumed (kWh)	Total electricity used during journey	1 per journey
Total Energy Consumption (MPGeq)	Average electricity consumption in journey	1 per journey
Start SOC (%)	Vehicle SOC at start of journey	1 per journey
End SOC (%)	Vehicle SOC at end of journey	1 per journey
Ambient Temperature (°F)	Average ambient temperature during journey	1 per journey
Average Speed (MPH)	Average speed during journey	1 per journey
Max Speed (MPH)	Maximum speed reached during journey	1 per journey
EV-Fraction	Proportion of time during journey in which PHEV was powered by the electric motor as compared to the ICE (PHEV only)	1 per journey
Auxiliary Load (kW)	Amount of energy consumed from the battery for non-driving functions, such as HVAC (PHEV and BEV only)	1 per journey
% Hard Acceleration	Total percentage of all acceleration events that are classified as “hard” acceleration.	1 per journey
% Hard Braking	Total percentage of all braking events that are classified as “hard” braking.	1 per journey
% Time Idle	Percentage of time during the journey in which the vehicle was idling (engine turned on but stationary) (PHEV or ICE)	1 per journey
Number of Idle Events	The count of the total number of idling sessions, where the engine was operating but the vehicle was stationary for more than 60 seconds continuously (PHEV or ICE)	1 per journey

Table 13: Telematics data collected for each vehicle – Charge Logs

Data collected	Description	Sampling frequency
Charge Session ID	Unique ID for each charge session; different charge sessions saved on different rows within the dataset	1 per charge event
Start Date & Time	Start date and time for each charge session	1 per charge event
Charge duration (hh:mm:ss)	Total duration of charge session (charge start to charge stop)	1 per charge event
Charging Power	Power output of the charger, categorised in levels (1 = Slow charge, 2 = Normal charge, 3 = DC fast charge)	1 per charge event
Charger Energy (kWh)	The total amount of energy the vehicle gains during the charging session	1 per charge event
Charger Loss (kWh)	The total amount of energy lost during charging due to heat and other factors	1 per charge event
Start SOC (%)	Vehicle SOC at start of charge session	1 per charge event
End SOC (%)	Vehicle SOC at end of charge session	1 per charge event
Latitude	Latitude GPS coordinates of charge session	1 per charge event
Longitude	Longitude GPS coordinates of charge session	1 per charge event

Table 14: Telematics data collected for each vehicle and journey – Raw journey data

Data collected	Description	Sampling frequency (s)
Start Time (MetaData)	Start time and date of the journey	1 per journey
Timestamp (ms)	Timestamp (ms) for each row in dataset	n/a
Odometer (kilometers)	Odometer reading (km)	30
Vehicle Speed (kph)	Vehicle speed (kph) measured during the journey at 1s intervals	1
RPM	Engine speed (PHEV)	1
ABS_LOAD	Absolute Engine Load (normalized air mass per intake stroke)	1
Fuel Level (%)	Fuel tank level as a percentage of the maximum nominal tank capacity: The Golf GT Edition (ICE) has a 50 litre tank capacity. The Golf GTE (PHEV) has a 40 litre tank capacity.	10
HV Battery Current (A)	DC Electrical current measured at the high voltage battery terminal in amps. + is defined as charging the battery. – is discharging the battery.	1
HV Battery Voltage (V)	DC electrical voltage measured at the high voltage battery terminal in volts. This number will always be positive, and will remain within a consistent range.	1
HV Battery SOC (%)	State of Charge (SOC) (%)	10
HV Battery Temperature (degC)	High-voltage battery pack temperature (°C)	60
OAT (DegC)	Ambient temperature (°C)	60
Is Driving (bool)	Represents a 1 or a 0 to indicate if the vehicle is driving	1
Latitude (deg)	Latitude GPS coordinates	10
Longitude (deg)	Longitude GPS coordinates	10

Table 15: Telematics data collected for each vehicle and journey – Raw charge data

Data collected	Description	Sampling frequency (s)
Start Time (MetaData)	Start time and date of the charge	1 per charge event
Timestamp (ms)	Timestamp (ms) for each row in dataset	n/a
HV Battery Current (A)	DC electrical current measured at the high voltage battery terminal in amps. + is defined as charging the battery. – is discharging the battery.	1
HV Battery Voltage (V)	DC electrical voltage measured at the high voltage battery terminal in volts. This number will always be positive, and will remain within a consistent range.	1
HV Battery SOC (%)	State of Charge (SOC) (%)	120
HV Battery Temperature (degC)	High-voltage battery pack temperature (°C)	60
Is Charging (bool)	Represents a 1 or a 0 to indicate if the vehicle is charging	1
Latitude (deg)	Latitude GPS coordinates	300
Longitude (deg)	Longitude GPS coordinates	300

A.14 Data management

All data storage and handling was performed in accordance with the International Standard for Information Security Management System (ISO 27001:2013).

On completion of the first recruitment survey, all participants were assigned a unique Participant ID number. All subsequent data collected was then linked to this Participant ID to ensure all data sources were linked, but participants' anonymity was retained.

A.14.1 *Questionnaire data*

The Pre-trial, Time Point 1 and Time Point 2 questionnaires were hosted online by Accent. The Filter Survey questionnaires and the Interim questionnaires were hosted online through TRL's corporate SmartSurvey account. Questionnaire data was downloaded by TRL in electronic format. Each questionnaire was recorded with the Participant ID to enable linking between the different questionnaires (e.g. Filter Surveys, Time Point 1 and Time Point 2) and to enable linking with other sources of data (e.g. telematics).

All questionnaire data was cleaned by TRL, including checking for missing or invalid values and unusual patterns in the data. For example, if participants always answered the first option for each question in a particular set then it suggested they may not have answered honestly and openly; data were flagged for such cases. The completion time for core questionnaires (Pre-trial, Time Point 1, Time point 2) was logged by Accent. Average completion times were assessed for each questionnaire, and extreme outliers were identified. Any outliers which are deemed to represent invalid responses were flagged (such as those which were completed unusually quickly or unusually slowly[21]).

A.14.2 *Choice experiment data*

Element Energy cleaned and processed the raw data from the choice experiment before undertaking the required consumer choice analyses. These analyses are described in more detail in section A.12 and in response to the research questions outlined in Appendix B.

A.14.3 *Telematics data*

Telematics data was provided by FleetCarma (see section A.13). All datasets were cleaned by TRL in order to remove data which did not represent valid participant use cases. The cleaning process included:

- Removing journeys less than 0.1km (100m) in distance or one minute in time (whichever was lesser) – to remove instances where, for example, the driver turned the vehicle on and off in order to check the charge, or moved the car in the driveway.
- Removing journeys carried out by TRL or Cenex staff as part of the vehicle handover process, or when the vehicle required maintenance (i.e. non-participant events).

GPS coordinates during charge events were anonymised by recoding the location data as either ‘Home’ or ‘Away from home’. Repeated charge events which occurred away from home were identified using appropriate labels (e.g. Away from home 1, Away from home 2, etc.) to enable analysis of journey patterns. For example, if a participant charged at work on multiple occasions, all charge events at this location were given a single location label (e.g. Away from home 1).

GPS coordinates captured within journeys (i.e. in the raw journey data files) were also anonymised and recoded to ensure protection of personal data.

To retain potential future value of the dataset, additional spatial information was coded into the journey dataset prior to anonymisation:

- Road type
- Distance from nearest chargepoint
- Distance from home
- Land use (e.g. urban major conurbation, rural hamlets and isolated dwellings)

[21] Completion times were captured for all questionnaires completed during piloting and during the trial. Using these data, an acceptable range of completion times was defined based on the average completion time +/- three standard deviations.

A.14.4 *Home charging and User App data (from the CPMS)*

Data from the chargepoint was pushed to the CPMS every five minutes during charging. Vehicle SOC was also pushed to the CPMS from the FleetCarma telematics dongle at two-minute intervals. These data were processed by EV Connect to:

- Remove plug-in events less than 5 minutes in duration.
- Remove non-participant plug-in events (i.e. when the vehicle was with TRL/Cenex staff)
- Remove plug-in events from non-participant vehicles (e.g. if a non-trial EV plugged into the home chargepoint)

The chargepoint, telematics and User App data were collated in order to provide a holistic 'Charge Event' dataset for home charging events. This included:

- Date and timestamps of plug-ins
- SOC at plug-in
- User entered charging preferences, including whether or not defaults were used (for UMC and SMC groups only)
- Date and timestamps of charge start
- User interactions during charging, including whether or not original UMC/SMC parameters overridden (for UMC and SMC groups only)
- Date and timestamps of charge end
- SOC at plug-out
- Savings Points earned for charge event

Data on charging 'away from home' was also captured and included:

- Date and timestamps of charge start
- SOC at charge start
- Date and timestamps of charge end
- SOC at charge end

A.14.4.1 *CPMS technical issues*

During the trial, some technical issues were encountered with the mobile communication between the CPMS and the Rolec back-office (see Figure 8). These technical issues included:

- Incorrect configuration of chargepoints, vehicles and participants in the CPMS resulting in incorrect or failed communication sequences
- Poor mobile 3G/4G signal at participants' homes resulting in loss of ability for CPMS to communicate with the chargepoints via the Rolec back-office, and loss of ability of FleetCarma telematics dongle to communicate SOC updates
- High volumes of traffic, and incidences of 'spam', on the Rolec server affecting functionality of the Rolec back-office to communicate with the CPMS within suitable timeframes

- Technical faults with chargepoint hardware resulting in loss of 'smart' functionality

These issues did not affect all participants, and were managed throughout the trial on a case-by-case basis by the project team. For some participants, the issues resulted in a loss of charging data collected during the trial. This was mitigated in two ways:

1) For participants who lost more than two weeks' worth of charging data but whose technical issues were resolved, their 8-week experience was extended in order to recover the lost data
2) For participants who lost more than two weeks' worth of charging data and whose technical issues could not be resolved, their data was excluded from the analysis and replacement participants were recruited to recover the lost data.

Data was also excluded for any participants who chose to withdraw from the trial before their 8-week experience was complete.

A.15 Data analysis

A.15.1 *Segmentation*

The majority of the questions developed for the ETI PiV study were subsequently used by Element Energy in a study commissioned by DfT of consumer attitudes to plug-in vehicles (Element Energy, 2015). In that study, a fresh clustering analysis was applied to data from the new sample of 2,020 participants. This new segmentation analysis (though on a very similar set of questions to the PiV study) resulted in six segments (as shown in Figure 16) and it was these consumer choice coefficients that were incorporated into the ECCo model.

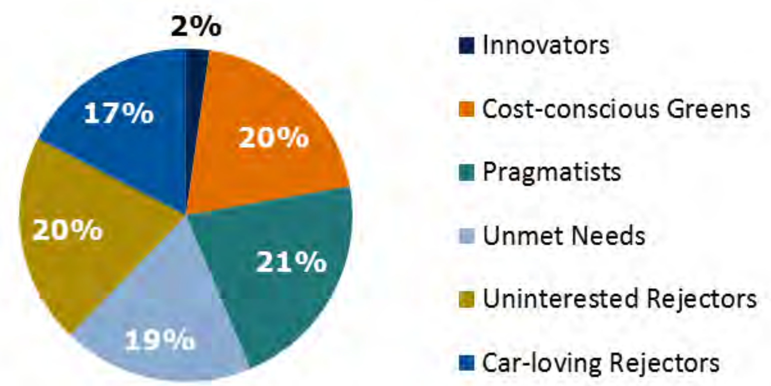


Figure 16: Consumer segment shares in choice experiment sample of the DfT survey (Element Energy, 2015)

The consumer segments were pre-defined in earlier work (Element Energy, 2015) as follows:

- **Innovators:** A small but motivated group. Can be described as technology savvy, willing to try new experiences, car and driving lovers and buyers of medium and large sized highly priced cars. The most likely group to be in employment, young and predominantly male. They have green credentials but not as concerned about the environment as Cost-conscious Greens.
- **Cost-conscious Greens**: The most environmentally-conscious, and most likely to express concern about the environment and the need for energy security. Most likely

to say they would pay more for lower running costs. They have an average enthusiasm for new technology. Average annual mileage, medium frequency of journeys over 80km.

- **Pragmatists**: Average interest in new technology and cars. They enjoy driving and somewhat agree that cars indicate status, but also have some pro-environmental motivations and value independence from oil. Average income, with an interest in reducing vehicle running costs. Highest annual mileage among the three segments, and the most frequent makers of journeys over 80km.
- **Unmet Needs:** Potential late adopters, their attitudes and relatively high expenditure on cars favour electric vehicle adoption, but due to practical reasons they are unlikely to purchase them (e.g. electric range perceived as not suitable for their frequent long trips). Most own two or more cars and have high annual mileage.
- **Uninterested Rejectors**: Attitudinally neutral about the environment, feel moral obligation to reduce greenhouse gases but do not see this as a priority. Do not particularly like cars or driving but recognise strong link between cars and status, and are interested in new technology. Tend to be young, with an even split between males and females. Average annual mileage, least frequent makers of journeys over 80km.
- **Car-loving Rejectors:** Have similar demographics to Innovators: high income, employment status and a high predominance of males. Also have similarly high interest in new cars but as the least green group, see little reason to switch from ICE vehicles to electric power. In seeing cars as a status symbol, they are in fact resistant to such a change.

For this CVEI Consumer Charging Trial, as with the Uptake Trial, the sample size was too small to undertake a fresh new clustering analysis to see whether a fresh set of segments could be derived. On this sample of 248, and with a large question set even when reduced through factor analysis (if we followed the original PiV and DfT methodology), there would be so many possible answer combinations that it would be very difficult to find a cluster structure among such a small number of people.

The solution to this was to rely on the robustness of the DfT study, which had itself been based on a tried and tested and theoretically rich question set (the original PiV study) and a large sample size of over 2,200 to derive its segments. Therefore, this dataset was used to generate a set of question weightings. These could then be assigned to the responses for each person in the Consumer Charging Trials in order to allocate them into a segment – i.e. the same segments as in the DfT study. The steps to do this were as follows:

1. The questions which featured in both the DfT study and the current Consumer Charging Trials[22] were identified; this was restricted to numerical or ordinal variables only. A set of 68 were identified.
2. A discriminant analysis (DA) was undertaken using these 68 questions. DA identifies which combination of attitude questions contributes the most to the separation between the segments (rather like multiple linear regression, but this time on a set of

[22] Where the CVEI survey made a distinction between BEV and PHEV in some questions, but the DfT survey just asked about 'EVs', the average of the two CVEI questions was used.

interval/categorical variables). This process was used to identify a set of 'golden questions' and a set of weightings for each one. The golden questions comprised the smallest number of questions that can be used to most accurately replicate the segment solution (using the question weights generated) on a new sample.

The DA was carried out at four separate levels to derive different sized sets of 'golden questions' and associated question weightings. The difference between these sets was the trade-off between the number of questions and the assignment accuracy. Each question set is compared in Table 16.

It is inevitable when using a reduced subset of the original survey questions (i.e. not using every single variable that was used in the original segmentation) that the accuracy of the allocation procedure will never be 100%. Statistically, the minimum requirement is that the model accuracy performs 25% better than would happen by chance. For instance, if there were two equally sized segments there would be a 50/50 chance that someone would be accurately classified in the correct group by random. For these segments, the chance of accurately classifying someone in the correct group is 20%, leaving a minimum acceptable hit ratio of 45%, although it is desirable to aim for a hit ratio of 70-80%.

Table 16: Reliability of the allocation algorithms for each segment for each DA solution[23]

	Predicted Accuracy (%)				
	All 68 variables	(1) 42 variables	(2) 29 variables	(3) 25 variables	(4) 21 variables
Uninterested Rejecters	85%	82%	81%	79%	76%
Cost-conscious greens	79%	76%	76%	74%	74%
Pragmatists	76%	76%	73%	75%	73%
Car-loving Rejecters	84%	83%	81%	80%	78%
Unmet needs	65%	63%	57%	56%	57%

3. Although it would have been possible to just choose the solution from above that has the most accuracy, there was not much difference between them. Given that the goal is to try and find the smallest number of questions that will work, all four solutions were applied to the new Consumer Charging Trial dataset. The DA function generates a set of weightings for each question and these are applied to each participant's scores on the predictor variables to predict the segment to which the individual belonged.
4. The four sets of segment assignments were compared in terms of how well they had generated a sensible and well discriminated set of segments from the new data. The solution with the greatest and clearest degree of separation was chosen. This involved using ANOVA analysis and comparing the F-ratio (which computes the variance

[23] Note: only 5 segments were predicted because the Innovator segment was derived a priori in the DfT study (as with the original PiV study) using a set of criteria (based on purchase price of last car, plans to purchase an EV) and not through the cluster analysis.

between groups relative to the variance within groups) and choosing the highest. The solution with the highest F-ratio was solution (3) with 25 variables (Total F for each solution (1) = 242.487 (2) = 230.920 (3) = 242.063 (4) = 198.131).

This process enabled participants in the Consumer Charging Trials to be allocated to the existing ECCo segments. The final set of 25 variables used, and the resulting five segment solution are introduced in section B.3. The segment which is earliest to adopt (i.e. Innovators, or the previously entitled 'Plug-in Pioneers' in the PiV study) were not identified in the Consumer Charging Trial sample (as with the Uptake Trial), in keeping with the objectives of the trial to eliminate Innovators during the recruitment process.

Table 17 shows the 25 variables used in the assignment of participants to segments. Out of the 25 variables, 21 differ significantly between all five groups. This ranking provides some information about each variable's contribution to the separation of the segments. The differences between segments can be seen from their representative values such as mean values of the input variables from each segment. Grey shading indicates that this variable does not differ statistically significantly ($p < 0.05$) between segments. Where this is the case across, these variables have essentially not contributed to the assignment of participants to segments. Green shading indicates which segment has the highest value of that variable, and blue the lowest.

Table 17: Variables included in the discriminant analysis and their ranking in terms of importance in assigning participants to segments

	Uninterested Rejecters	Cost-conscious Greens	Pragmatists	Car-loving Rejecters	Unmet Needs	*Full sample mean*	F	Sig.
A car provides **status and prestige**	1.92	2.00	3.30	2.81	3.09	*2.95*	22.388	.000
My car says something about who I am	2.11	2.64	3.40	2.63	3.57	*3.15*	19.382	.000
I am usually among the **first to try new technology**	1.92	2.29	3.35	2.56	2.52	*2.88*	18.356	.000
Driving gives me a **chance to express myself**	1.65	2.07	2.99	2.63	2.52	*2.63*	17.381	.000
Total mileage in past 12 months for the car you drive most often[2]	9223	7589	10374	17656	11705	*10751*	14.039	.000
I like the idea of being able to **'refuel' at home** rather than have to go to petrol stations[1]	4.01	4.67	4.05	3.50	4.32	*4.1*	9.590	.000
I like **magazines / websites** about new cars	2.14	2.07	3.24	2.38	2.68	*2.85*	9.512	.000
Household residents **50-64 years**	.78	1.07	.46	.50	1.20	*.68*	8.260	.000
BEVs/PHEVs are a good thing because they make us **less dependent on oil**[1]	3.73	4.68	3.9	3.44	4.07	*3.93*	8.131	.000
I don't like driving	1.70	2.07	1.37	1.56	1.98	*1.58*	7.208	.000
I **enjoy driving on my own**	3.62	3.36	4.13	4.00	3.80	*3.94*	6.951	.000
I am not the sort of person that looks to **experience driving different cars**	3.16	3.29	2.23	2.69	2.59	*2.52*	6.747	.000
Total household **income** from all sources before tax and other deductions[3]	5.27	4.36	4.75	6.19	6.07	*5.13*	5.699	.000
Household residents **17-29 years**	.27	.64	.46	.31	.86	*.50*	4.505	.002
I would pay more for a car with **lower running costs**	3.41	3.86	3.63	2.94	3.66	*3.57*	4.393	.002
I would prefer my car to be **fuelled by something other than petrol or diesel**	3.68	4.36	3.74	3.13	3.77	*3.73*	4.299	.002

	Uninterested Rejecters	Cost-conscious Greens	Pragmatists	Car-loving Rejecters	Unmet Needs	*Full sample mean*	F	Sig.
Reducing my car's environmental impact would make me feel good	3.62	4.14	3.82	3.44	4.07	*3.83*	3.107	.016
I couldn't manage without a car	4.08	3.50	4.34	4.63	4.39	*4.28*	2.982	.020
When I feel fuel prices are getting too high, I try and reduce the amount I drive	2.30	2.79	2.68	2.63	3.02	*2.69*	2.942	.021
Sometimes I feel under pressure to say that I am doing more to help the environment than I am	2.30	2.00	2.61	2.31	2.61	*2.51*	2.569	.039
It's not worth me doing things to help the environment if others don't do the same	2.00	2.93	2.41	2.44	2.20	*2.34*	2.555	.040
I tend to stick to the same brand of car (e.g. Ford, Toyota, Nissan)	2.27	2.43	2.85	2.88	2.75	*2.73*	2.388	.052
Being environmentally responsible is an important part of who I am	3.41	3.79	3.39	3.13	3.59	*3.44*	1.465	.214
Household residents **65+ years**	.32	.21	.14	.19	.16	*.18*	1.033	.391
The so called 'environmental crisis' has been greatly exaggerated	2.19	2.36	2.15	1.88	2.09	*2.14*	.570	.685

Notes: [1] *Mean score on 5-point Likert scale from 1 (strongly disagree) – 5 (strongly agree);* [2] *Mean total miles travelled in the most driven car by segment members;* [3] *Mean score on 9-point household income scale starting at 1 (Up to £9,999 per year (£199 per week) per year up to 9 (£150,000 or more per year (£2,940 or more per week); Grey shading denotes no statistically significant difference between segments; Green shading indicates the highest values, and blue the lowest*

In interpreting the results of the segments, some caveats need to be considered:

- The original PiV and subsequent DfT segmentations were carried out on random samples of the national UK population, whereas the Consumer Charging Trials have been conducted on geographically specific samples.
- In addition, there is no way of avoiding some bias in a study which asks people to take part in a trial (especially one that requires certain infrastructure such as off-street parking/ garage which is already an unrepresentative subset of the whole population). Although the nature of the study (low carbon vehicles) was not disclosed to participants until they were some way in to the trial, they still had to be prepared to invest time and effort into such an activity. In some cases this could mean they were disproportionately keen to be involved in vehicle trials which could introduce attitudinal bias. It is not possible to control or correct for these biases as they are non-observable characteristics.

These differences between the samples, combined with several years between the different surveys in which the general population have gained greater awareness of EVs, plus the smaller sample size of the Consumer Charging Trials, will have introduced a variety of reasons why the different segmentation exercises will result in different group proportions.

A.15.2 *Factor analysis and reliability measures*

The questionnaires were made up of many attitudinal items which measured participants' attitudes and personality traits. For example, the driving style questions were made up of 44 items, each on a six-point scale from 'not at all' to 'very much', which provided information on self-reported driving style.

In order to reduce the number of variables to a more manageable number for statistical analysis, a data reduction technique called factor analysis was applied to these items. This combined the information from a large number of similar items into a smaller set of factors. It did this by looking at the inter-correlations between items and identifying common groups. The resulting factors represented coherent subscales and was used in subsequent analysis.

The reliability of these subscales will be confirmed using reliability measures such as Cronbach's alpha (α). A highly reliable scale implies that all the items collectively describe the same personality or behaviour. A scale is considered to have good internal consistency if the output from the reliability of the scale gives a Cronbach's alpha coefficient of 0.7 or higher.

To ensure that results were comparable between each of the questionnaires, the same factoring was used for both the Time point 1 and Time point 2 questionnaires.

A.15.3 *Statistical comparisons*

Comparison of the factors, discussed above, was conducted using repeated-measures statistical methods. This enabled identification of differences in attitudes before and after involvement in the trial. These repeated-measures techniques included:

- Analysis of Variance (ANOVA) or Generalised Estimating Equations (GEE)
- Paired t-tests or Wilcoxon matched-pairs tests
- Cochran's Q or the McNemar dichotomous variables test

In addition, comparisons of attitudinal data were made between the three experimental groups. This enabled identification of differences in attitudes between the three experimental groups. Since each group contains different participants, a between-subjects analysis was not required. These techniques included:

- Analysis of Variance (ANOVA)
- Independent samples t-tests
- Chi-squared tests

Statistical tests were also performed on the charging data to test for differences in behaviour between participants in the Control group and those in the UMC and SMC groups.

Charge events were split into those that took place on a weekday or a weekend, and those at home and locations away from home, and separate tests were performed for each. For analysis of plug-in times and charge start times, data were grouped into four time bands (see Table 18). Chi-squared tests were then used to compare between the three groups.

Table 18: Time period groupings used to analyse differences in charging behaviours between control and managed charging groups

Time period	Control group	UMC group	SMC group
Morning (6am-12pm)	Proportion of events (weekday/weekend, home/away)	Proportion of events (weekday/weekend, home/away)	Proportion of events (weekday/weekend, home/away)
Afternoon (12pm-4pm)	Proportion of events (weekday/weekend, home/away)	Proportion of events (weekday/weekend, home/away)	Proportion of events (weekday/weekend, home/away)
Evening (4pm-10pm)	Proportion of events (weekday/weekend, home/away)	Proportion of events (weekday/weekend, home/away)	Proportion of events (weekday/weekend, home/away)
Overnight (10pm-6am)	Proportion of events (weekday/weekend, home/away)	Proportion of events (weekday/weekend, home/away)	Proportion of events (weekday/weekend, home/away)

Each test is reported with a test value (e.g. a Z or χ^2 value) and a measure of statistical significance (otherwise known as a *p*-value). The test value is a statistical calculation and relates to the degree of difference in the data being compared. Generally speaking, the greater the magnitude of a test value, the more significant the result. The test values each relate to a *p*-value. The typical *p*-value used in social science is 0.05; if the *p*-value is less than 0.05 it means that there is a more than 95% probability that the results observed (or more extreme results) did not occur by chance alone and is referred to as a statistically significant result. Some results in this report are reported as 'marginally significant' with a *p*-value of less than 0.1.

A.15.4 *Regression analysis*

Responses to questions on energy tariff choice were used to supplement the findings from the stated choice experiment to understand whether personal characteristics (e.g. personality, self-congruity, driving style, demographic variables) or personal-situational variables (e.g. income) were predictive of mainstream consumers' preferences between SMC, UMC, and Unmanaged Charging (NMC).

Multinomial regression, which is used when the dependent variable is categorical, was used to determine which variables predicted energy tariff choice. The analysis used responses to the question: "If you owned a BEV (PHEV), which type of energy tariff would you choose?" as the dependent variable and assessed which variables best predicted the answer to this question.

A.15.5 *Choice experiment*

The results of the choice experiment were analysed using the statistical package NLogit (Version 4.0), which fits a simple multinomial logit model to derive the choice coefficients (β) for each of the vehicle attributes investigated. The logit model used is presented in Table 19, and consisted of utility equations for each of the three charging scheme alternatives.

Table 19: Components of the utility equations for each alternative (SMC, UMC and NMC[24]) in the choice experiment. Total utility is the sum of each column.

Attribute	U_{SMC}	U_{UMC}	U_{NMC}
Expected annual charging cost savings	$\beta_{savings} \times Annual\ Savings_{SMC}$	$\beta_{savings} \times Annual\ Savings_{UMC}$	-
Additional cost of charging during peak hours relative to unmanaged charging	$\beta_{peak,SMC} \times Additional\ Peak\ Cost_{SMC}$	$\beta_{peak,UMC} \times Additional\ Peak\ Cost_{UMC}$	-
Access to rapid charging close to home (BEVs) or 7kW public chargepoints (PHEVs)	$\beta_{charging\ prox\ =\ 5mins,SMC} \times Charging\ Prox[5mins]_{SMC} + \beta_{charging\ prox\ =\ 15mins,SMC} \times Charging\ Prox[15mins]_{SMC} + \beta_{charging\ prox\ =\ 30mins,SMC} \times Charging\ Prox[30mins]_{SMC}$	$\beta_{charging\ prox\ =\ 5mins,UMC} \times Charging\ Prox[5mins]_{UMC} + \beta_{charging\ prox\ =\ 15mins,UMC} \times Charging\ Prox[15mins]_{UMC} + \beta_{charging\ prox\ =\ 30mins,UMC} \times Charging\ Prox[30mins]_{UMC}$	-
Existence of an override function	$\beta_{partial\ override} \times Override_{partial} + \beta_{full\ override} \times Override_{full}$	-	-
Alternative Specific Constant[25]	ASC_{SMC}	ASC_{UMC}	-

This model resulted in a log-likelihood function value for the whole sample that was closest to 0, and therefore demonstrated the greatest statistical significance. The log-likelihood function provides a measure of the model fit (Hensher, Rose, & Greene, 2005). Attributes with only a single choice coefficient, such as annual savings and additional peak charging cost, were modelled as continuous and the coefficient represents the change in utility for each unit change in the attribute's value (for example, each additional pound of annual savings). This is sufficient if the relationship between attribute value and utility is considered to be linear.

For other attributes, a choice coefficient was derived for each attribute level featured in the choice experiment. This is required if the attribute values are categorical (do not lie on a numerical scale), such as the override function, or the relationship between attribute value and utility appears to be non-linear, such as proximity to charging infrastructure. In this case, utility is measured relative to one of the attribute levels (i.e. the base level).

The derived choice coefficients for each attribute can be expressed in terms of willingness-to-pay (WTP) by dividing by the annual savings coefficient, $\beta_{savings}$. In this case, WTP for an attribute represents the change in annual savings that would have an equivalent effect on the charging scheme's utility as a change in that attribute's value. For example, if WTP for an attribute is £50/yr, then participants are willing to give up £50/yr more in annual savings for

[24] Unmanaged Charging (NMC)

[25] Note the Alternative Specific Constant encompasses the value of the unobserved factors not explicitly investigated in the choice experiment, as well as correcting for the fact that some options gain utility from attributes that are not relevant to others (e.g. existence of override function applies only to SMC).

a managed charging scheme with that attribute than an equivalent scheme without it. In other words, adding that attribute to a managed charging scheme would increase the share of participants choosing it by the same amount as increasing the annual savings by £50/yr.

Choice coefficients were derived separately for participants in the BEV trial and the PHEV trial. For both sets of participants, they were instructed to answer the choice experiment questions assuming they owned the car they used during the trial. Derived coefficients were tested for statistical significance, using their probability value (p-value) reported by NLogit. A coefficient is considered statistically significant if its p-value is less than 0.05. This signifies that there is only a 5% chance that a non-zero coefficient was identified due simply to a random sampling error. Where relevant, results which are not statistically significant are still presented in this report but caveated with their p-value.

A.15.5.1 *Simple choice model*

To illustrate the impact of each attribute on consumer preference, a simple choice model was constructed, using the derived choice coefficients. For a particular set of attribute values, the model predicts the share of trial participants that would choose each of the three alternatives (SMC, UMC and NMC) under choice experiment conditions. Note that this is not necessarily the same as the predicted uptake share under market conditions. Predicting uptake of managed charging amongst real world consumers may require additional steps to account for the facts that participants were not considering real money in a choice experiment, that other alternatives may be available, and that consumers may show inertia in switching away from unmanaged charging. The latter may result because consumers at present by default will not use a managed charging scheme, and so choosing to even consider whether the switch to a managed charging scheme will require effort (which adds disutility). A similar characteristic is observed in consumers' unwillingness to switch electricity or gas supplier, despite a cheaper supplier potentially being available. The results of the choice experiment may also be influenced by the fact that participants were answering the choice questions assuming they owned the vehicles used in the trial. Real world choice may also be affected by the specifications of the vehicle owned, for example, electric range and charging speed. Therefore, rather than modelling real world choice, this choice model should be considered as an illustration of the influence each attribute has on choice between the three specific alternatives.

The model reproduces the multinomial logit model used to derive the choice coefficients. The share for alternative i is calculated via the logit equation:

$$share_i = \frac{e^{U_i}}{\sum_j^n e^{U_j}}$$

- U_i is the utility of alternative i
- n is the total number of alternatives, which in this case is 3 (SMC, UMC and NMC)

The choice model contains a set of 'reference' values for each attribute. The impact of changing the value of a single attribute on participant choice can then be illustrated by keeping all other attributes at their reference values. Although the actual reference values used do not matter, since they are used merely to illustrate one attribute's influence on choice, they should be realistic. They have therefore been based on estimates for the year 2025 from the CVEI Demand Management Aggregator Framework Model (see Deliverable

D7.5 – Systematic Sensitivity Analysis), which uses charging data derived from this trial. The values used are shown in Table 20.

Table 20: Reference values used for each attribute in the choice model[26]

	SMC	UMC	NMC
Expected annual charging cost savings	£130 for BEVs £40 for PHEVs	£130 for BEVs £40 for PHEVs	-
Additional cost of charging during peak hours relative to unmanaged charging	10 p/kWh	10 p/kWh	-
Access to rapid charging close to home (BEVs) or 7kW public chargepoints (PHEVs)	10 minutes	10 minutes	-
Existence of an override function	Override available, but changing configuration results in loss of all financial reward for that charge event	-	-

Outputs from the choice model are displayed in Appendix B to support answers to the study research questions.

[26] A detailed explanation of why each attribute was presented in the way shown is included in Appendix K of CVEI 170922-6.1 D5.1 – Part 4 – Appendices for Consumer Charging Trial, as well as in Appendix A.12.2 of this report.

Appendix B Results

This Appendix provides full details of the results from analysis of the trial data. A discussion of the key findings and overall conclusions from the trial can be found in the accompanying Summary Report.

B.1 Sample characterisation

- **A total of 248 participants completed the trials (127 in the BEV Charging Trial and 121 in the PHEV Charging Trial).**
- **The final sample for the PHEV trial closely matched the target stratification criteria for age, gender and resident area. Due to the constraint that the BEV sample had usage patterns compatible with the restricted range of a BEV, the BEV sample represented a subset of the mainstream consumer population whose vehicle usage was compatible with BEVs, and therefore there was no target stratification for this group. Nevertheless, the proportions of BEV participants across age groups, gender and resident area broadly matched the PHEV sample.**
- **The types of main car owned by participants in both samples aligned with the most popular car segments in the UK (Lower medium, Upper medium, Supermini and Dual purpose).**
- **Some differences between the samples and the wider national population were identified, likely due to the recruitment criteria and the trial locations used for the trial:**
  - **Households with two or more cars were overrepresented.**
  - **The two samples underrepresented drivers who travel less than 5,000 miles per annum. Drivers who travel more than 15,000 miles per annum were overrepresented in the PHEV trial.**
  - **Both samples underrepresented households with an annual income of less than £30,000.**
  - **Both samples overrepresented married individuals, and underrepresented single or separated/divorced individuals.**

B.1.1 *BEV Charging Trial*

The final sample of BEV Charging Trial participants is shown in Table 21. Differences between the final sample and the target sample are shown for each cell; this confirms that the final sample represented a close match to the original target of 40 participants per group, and 20 participants per Summer/Winter sub-group.

Table 21: Final sample of BEV Charging Trial participants (differences between final and target sample shown in parentheses)

Group	Number of participants		
	Summer	Winter	Total
Control	n/a	n/a	**41 (+1)**
Supplier-Managed Charging (SMC)	22 (+2)	18 (-2)	**40 (0)**
User-Managed Charging (UMC)	24 (+4)	22 (+2)	**46 (+6)**
Total			**127 (+7)**

Due to the constraint that the BEV sample had usage patterns compatible with the restricted range of a BEV (see section A.3.1), the BEV sample represented a population of "usage-compatible mainstream consumers" – that is, mainstream consumers for whom the vast majority of return journeys were shorter than 80 miles. As a result, the sample was not directly stratified by age, gender and location (as was done in the PHEV Consumer Charging Trial); nevertheless, the proportions of participants across age groups, gender and location broadly matched the PHEV sample. The distribution across these variables is shown in Table 22.

Table 22: Demographics of BEV Charging Trial participants

Resident area	Age group	Gender		Total
		Male	Female	
Rural	19-29	3	3	**6**
	30-49	9	5	**14**
	50+	10	2	**12**
Urban	19-29	10	8	**18**
	30-49	25	15	**40**
	50+	24	13	**37**
Total		**81**	**46**	**127**

Of the 127 BEV trial participants, 64% were male and 36% were female. The majority (75%) of participants lived in urban areas. About 43% were aged 30-49 years.

Additional data were collected from each participant using the Filter surveys, Pre-trial Questionnaire and TP1 questionnaire to enable further characterisation of the final sample; these data are summarised for the BEV sample level in the following sections. Further profiling of the sample at the consumer segment level is provided in section B.3.

B.1.1.1 *Household vehicle ownership and use*

Participants were asked to provide information on the number and type of cars, and number of drivers in the household. The distribution of the number of cars in each household in the BEV Charging Trial sample is shown in Figure 17 – left. Almost 60% of the participants reported having two cars in their household, 25% reported having only one car, and the remaining 16% had more than 2 cars.

Data from the National Travel Survey (NTS, 2017) was used to assess the extent to which the distribution of car ownership in the sample was representative of the wider national population (see Figure 17 – right)[27]. Households with 2 or more cars were overrepresented in the sample compared with the UK population as a whole; 75% of participants reported having 2 or more vehicles, compared with 35% of households in the wider population. This was at least in part due to the recruitment criteria for the trial; firstly participants were required to have access to their own private vehicle (ruling out households with no cars) and secondly participants were required to have off-street parking for at least one vehicle, meaning the majority of participants lived in houses with driveways and/or garages where it is more common for there to be multiple vehicles compared with other types of accommodation.

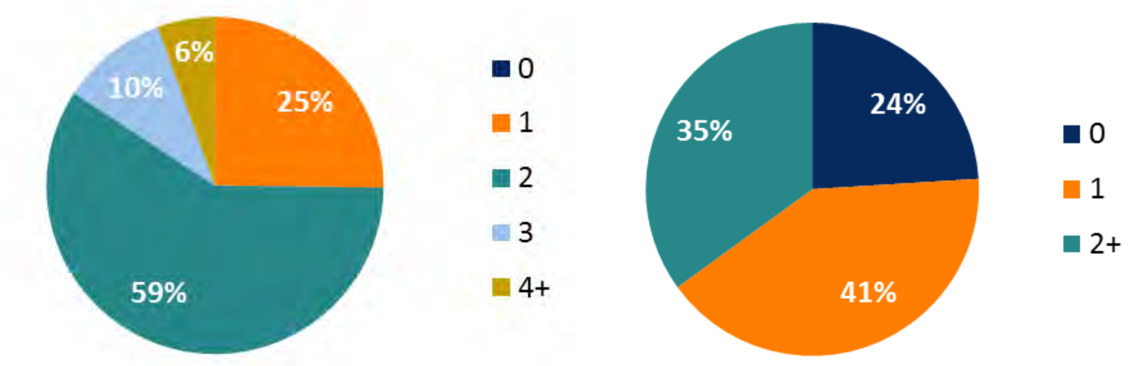


Figure 17: Number of cars owned by 127 participants in BEV Charging Trial (left) and distribution of household car ownership in the national population (NTS, 2017) (right)

The distribution of different types of cars owned by participants in the sample is shown in Figure 18. The Lower medium, Upper medium, and Supermini segments were the most common categories of cars owned by participants. Data on the proportions of these car categories across the entire UK vehicle parc are not available. However, the Society of Motor Manufacturers and Traders (SMMT) reports the number of annual new car registrations by segment type which can be used as a proxy. These data show the top four segments with the highest number of registrations in 2017 were Supermini (29.5%), Lower medium (28.7%), Dual purpose (18.1%) and Upper medium (9.6%) (SMMT, 2018); thus suggesting the types of

[27] The National Travel Survey, published by the UK's Department for Transport, provides statistics on personal travel within Great Britain by a sample of residents of England:

https://www.gov.uk/government/collections/national-travel-survey-statistics vehicles owned by participants in the sample followed a broadly similar pattern to national trends.

Type of car	Count of participants
Lower medium	47
Upper medium	22
Supermini	25
Dual purpose	9
Specialist sports	6
MPV	7
Mini	5
Executive	6
Luxury	0
Total	**127**

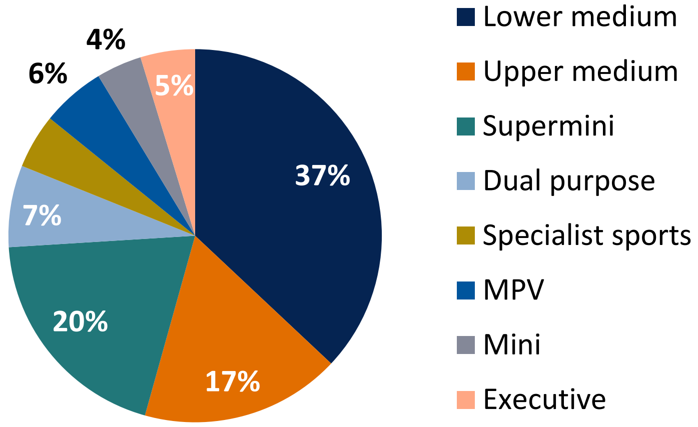


Figure 18: Type of car owned by BEV participants

Figure 19 presents the number of licensed drivers in participants' households. The large majority of the sample had either one driver (13%) or two drivers (72%) in the household.

Number of drivers in household	Count of participants
1	17
2	92
3	13
4	4
5	1
Total	**127**

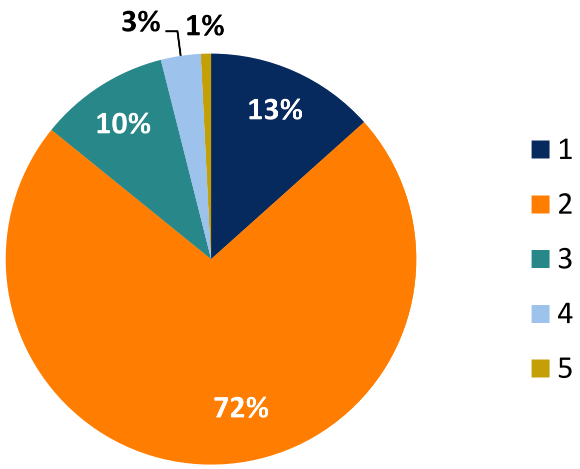


Figure 19: Number of drivers in the household in BEV Charging Trial

Figure 20 displays participants' reported number of private and company cars which were kept at their households. The majority of participants (84%) reported having either 1 or 2 private cars. Very few participants (3%) reported having a company car, in line with the recruitment criteria for the trial which ruled out any prospective participants who had a company car as their main vehicle (see section A.3.3).

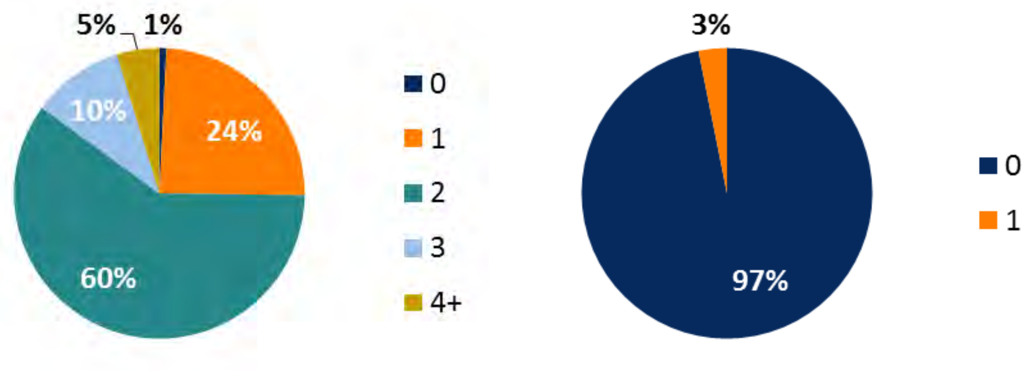


Figure 20: Number of private cars (left) and company cars (right) kept at the households of BEV participants

The characteristics of participants' main cars at the time of purchase are shown in Figure 21, in terms of the age of the vehicle (one missing response removed) and the purchase price. The majority of participants' main vehicles were more than 2 years old at the time of purchase and half paid £10,000 or less for their main car.

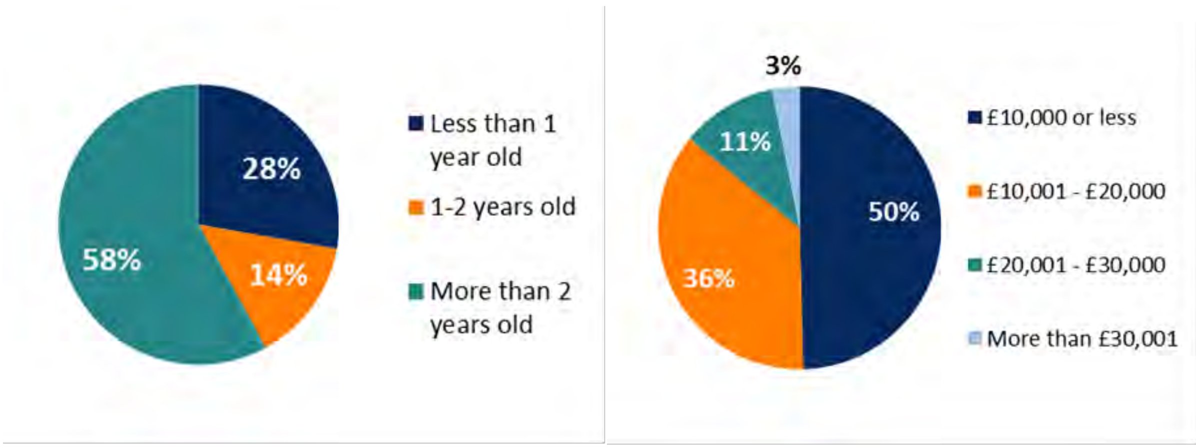


Figure 21: Age (left hand panel) and value (right hand car) of main car at time of purchase of BEV participants in the final sample

B.1.1.2 *Car mileage*

A summary of BEV trial participants' reported annual mileage travelled by car is shown in Figure 22 in comparison with the distribution of self-reported annual mileage from the National Travel Survey (2017). The proportion of low mileage drivers was underrepresented in the BEV Charging Trial sample compared with the national population (see Figure 22 – right); around 50% of the wider population travel less than 7,000 miles and around 23% of the BEV sample travel less than 7,500 miles per annum. This is likely due to the recruitment criteria for the trial which required participants to be a current car owner and drive regularly (at least once every two or three days).

Although the proportion of the sample who reported high annual mileage (more than 15,000 miles) was similar to that in the NTS data, it should be noted that company car drivers (who are disproportionately more likely than private users to have high annual mileage) were excluded from the study for insurance reasons (see section A.3.3). As such the sample does not represent this group and instead only represents private vehicle users..

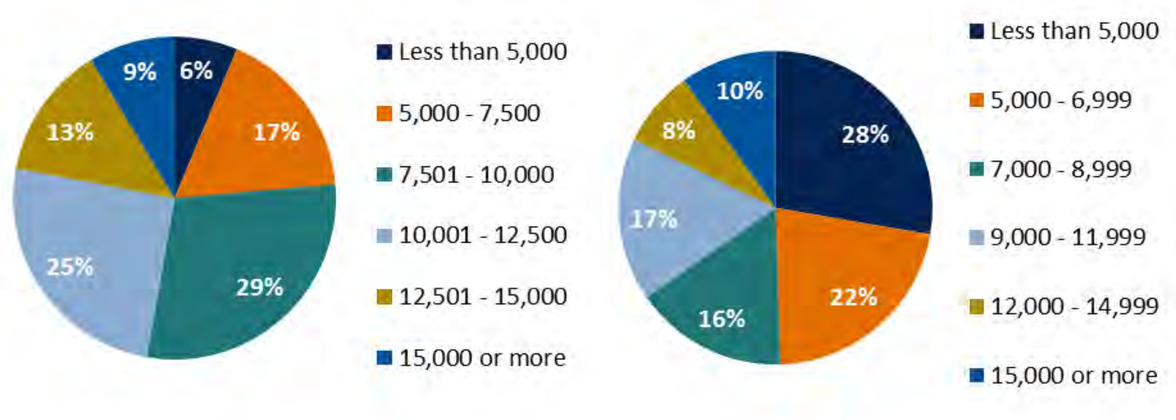


Figure 22: Self-reported annual mileage of 127 BEV participants (left) and distribution of national annual mileage (NTS, 2017) (right)

Figure 23 presents information on the typical self-reported weekly mileage of participants. The left hand panel summarises the typical car driving mileage on a weekday, and the right hand panel summarises the typical mileage on a day at the weekend. The two distributions are fairly similar, although a higher proportion of participants reported driving more than 70 miles on a typical weekday (17%) compared with on a typical weekend day (8%).

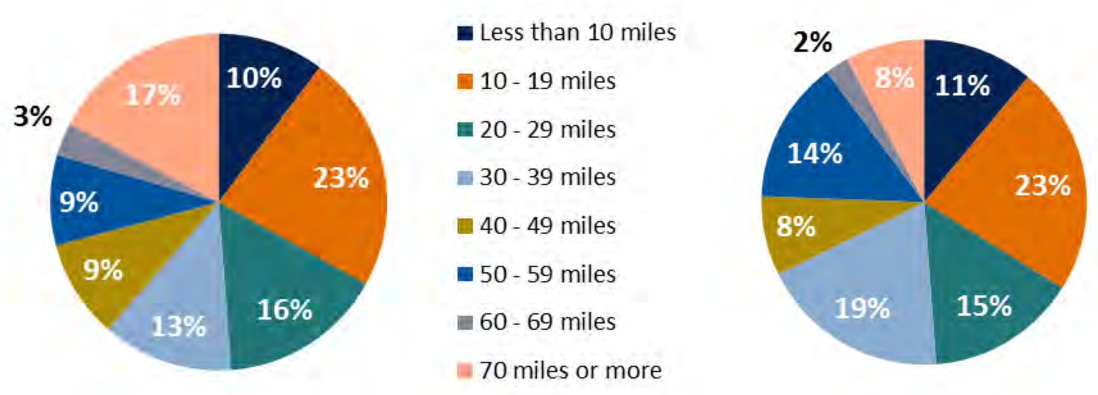


Figure 23: BEV participants' self-reported car driving mileage on a typical weekday (left) and weekend day (right)

B.1.1.3 *Education, income and living situation*

The highest educational qualifications achieved by BEV Charging Trial participants, and their employment status at the time of the trial, are summarised in Figure 24.

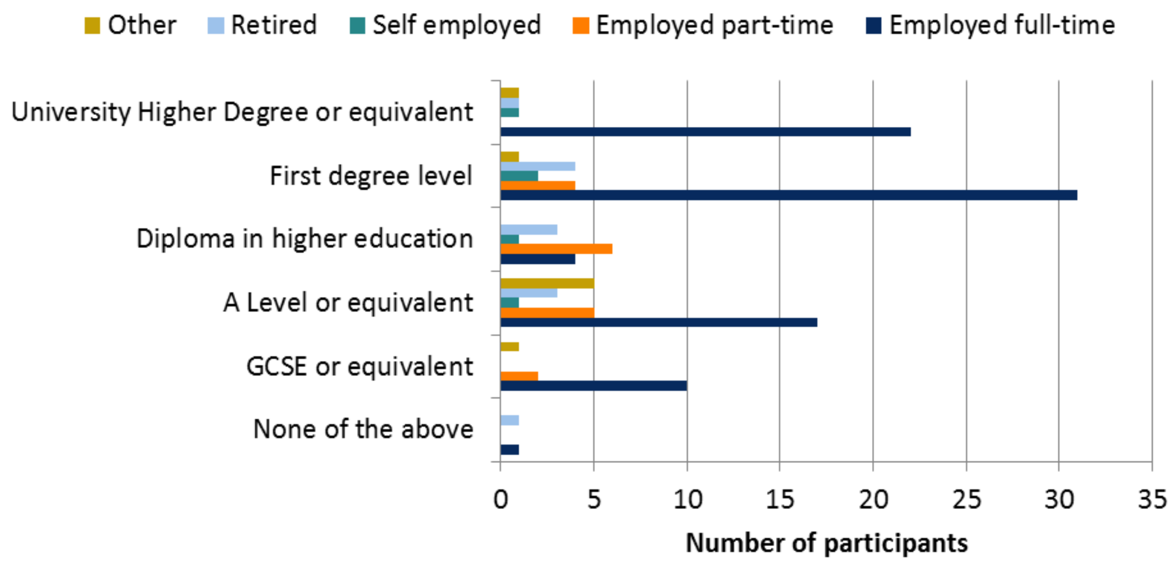
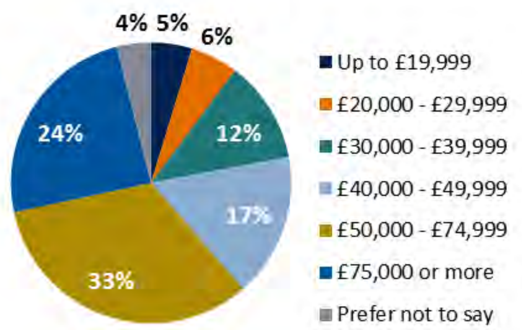


Figure 24: Highest educational qualification and employment status of BEV participants

Participants were asked to indicate their total household income (from all sources before tax and other deductions). These data are summarised in Figure 25 along with the proportion of households in the UK by gross annual income band, as reported by the Office of National Statistics (ONS). The distribution of household income in the sample differs from the wider national population (for 2016/17 financial year); households with an annual income of less than £30,000 were underrepresented in the BEV Charging Trial sample (around 10%) compared with the wider population (46%). This is also likely to be a consequence of the recruitment criteria.



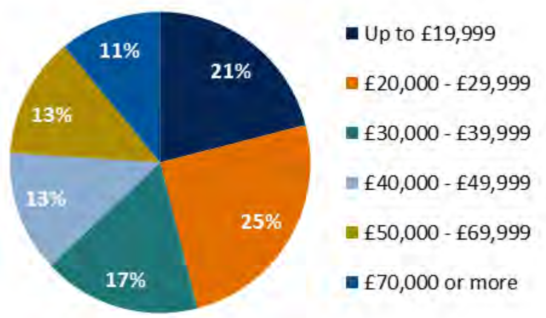


Figure 25: BEV participants' reported total household income (left) and average annual household gross income UK 2016/17 (ONS, 2018a) (right)

The relationship status and living arrangements of participants are summarised in Figure 26. The large majority of the sample were married/in a civil partnership and living with their family/partner (69%). In 2017, the ONS reported 49% of the UK population aged over 16 years old were married (ONS, 2018b). As illustrated in Figure 27, married individuals were slightly overrepresented and single or separated/divorced individuals were underrepresented in the BEV Charging Trial sample.

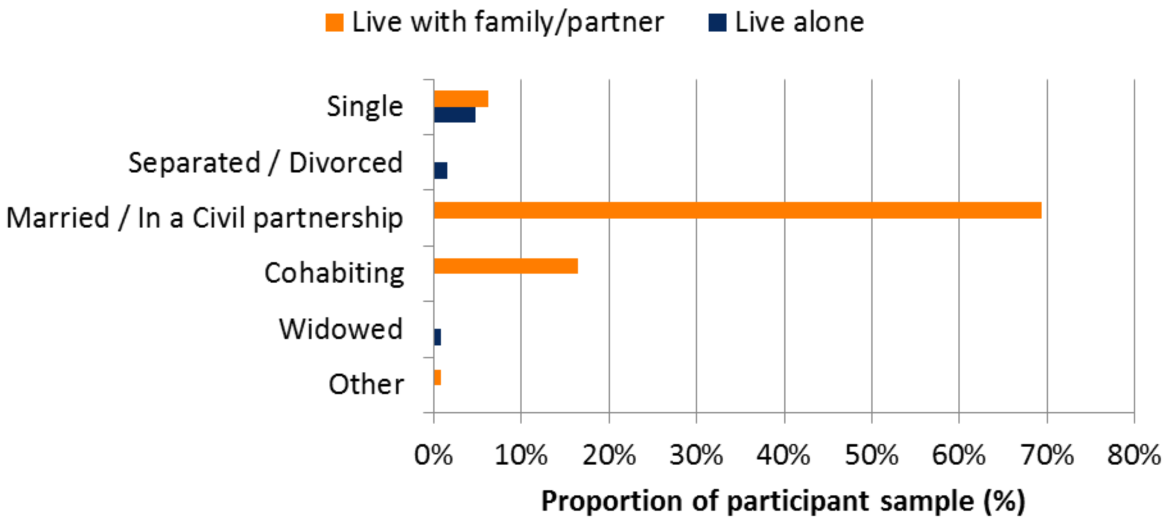


Figure 26: BEV participants' reported relationship status and living arrangements

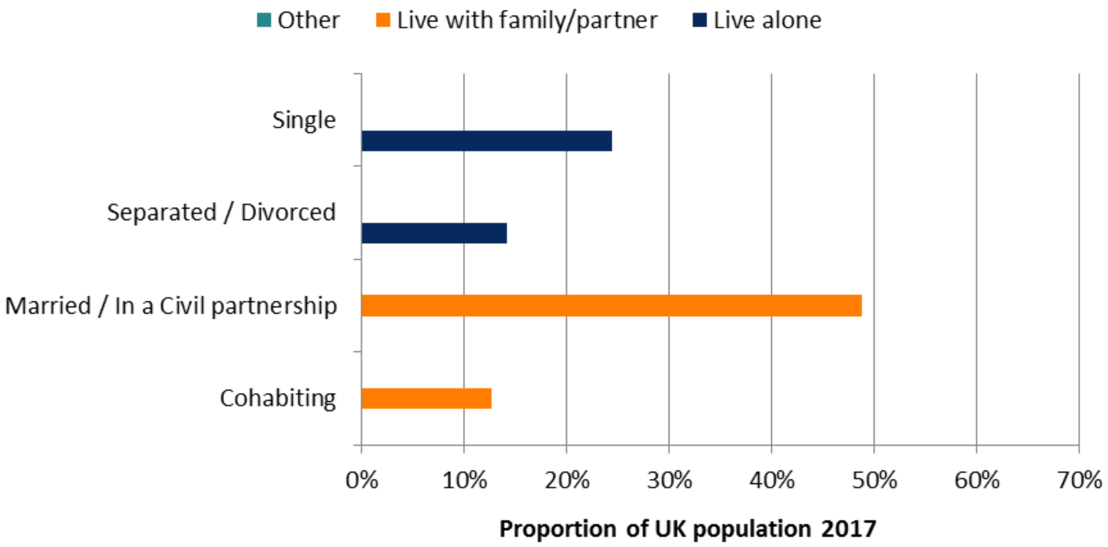


Figure 27: Proportion of UK population in 2017 by relationship status and living arrangements (ONS, 2018b)

B.1.2 *PHEV Charging Trial*

The final sample of PHEV Charging Trial participants is shown in Table 23.

Table 23: Final sample of PHEV Charging Trial participants (differences between final and target sample shown in parentheses)

Group	Number of participants		
	Summer	Winter	Total
Control	n/a	n/a	**40 (0)**
Supplier-Managed Charging (SMC)	16 (-4)	23 (+3)	**39 (-1)**
User-Managed Charging (UMC)	21 (+1)	21 (+1)	**42 (+2)**
Total			**121 (+1)**

Differences between the final sample and the target sample are shown for each cell; this confirms that the final sample represented a very close match to the original target of 40 participants per group, and 20 participants per Summer/Winter sub-group.

Resident area, age group and gender were used for stratifying the sample. Table 24 shows the sample representativeness (on these variables) compared to the GB driving population. The results show that the sample was well matched on the location and age variables, but males were overrepresented relative to females.

Table 24: Demographics of final sample of PHEV Charging Trial participants (differences between final and target sample shown in parentheses)

Resident area	Age group	Gender		Total
		Male	Female	
Rural	19-29	1 (0)	0 (-1)	**1 (-1)**
	30-49	7 (+3)	3 (-1)	**10 (+2)**
	50+	9 (+2)	4 (-2)	**13 (0)**
Urban	19-29	13 (+4)	5 (-2)	**18 (+2)**
	30-49	23 (+3)	17 (-1)	**40 (+2)**
	50+	21 (-2)	18 (-1)	**39 (-3)**
Total		**74 (+10)**	**47 (-9)**	**121 (+1)**

Additional data were collected from each participant using the Filter surveys, Pre-trial Questionnaire and TP1 questionnaire to enable further characterisation of the final sample; these data are summarised for the PHEV trial sample in the following sections. Further profiling of the sample at the consumer segment level is provided in section B.3.

B.1.2.1 *Household vehicle ownership and use*

Participants were asked to provide information on the number and type of cars, and number of drivers in the household. The distribution of the number of cars in each household in the PHEV Charging Trial sample is shown in Figure 28 – left. Over half (53%) of the participants reported having two cars in their household, 18% reporting having only one car, and the remaining 29% had more than 2 cars.

Data from the National Travel Survey (NTS, 2017) was used to assess the extent to which the distribution of car ownership in the sample was representative of the English national population (see Figure 28 – right). Households with two or more cars were overrepresented in the PHEV Charging Trial sample compared with the national population as a whole; more than 80% of participants reported having two or more vehicles, compared with 35% of households in the wider population. This was likely due to the recruitment criteria for the trial: firstly participants were required to have access to their own private vehicle (ruling out households with no cars) and secondly participants were required to have off-street parking for at least one vehicle, meaning the majority of participants lived in houses with driveways and/or garages where it is more common for there to be multiple vehicles compared with other types of accommodation.

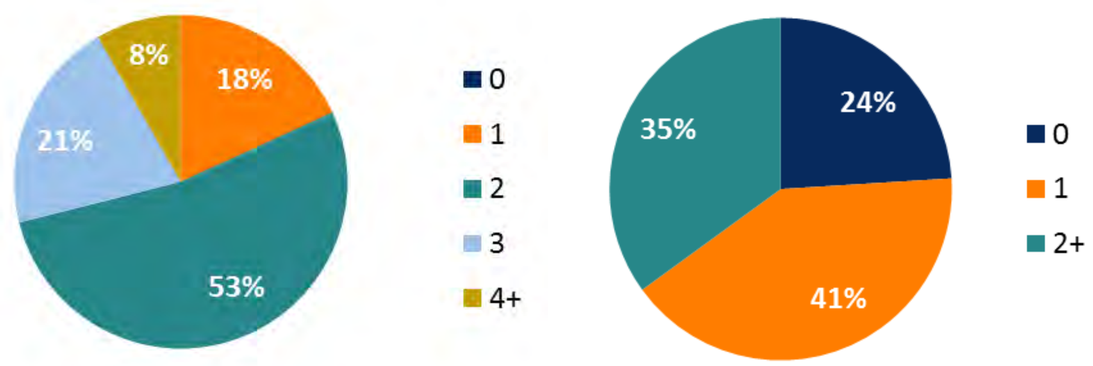


Figure 28: Number of cars owned by 121 PHEV participants (left) and distribution of household car ownership in national population (NTS 2017) (right)

The distribution of different types of cars owned by participants in the sample is shown in Figure 29. The Lower medium, Upper medium, and Supermini segments were the most common categories of cars owned by participants. The Society of Motor Manufacturers and Traders (SMMT) reports the number of annual new car registrations by segment type, which serves as a proxy for the proportion of car categories in the UK vehicle parc. These data show the top four segments with the highest number of registrations in 2017 were Supermini (29.5%), Lower medium (28.7%), Dual purpose (18.1%) and Upper medium (9.6%) (SMMT, 2018); thus suggesting the types of vehicles owned by participants in the sample followed a broadly similar pattern to national trends.

Type of car	Count of participants
Lower medium	36
Upper medium	21
Supermini	19
Dual purpose	13
Specialist sports	3
MPV	13
Mini	5
Executive	8
Luxury	2
Total	**121**

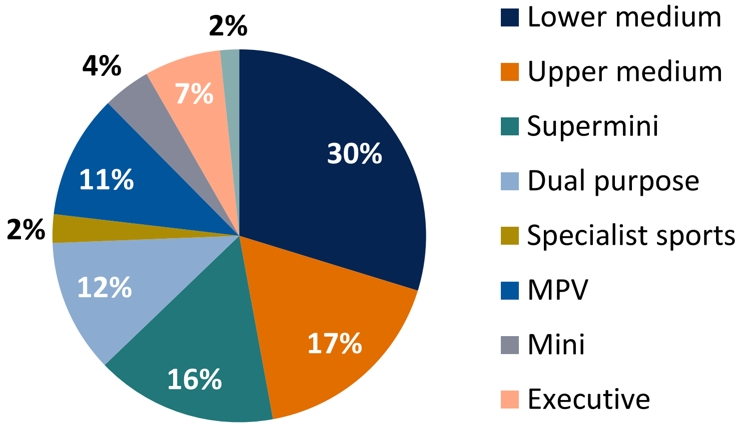


Figure 29: Type of car owned by PHEV participants

Figure 30 presents the number of licensed drivers in participants' households. The majority (63%) of the sample had two drivers in the household.

Number of drivers in household	Count of participants
1	13
2	76
3	23
4	8
5	1
Total	**121**

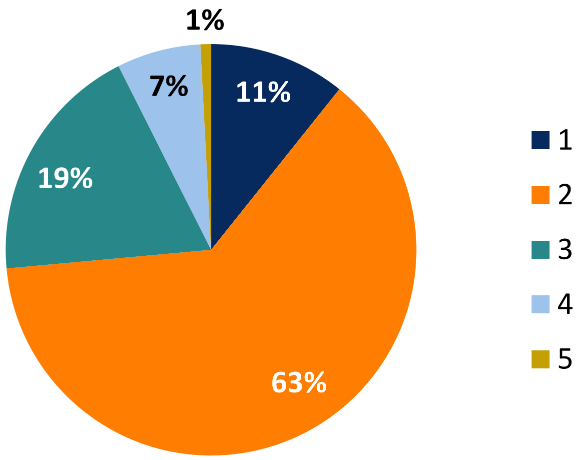


Figure 30: Number of drivers in the household in PHEV Charging Trial

Figure 31 displays participants' reported number of private and company cars which were kept at their households. The majority of participants (77%) reported having either one or two private cars. Very few participants (7%) reported having a company car, in line with the recruitment criteria for the trial which ruled out any prospective participants who had a company car as their main vehicle (see section A.3.3).

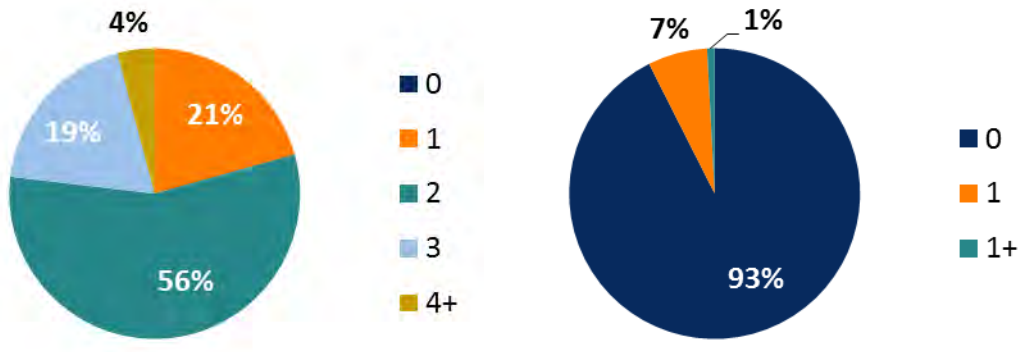


Figure 31: Number of private cars (left) and company cars (right) kept at the households of PHEV participants

The characteristics of participants' main cars at the time of purchase are shown in Figure 32, in terms of the age of the vehicle and the purchase price. Over half of participants' main cars were over two years old at the time of purchase and nearly half of the sample (47%) paid £10,000 or less for their main car.

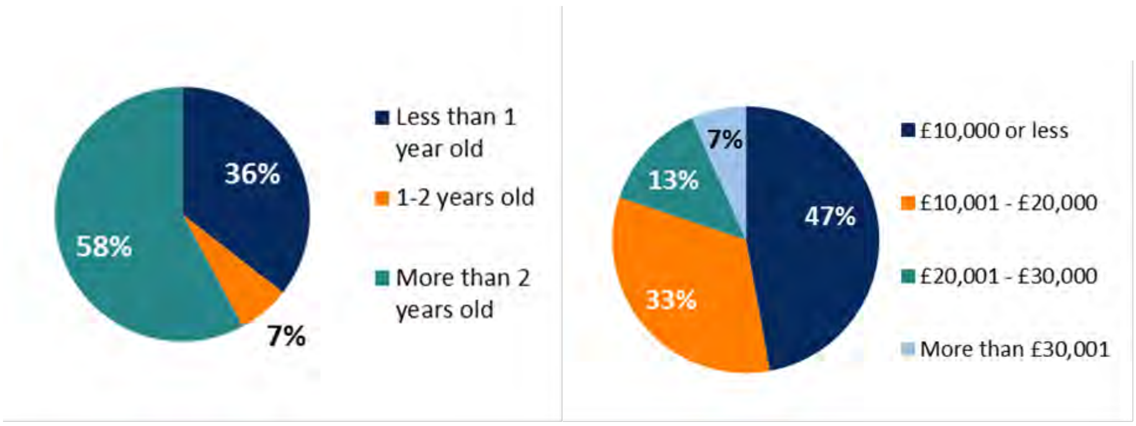


Figure 32: Age (left) and value (right) of main car at time of purchase of PHEV participants in the final sample

B.1.2.2 *Car mileage*

A summary of PHEV trial participants' reported annual mileage travelled by car is shown in Figure 33 – left. Comparison of the distribution of participants' annual mileage with data from the National Travel Survey (2017) shows that there was a smaller proportion of people with low annual mileage. Around 50% of the wider population travel less than 7,000 miles per annum and around 17% of the PHEV sample travel less than 7,500 miles per annum. There was also a larger proportion of people who travel more than 15,000 miles in the PHEV Charging Trial sample compared with the UK car-using population (see Figure 33 – right). This is in line with the recruitment criteria for the trial which required participants to be a current car owner and drive regularly (at least once every two or three days).

As with the BEV Charging Trial, it should be noted that company car drivers were excluded from the study for insurance reasons. As such, the sample does not represent this group and instead only represents private vehicle users; the findings should therefore be interpreted with caution when extrapolating to the wider population.

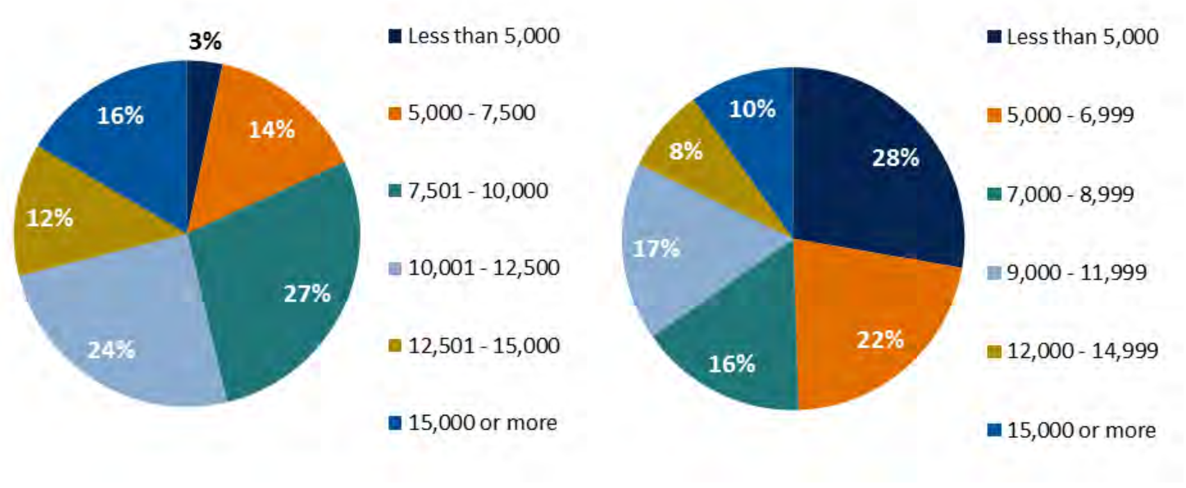


Figure 33: Self-reported annual mileage of 121 PHEV participants (left) and distribution of national annual mileage (NTS, 2017) (right)

Figure 34 presents information on the self-reported typical weekly mileage of participants. The left hand panel summarises the typical car driving mileage on a weekday, and the right hand panel summarises the typical mileage on a day at the weekend. The two distributions are fairly similar, although a higher proportion of participants drive more than 70 miles on a typical weekday (26%) compared with on a typical weekend (13%).

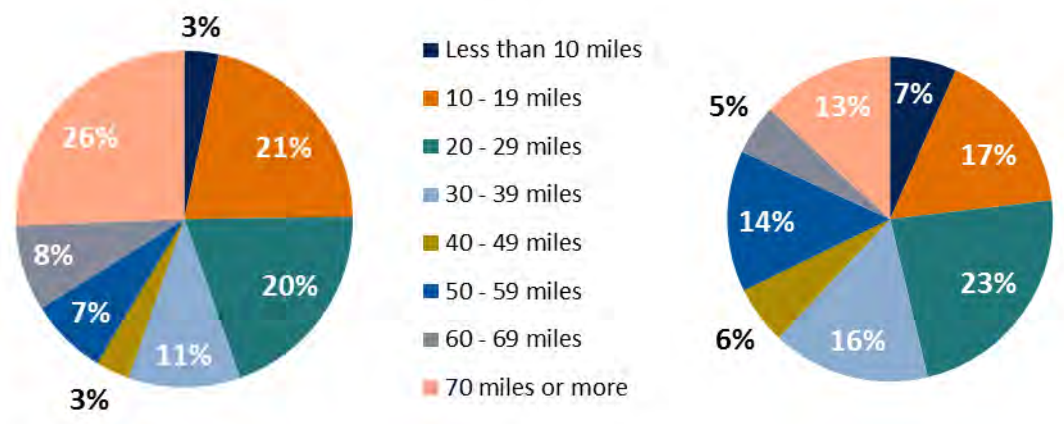


Figure 34: PHEV participants' self-reported car driving mileage on a typical weekday (left) and weekend day (right)

B.1.2.3 *Education, income and living situation*

The highest educational qualifications achieved by PHEV Charging Trial participants, and their employment status at the time of the trial, are summarised in Figure 35.

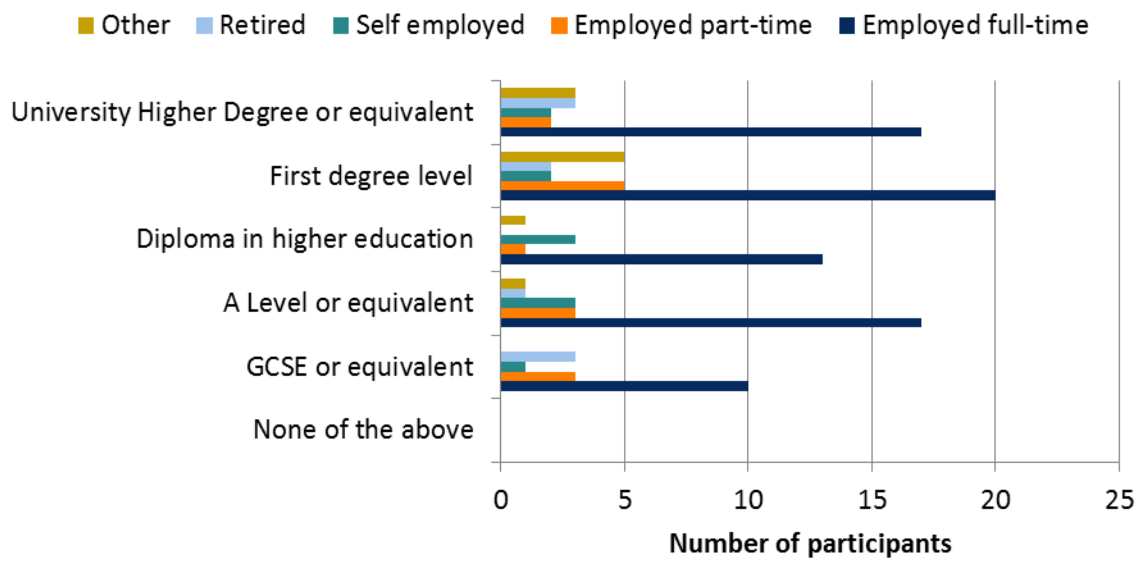
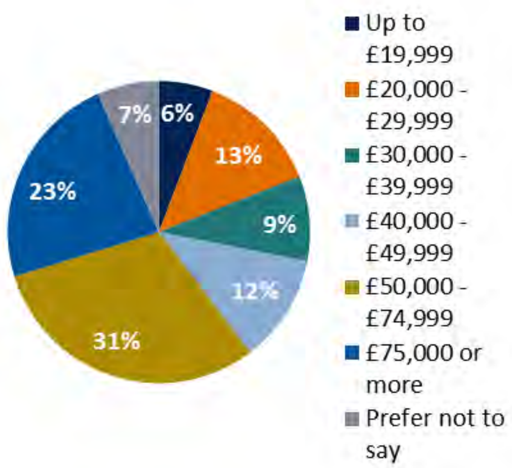


Figure 35: Highest educational qualification and employment status of PHEV participants

Participants were asked to indicate their total household income (from all sources before tax and other deductions). Figure 36 summarises these data. The proportion of households in the UK by gross annual income band is reported by the Office of National Statistics (ONS) and shown in Figure 36 – right. The distribution of household income in the sample differs to the wider population (for 2016/17 financial year); households with an annual income of less than £30,000 are underrepresented in the PHEV Charging Trial sample (19%) compared with the wider population (46%). This is also likely to be a consequence of the recruitment criteria.



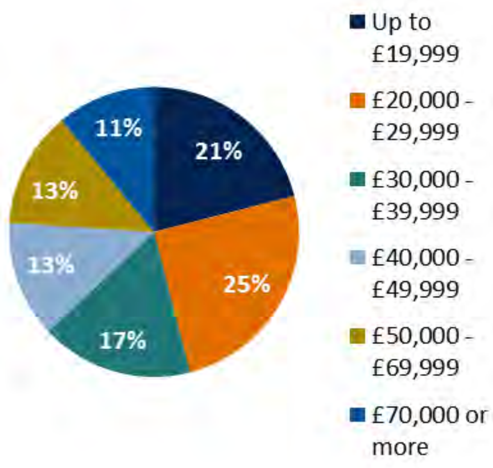


Figure 36: PHEV participants' reported total household income (left) and average annual household gross income UK 2016/17 (ONS, 2018a) (right)

The relationship status and living arrangements of participants are summarised in Figure 37. The large majority of the sample were married/in a civil partnership and living with their family/partner (61%). In 2017, the ONS reported 49% of the UK population aged over 16 years old were married (ONS, 2018b). Married individuals were slightly overrepresented and single or separated/divorced individuals were underrepresented in the PHEV Charging Trial sample.

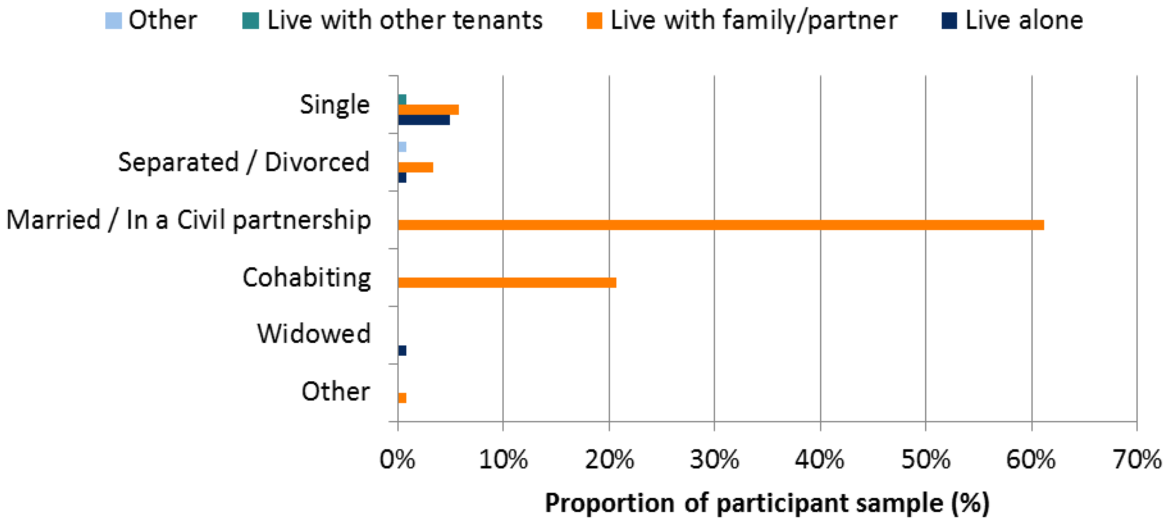


Figure 37: Participants' reported relationship status and living arrangements

B.2 Assessment of bias

- → **The recruitment method was not found to affect participants' reported likelihood to purchase a PHEV or BEV.**
- → **There were a few significant differences between participants assigned to the three groups (Control, SMC and UMC) in the two trials:**
  - → **The 'extraversion' personality score was significantly different between the SMC and UMC groups for the BEV trial; however, the magnitude of this difference was small (mean scores of 6.78 and 5.63 respectively).**
  - → **The 'openness' personality score was significantly different between the SMC and Control groups for the PHEV trial; however, the magnitude of this difference was small (mean scores of 8.64 and 6.95 respectively).**
- → **No systematic bias on participants' reported likelihood to purchase a BEV or PHEV, or for key journey/charging behaviour metrics was identified between participants whose trial was extended due to issues with charging and those who weren't.**

B.2.1 *BEV Charging Trial*

Three separate analyses were performed to test for systematic biases:

1. Recruitment bias: Comparison of Time Point 1 likelihood to purchase a BEV and PHEV responses between participants who were recruited for the study via different recruitment methods.
2. Random allocation of participants to groups: Comparison of sample characteristics (e.g. gender, age, etc.) between the three groups (Control, SMC and UMC) to ensure the samples are comparable on these attributes.
3. Trial extensions: A small number of participants had their trial extended by a few weeks due to technical issues with charging (see section A.14.4.1). This analysis

compares key questionnaire item responses and the charging/journey behaviour of participants with extensions to those without.

The results from these analyses are described in the following sections.

B.2.1.1 *Recruitment method*

To maximise chances of achieving the stratified sample requirements, participants were recruited using a variety of methods. To test whether the method of recruitment resulted in any systematic biases in participants' reported likelihood to purchase a BEV or PHEV, responses to the TP1 questionnaire were compared between the nine distinct recruitment approaches:

1. Advert emailed to contacts on TRL's Participant Database ('TRL database email')
2. Email advert sent to local businesses ('Business email')
3. Email advert with flyer for printing (containing QR code) sent to local businesses ('Business email: QR')
4. Flyer emailed to prospective participants – participants clicked link ('Flyer: URL')
5. Flyer emailed to prospective participants – participants scanned QR code ('Flyer: QR')
6. Printed flyer handed out to prospective participants – participants scanned QR code ('Printed flyer: QR')
7. Survey link emailed directly to prospective participants who contacted TRL about getting involved ('General advert link')
8. Advert posted on TRL's LinkedIn account ('LinkedIn')
9. Advert posted on TRL's Twitter account ('Twitter')

These bias checks were undertaken using data from TP1 on likelihood to purchase a BEV or PHEV, because those measures can be used in as proxies for participants' general attitudes and interest in PiVs. Hence, these tests enabled a check of whether a particular recruitment source had resulted in participants with particularly high or particularly low interest in PiVs.

The proportions of the final sample of participants who were recruited via each of these methods are shown in Figure 38.

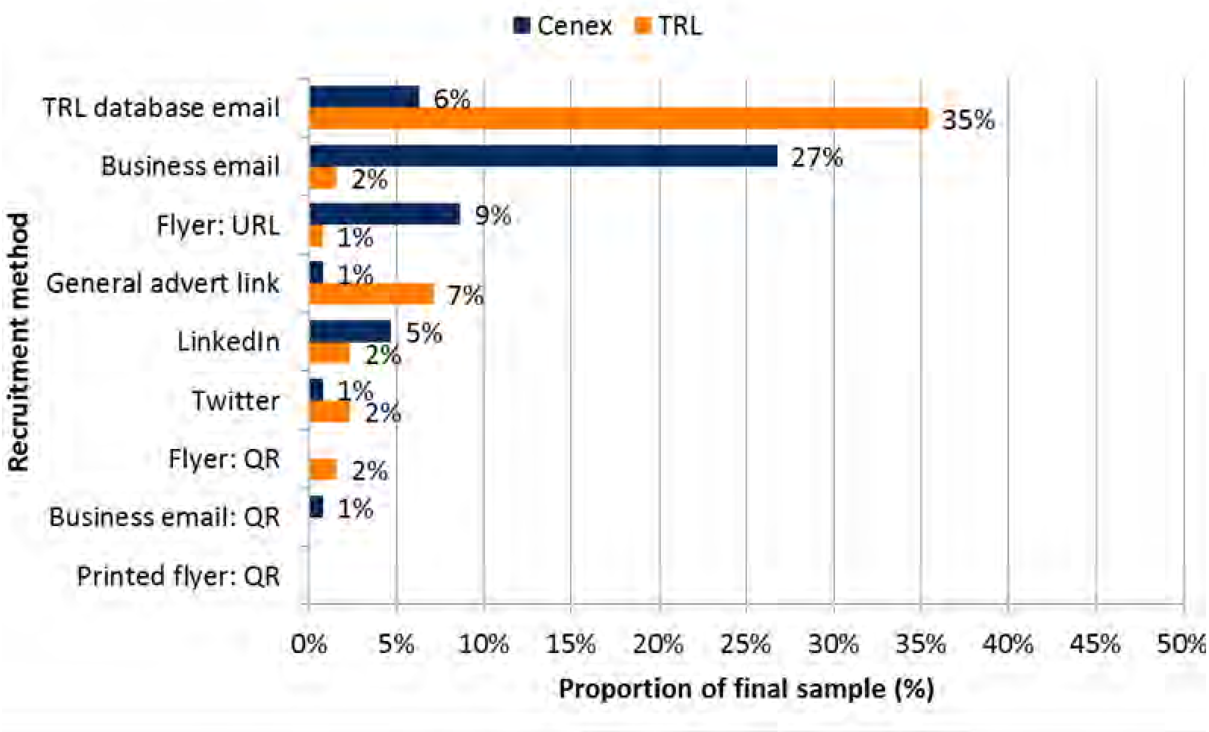


Figure 38: Proportion of final BEV sample recruited via each approach, split into TRL and Cenex participants

The majority of participants (42% across both TRL and Cenex) were recruited using TRL's Participant Database, followed by email adverts distributed to businesses local to TRL and Cenex (28% across both locations). For the other recruitment methods the number of participants recruited via these means was too small to enable statistical comparisons; however, the responses to the TP1 'likelihood to purchase a BEV and PHEV' items (combined across the two locations) were compared between the two largest groups: 'TRL database email' and 'Business email'. An independent samples non-parametric Mann-Whitney test revealed no statistically significant differences in the TP1 'likelihood to purchase' responses between participants recruited by 'Business email' or 'TRL database email' (BEV Main car: p = 0.938; BEV Second car: p = 0.158; PHEV Main car: p = 0.118; PHEV Second car: p = 0.481).

B.2.1.2 *Random allocation of participants to an experimental group*

The trial was designed to randomly allocate participants into one of the three groups; Control, SMC and UMC. In order to check how successful this random allocation was, the characteristics of those recruited into each group were compared. Chi-squared tests were used to compare the distribution of participants in each group across a range of variables (gender, age, resident area, annual mileage and household income) – the results are shown in Table 25. There were no significant differences in any of these characteristics across the three groups.

Table 25: Comparison of BEV sample characteristics between Control, SMC and UMC

Sample characteristic	Categories	Count of participants: Control	SMC	UMC	Chi-square statistic	*p*-value
Gender	Male	26	22	33	2.599	0.273
	Female	15	18	13		
Age	19-29	12	6	6	4.877	0.300
	30-49	17	17	20		
	50+	12	17	20		
Resident area	Urban	30	33	32	1.985	0.371
	Rural	11	7	14		
Annual mileage	Less than 7,500	9	9	12	2.000	0.920
	7,501-10,000	12	14	11		
	10,001-12,500	12	8	12		
	12,500 or more	8	9	11		
Household income	Up to £29,999	4	5	4	2.172	0.903
	£30,000-£49,999	9	14	13		
	£50,000-£74,999	14	12	16		
	£75,000+	12	9	10		

In addition to the sample characteristics listed above, participants were also asked a range of questions related to their personality traits and driving style.

Specifically, the Newcastle Personality Assessor (NPA) was used as a brief measure of personality. Five dimensions of personality (extraversion, neuroticism, conscientiousness, agreeableness and openness) were assessed by 12 items rated on five-point scales, with 1 being “very uncharacteristic” and 5 being “very characteristic”. Scores for each personality dimension were formed by summing the scores from the relevant two or three items. Higher scores indicate a higher level of the personality trait.

In addition, the Multidimensional Driving Style Inventory (MDSI; Taubman-Ben-Ari, Mikulincer & Gillath, 2004) was used to measure driving style. This inventory was constructed to provide a conceptualisation of an individual's habitual driving style. “Style” is defined as the way the driver chooses to drive, or habitually drives and is thought to be influenced by attitudes and beliefs regarding driving, as well as by more general goals, including symbolic goals to signal aspects of identity. The MDSI characterises driving style using eight scales: Angry, Anxious, Cautious, Dissociative, Distress Reduction, High Velocity, Patient, and Risky. The raw scores (the average of items on each scale) were used in this analysis.

Table 26 presents the average of these scores for each group.

Table 26: Comparison of personality and driving style characteristics between Control, SMC and UMC groups in the BEV trial

Sample characteristic	Categories	Mean score			F-value	*p*-value
		Control	SMC	UMC		
Personality	Openness	7.98	7.98	7.59	0.316	0.730
	Conscientiousness	7.68	7.58	7.30	0.547	0.580
	Extraversion	6.07	6.78	5.63	4.806	**0.010**
	Agreeableness	12.29	12.25	12.67	0.645	0.526
	Neuroticism	5.59	4.98	5.20	0.937	0.395
Driving style	Dissociative	1.46	1.40	1.48	0.567	0.569
	Anxious	2.09	2.12	2.17	0.216	0.806
	Risky	1.26	1.36	1.36	0.571	0.566
	Angry	1.98	1.92	1.96	0.076	0.927
	High Velocity	2.10	2.13	2.22	0.497	0.610
	Distress Reduction	1.82	1.88	2.09	1.988	0.141
	Patient	4.71	4.83	4.97	1.589	0.208
	Cautious	4.96	4.90	5.02	0.448	0.640

One-way ANOVA was used to compare the average score for each scale across groups. There were significant differences on the extraversion score for the three groups ($F = 4.806$, $p = 0.010$) with post-hoc tests indicating significantly different extraversion scores in the UMC compared with the SMC groups. The mean Extraversion scores for these groups were 5.63 and. 6.78; scores on this scale run from 2 (Low extraversion) to 10 (High extraversion). Therefore, the magnitude of the difference between groups can be considered small, with the mean scores sitting roughly in the middle of the scale.

B.2.1.3 *Trial extensions*

During the trial, a small number of participants experienced technical issues with charging the vehicle (see section A.14.4.1). As a result, the trial was extended for some participants to recover lost data. The maximum extension was three weeks.

This section performs a sensitivity analysis on the data from participants who were extended, comparing them with those who experienced charging as expected during the trial, to determine if there were any clear biases in the results for those with extensions.

In the BEV trial, there were 11 participants who were extended (5 SMC participants and 6 UMC participants). Figure 39 shows the distribution of responses to the ‘likelihood to purchase’ questions at Time Point 2 for those who were extended and those who were not.

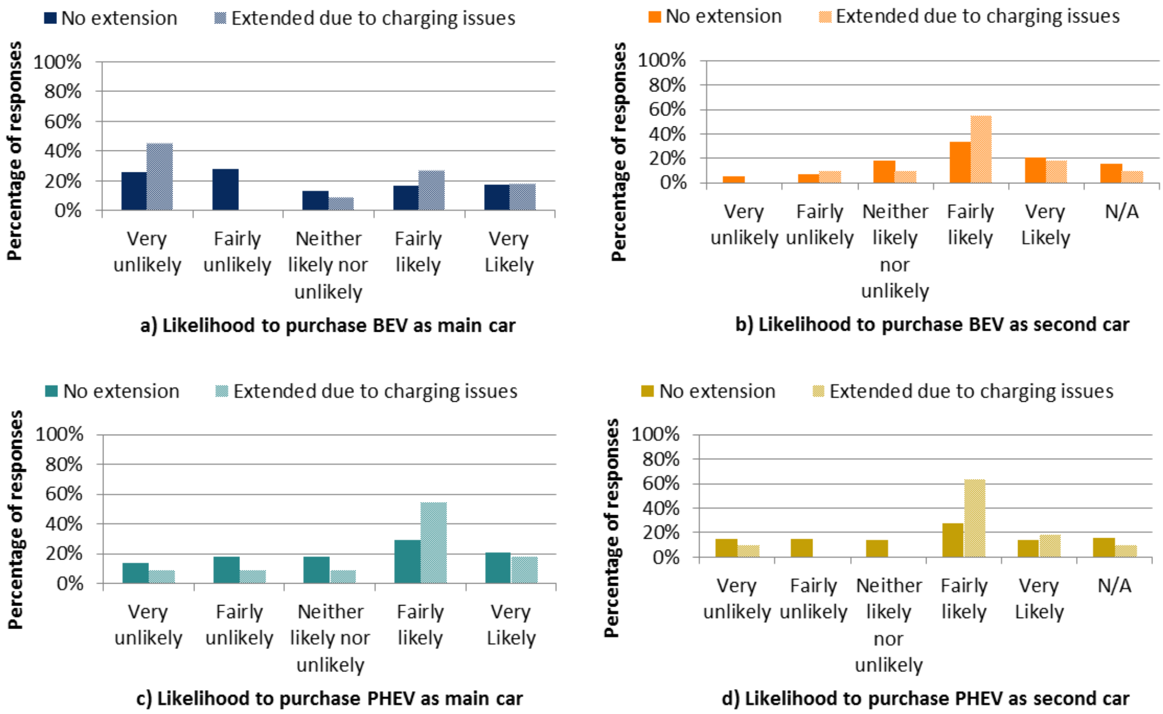


Figure 39: Proportion of responses to TP2 questionnaire items for no extension and extended BEV participants on likelihood to purchase a BEV as main (a) and second (b) car and a PHEV as main (c) and second (d) car

Figure 40 shows the same comparison for the questions around likelihood to choose the charging tariff they experienced.

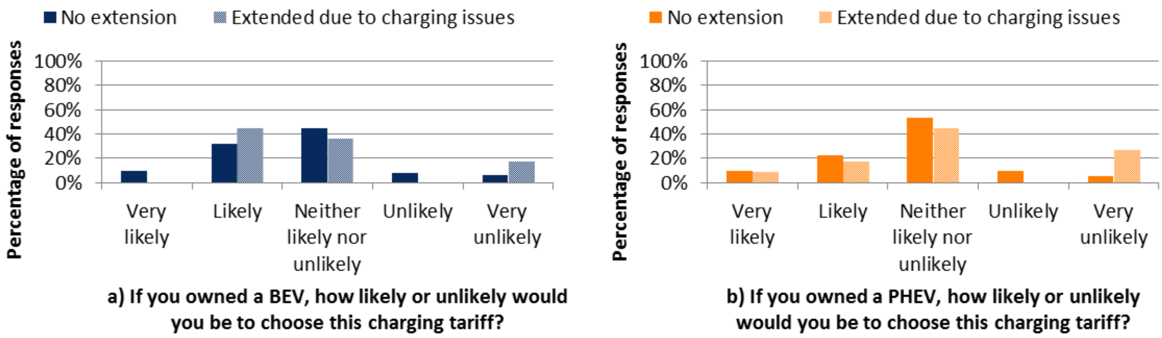


Figure 40: Proportion of responses to TP2 questionnaire items for no extension and extended BEV participants on likelihood to choose the charging tariff if they owned a BEV (a) or PHEV (b)

Due to the small sample size for the extended participants (11), the sample size was not sufficient for statistical tests to be run. Although based only on the distribution of responses, the data suggest that participants who were extended did not differ markedly from those who did not have an extension.

Figure 41 shows how easy or difficult each group of participants found charging during the trial. Almost all extended participants (10 out of 11) rated charging as either ‘easy’ or ‘very easy' despite the issues they experienced. The sample size for this group was too small for robust statistical comparisons to the non-extended group to be made; but the distribution of responses appears to be similar.

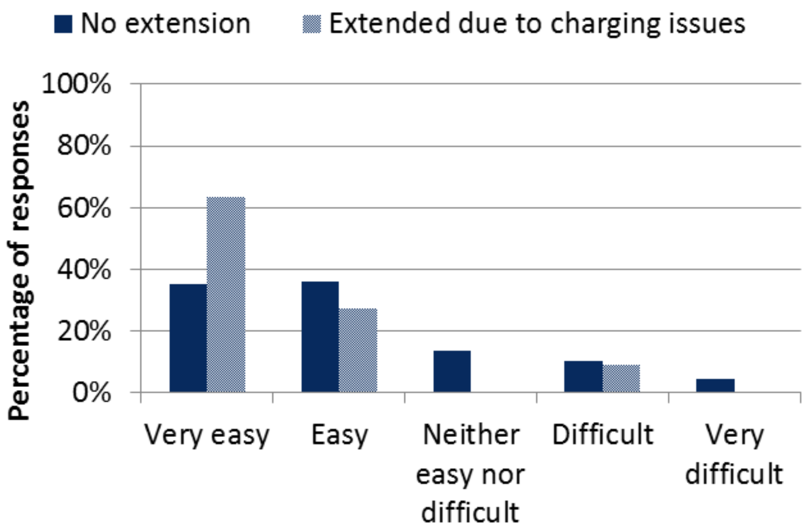


Figure 41: Proportion of responses to TP2 questionnaire items for no extension and extended BEV participants for the question: "How easy or difficult was it to charge the plug-in vehicle?"

Table 27 compares a selection of journey and charge metrics between the two groups. There were no major apparent differences in these metrics between the groups.

Table 27: Comparison of BEV charging and journey characteristics between participants who were extended and those who were not

Metric	No extension	Extended due to charging issues
Average number of charges per participant per week	5.5	6.2
Proportion of charge events at home	83%	89%
Average number of journeys per participant per week	25.1	23.4
Average journey distance (miles)	8.9	7.4

B.2.2 *PHEV Charging Trial*

B.2.2.1 *Recruitment method*

To test whether the method of recruitment resulted in any systematic biases in participants' reported likelihood to purchase a BEV or PHEV, responses to the TP1 questionnaire were compared between the nine distinct recruitment approaches (outlined in section B.2.1.1). The proportions of the final sample of participants who were recruited via each of these methods are shown in Figure 42.

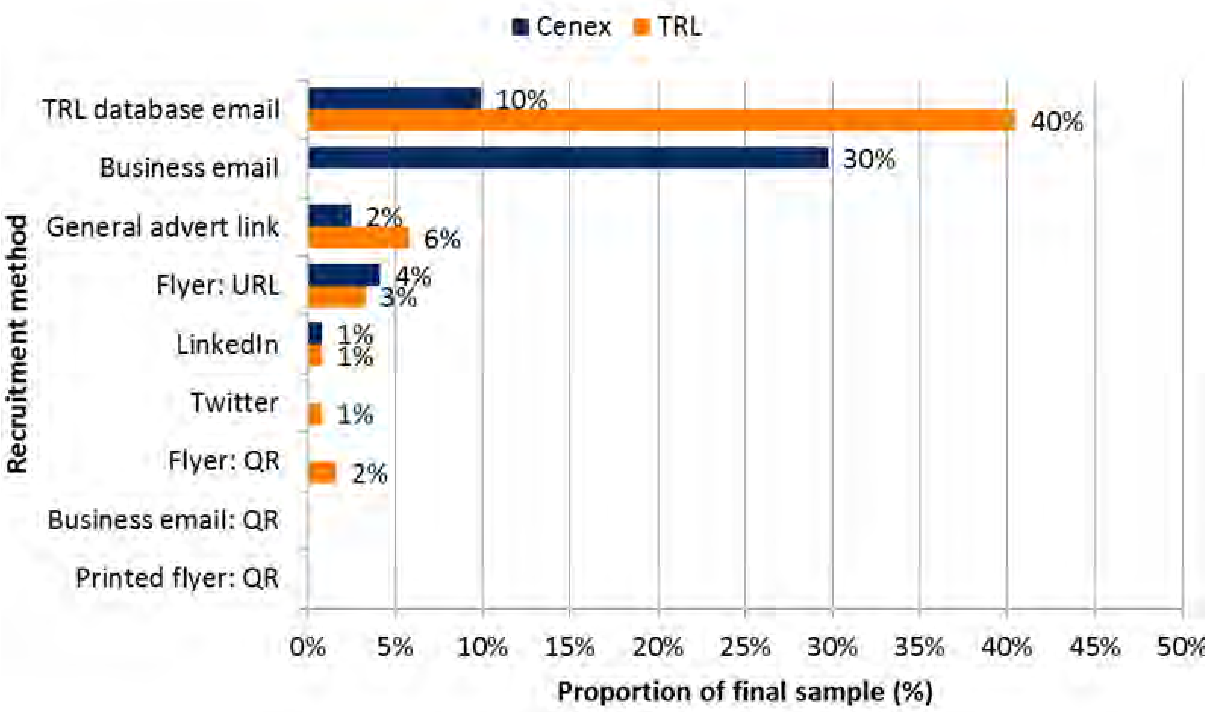


Figure 42: Proportion of final PHEV sample recruited via each approach, split into TRL and Cenex participants

The majority of participants (50% across both TRL and Cenex) were recruited using TRL's Participant Database, followed by email adverts distributed to businesses local to TRL and Cenex (30% across both locations). For the other methods of recruitment the number of participants recruited via these means was too small to enable statistical comparisons; however, the responses to the TP1 'likelihood to purchase a BEV and PHEV' items (combined across the two locations) were compared between the two largest groups: 'TRL database email' and 'Business email'. An independent samples non-parametric Mann-Whitney test revealed no statistically significant differences in the TP1 'likelihood to purchase' responses between participants recruited by 'Business email' or 'TRL database email' (BEV Main car: p = 0.812; BEV Second car: p = 0.784; PHEV Main car: p = 0.576; PHEV Second car: p = 0.822).

B.2.2.2 *Random allocation of participants to an experimental group*

Chi-squared tests were used to compare the distribution of participants in each group across a range of variables (gender, age, resident area, annual mileage and household income) – the results are shown in Table 28. There were no significant differences in any of these characteristics across the three groups.

Table 28: Comparison of PHEV sample characteristics between Control, SMC and UMC

Sample characteristic	Categories	Count of participants			Chi-square statistic	*p*-value
		Control	SMC	UMC		
Gender	Male	27	22	25	1.095	0.579
	Female	13	17	17		
Age	19-29	5	5	9	2.547	0.636
	30-49	19	17	14		
	50+	16	17	19		
Resident area	Urban	34	32	31	1.742	0.418
	Rural	6	7	11		
Annual mileage	Less than 7,500	8	7	7	2.052	0.915
	7,501-10,000	12	13	9		
	10,001-12,500	9	9	12		
	12,500 or more	11	10	14		
Household income	Up to £29,999	7	7	9	2.571	0.860
	£30,000-£49,999	8	10	7		
	£50,000-£74,999	11	10	16		
	£75,000+	10	10	8		

In addition to the sample characteristics listed above, participants were also asked a range of questions related to their personality traits (using the Newcastle Personality Assessor) and driving style (using the MDSI).

Table 29 presents the average of these scores for each group. One-way ANOVA was used to compare the average score for each scale across groups. There were significant differences on the openness score for the three groups (F = 5.919, p = 0.004) with post-hoc tests indicating slightly but significantly lower scores in the Control compared to the SMC group. There was also a marginally significant difference between the extraversion score for the three groups (F = 3.106, p = 0.049); but post-hoc tests showed that there were no significant pairwise comparisons.

Table 29: Comparison of personality and driving style characteristics between Control, SMC and UMC groups in PHEV trial

Sample characteristic	Categories	Mean score Control	Mean score SMC	Mean score UMC	F-value	*p*-value
Personality	Openness	6.95	8.64	7.48	5.919	**0.004**
	Conscientiousness	7.49	7.31	7.50	0.198	0.821
	Extraversion	6.74	6.90	5.93	3.106	**0.049**
	Agreeableness	12.08	12.54	11.64	2.372	0.098
	Neuroticism	5.26	5.03	5.19	0.136	0.873
Driving style	Dissociative	1.41	1.40	1.46	0.239	0.788
	Anxious	1.98	2.11	2.06	0.527	0.592
	Risky	1.22	1.55	1.33	2.898	0.059
	Angry	1.91	2.26	1.94	2.729	0.069
	High Velocity	2.06	2.23	2.12	0.629	0.535
	Distress Reduction	1.96	2.04	1.77	1.750	0.178
	Patient	4.68	4.71	4.61	0.197	0.821
	Cautious	5.00	4.94	5.22	3.047	0.051

B.2.2.3 *Trial extensions*

This section performs a sensitivity analysis on the data from participants whose trial was extended, comparing them with those who experienced charging as expected during the trial, to determine if there were any biases in the results for those who were extended.

In the PHEV trial, there were eight participants who were extended (1 Control, 4 SMC and 3 UMC participants). Figure 43 shows the distribution of responses to the likelihood to purchase questions at Time Point 2 for those who were extended and those who were not. Note that one PHEV non-extended participant was removed from this analysis as they did not complete the TP2 questionnaire.

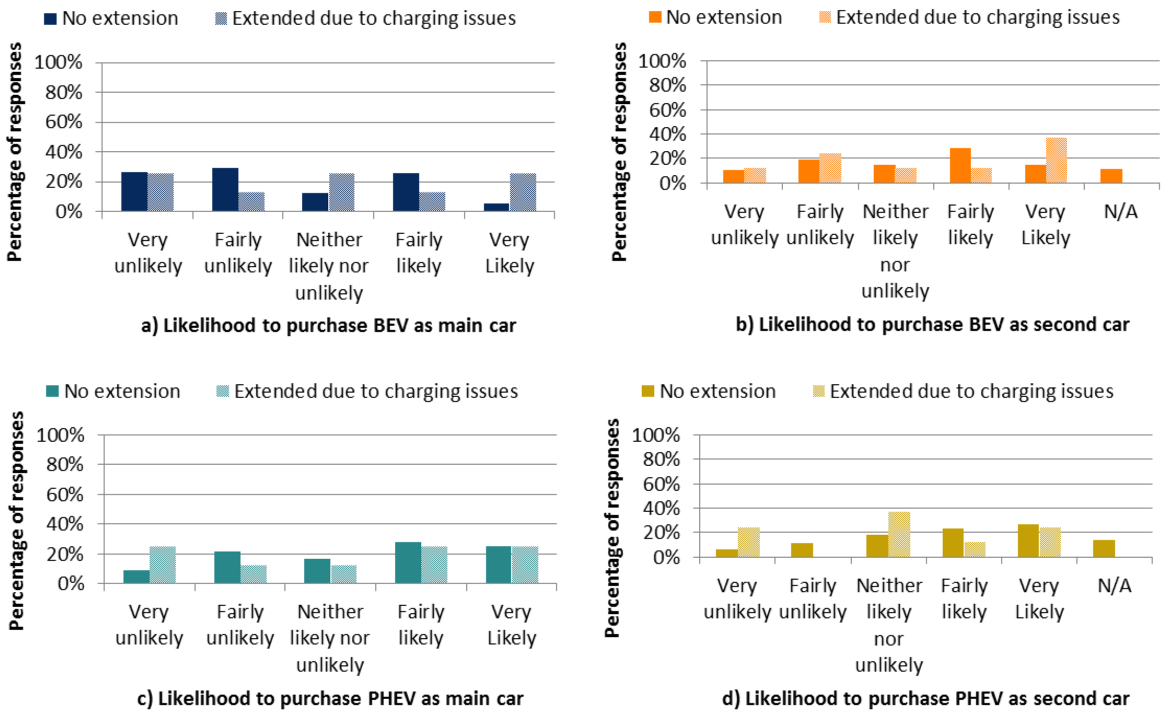


Figure 43: Proportion of responses to TP2 questionnaire items for no extension and extended PHEV participants on likelihood to purchase a BEV as main (a) and second (b) car and a PHEV as main (c) and second (d) car

Figure 44 shows the same comparison for the questions around likelihood to choose the charging tariff they experienced.

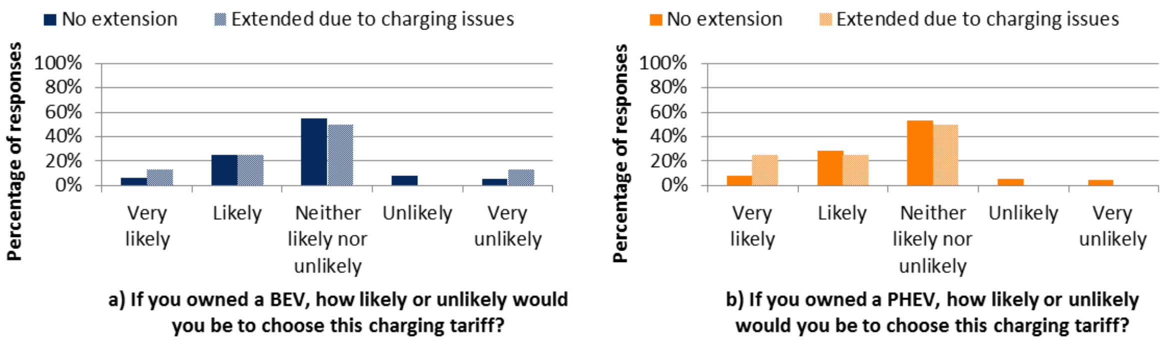


Figure 44: Proportion of responses to TP2 questionnaire items for no extension and extended PHEV participants on likelihood to choose the charging tariff if they owned a BEV (a) or PHEV (b)

Due to the small sample for the extended participants (8), the sample size was not sufficient for statistical tests to be run. However, the distribution of responses presented above do not suggest that participants who were extended differ markedly to those who did not have an extension. Similarly, there were no notable difference between the groups when comparing how easy or difficult participants found charging during the trial.

Table 30 compares a selection of journey and charge metrics between the two groups. The sample size of the extended group was too small for robust statistical comparisons to be conducted but the data suggest some differences between the usage patterns of the vehicles and mean charge events. As the extended group is so small, it is difficult to determine if these differences were the result of a systematic impact of the extension. This seems unlikely as extended participants conducted more journeys (suggesting they continued to use the vehicle), albeit these were generally shorter in length, which possibly explains the lower mean number of charges per week.

Table 30: Comparison of PHEV charging and journey characteristics between participants who were extended and those who were not

Metric	No extension	Extended due to charging issues
Average number of charges per participant per week	6.8	4.6
Proportion of charges at home	88%	98%
Average number of journeys per participant per week	14.3	22.4
Average journey distance (miles)	15.5	9.3

B.3 Segmentation

The procedure used to assign participants in the Consumer Charging Trial's samples to the five consumer segments is explained in section A.15.1. The segments were derived based on data collected before the trial (i.e. using pre-trial and TP1 data). This section provides some initial characterisation of the segments, followed by the differences with respect to their experiences and perceptions around charging following experience with the vehicles.

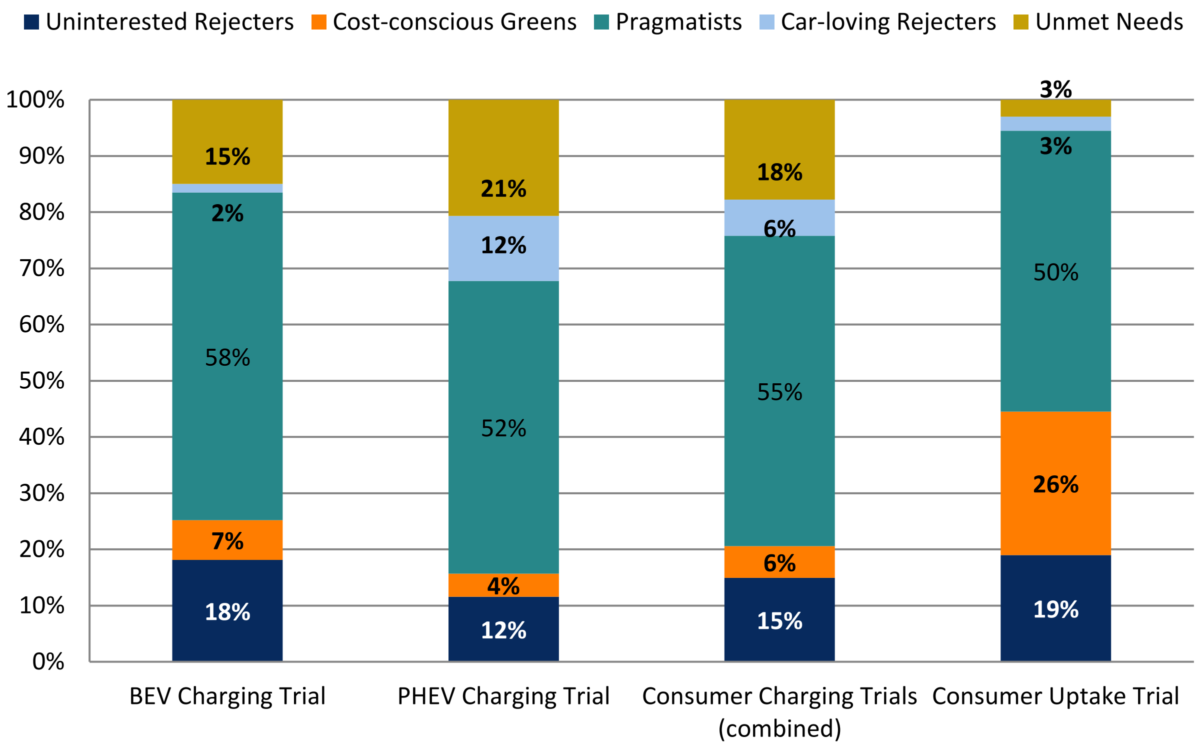


Figure 45: Participant segments and sizes in the different samples

The distribution of the five segments in the different sample groups is show in Figure 45. In all cases, as with the Consumer Uptake Trial, the Pragmatists were the largest group with half or slightly more of the sample. There were more Pragmatists and Uninterested Rejecters in the BEV sample, and more Car-loving Rejecters and members of the Unmet Needs segment in the PHEV sample. These differences between the two samples were statistically significant at $p < 0.01$. The very small sample sizes in some of the segments means that the results for these individual segments should be considered with some caution.

There were also differences between the segment distributions in the Consumer Charging Trials and the Consumer Uptake Trial, as shown in Figure 45. These will be reflected upon in the discussion below. In summary, this analysis has found that the Cost-conscious Greens are less represented in this Trial compared to the Uptake Trial, but Unmet Needs make up a greater proportion.

B.3.1 *Profiling using the attitudes used to create the segments*

The summary of the characteristics of each segment based on their attitudinal and demographic profiles can be seen in Table 31.

Table 31: Demographic and attitudinal characteristics of segments based on self-reported data

	Uninterested Rejecters	Cost-conscious Greens	Pragmatists	Car-loving Rejecters	Unmet Needs
BEV adoption	No differences	No differences	No differences	No differences	No differences
PHEV adoption	Least likely to adopt	Most likely to adopt	Slightly positive	Low likelihood	Slightly positive
Innovativeness	Least engaged when searching for new cars and in new technology	Relatively unengaged in technology but they believe they have some knowledge about it	Somewhat open to new car technology, informing themselves about new cars and influencing other people	Open to new technology and claims to spend a lot of time checking out new models	Low engagement with new technology
Greenness	Low	Very high; prepared to pay a premium for fuel economy	Some degree of pro-environmental motivation	Very low	Some modest sympathy with environmental issues but unlikely to be a strong motivating factor
Who are they?	Disproportionately female; Older; Higher number of part time and retired; Medium income	Disproportionately male; Oldest; High number of retired; Lowest income	Mainly employed; Spread of age groups; Medium income	Disproportionately male; Youngest; High number of employed/self-employed; Very high income	Disproportionately female; Mixed employment status; High income
What cars do they buy?	Tend to own nearly new cars	Low intention to buy a brand new car	Buy a mix of new and second hand cars. Lowest number of licence holders per household.	Most likely to buy brand new cars	Open to new and old cars; Largest number of licence holders per household
How much do they currently drive?	Below average mileage	Lowest Mileage – a fifth say they do less than 5,000 miles a year, none more than 15k. Shortest one way distance to work and least amount of motorway driving.	Average mileage	Highest mileage – over a third greater than 20k per year, none under 5k. Most likely to say they undertake frequent longer journeys. Longest one way distance to work and most amount of motorway driving.	Above average mileage. Longer than average one way distance to work.
What do they think about cars in general?	Low car running costs not much of a motivator.	Most likely to pay more for lower running costs. Least likely to view the car as a	Low running costs are a motivator, and derive satisfaction from good	Least likely to say they will pay more for lower running costs or to get	Low running costs are a motivator, and derive satisfaction from good fuel

	Relatively uninterested in cars in general and new technology in particular. Relatively indifferent about the car they drive.	status symbol and most likely to say that the car they drive matters to them. Do not really like driving.	fuel economy. Believe that cars express self-identity, and enjoy driving.	satisfaction from good fuel economy. Admit to liking to drive just for the fun of it though not so likely to admit to the car being a status symbol.	economy and sensitive to fuel price changes. Believes the car is an expression of self-identity.
What do they like or dislike about EVs?	Agnostic about alternatively fuelled cars. Consistently negative towards both powertrains with low 'feel good factor'.	Most likely to say they want an alternatively fuelled car and likes the idea of being able to refuel at home. Stand out for being the most positive about attributes of both types of vehicle technology. Significantly higher stated willingness to pay more for both powertrains.	Mixed views about alternatively fuelled cars. They recognise a 'feel good factor' for both types of car and believe that they would be good to drive and not out of keeping with their social identity. But they have some concerns about them holding their value, whether they really are environmentally friendly and overall whether they are any better than an ICE.	Least likely to say they want an alternatively fuelled car. Most likely to believe EVs are a 'fad'. Consistently most negative about BEVs and lowest 'feel good factor'. Believe BEVs would not suit their lifestyle.	Agnostic about alternatively fuelled cars but some positivity about being able to refuel at home. Believe they are environmentally beneficial and cheaper to run and so some 'feel good factor' about them. Negative about comfort and driving experience. Most likely to believe that BEVs would be less comfortable than ICEs.
Charging	They are the most worried about adapting to charging with high worry about running out of charge, even with a PHEV. Low awareness of chargepoints at work but high at retail sites. Availability of charging regimes makes them no more or less likely.	Least likely to say that adapting to charging a BEV would be difficult. Overall a much more positive view of the charging behaviours involved. High awareness of chargepoints at work, but low at retail sites.	Moderately high belief that adapting to charging a BEV would be difficult, but possibly a greater understanding that PHEVs are less of a worry. Medium awareness of chargepoints at work but high at retail sites.	Most likely to say that adapting to charging a BEV would be difficult. High awareness of chargepoints at work.	Generally worried about most aspects of charging and range – including for PHEVs. Most likely to say they would consider a BEV/PHEV if had a rapid charger at home or somewhere. Low awareness of chargepoints at work.

B.3.2 *Observations on the utility of the segmentation analysis for the Charging Trial*

When split into the BEV and PHEV trial participants, the segments did not differ significantly with respect to their self-reported experiences and attitudes to charging. Indeed, there are really very few variables to report as there were so few differences. To some degree, the lack of differences will be due to the low sample sizes upon splitting the sample in this way. Nevertheless, given the lack of differences between the segments even when the two samples were merged, the main conclusion from this analysis is that the segments used are not useful for distinguishing people on the basis of their attitudes to charging and the relevance of charging to future uptake behaviours.

This is not entirely a surprise. The original segments were generated from data collected in 2011 and for the purposes of understanding variability in attitudes towards cars in general and BEVs and PHEVs in particular. The questions used as the basis for the cluster analysis had been included on the questionnaire on the basis of both theoretical pointers in the literature and using focus group data collected for the same PiV study. Thus, they were incredibly rich and informative for the purpose they were designed for – i.e. to understand potential differences in uptake behaviour. Indeed, in the Consumer Uptake Trial, there were many attitudinal differences between segments which made sense and informed some aspects of their responses to the Uptake Trial. However, for charging behaviour and propensity towards different charging regimes, it is very likely that a new segmentation would be required that has as its basis the variables which are most likely to differentiate people on this topic. For instance, engagement with energy use, time of day tariffs, sensitivity to perceptions about needing a car for long or spontaneous journeys, and trust in the electricity provider, are all likely to be much more associated with attitudes towards charging and thus make for a more informative segmentation. Although there are useful questions included in the Consumer Charging Trial questionnaires that would go a long way to forming the basis of such a cluster analysis, the sample sizes in this case are much too small to allow this.

We have briefly outlined all of the areas for each sample that could be robustly reported below.

B.3.3 *BEV Charging Trial sample*

There were a couple of areas where the BEV sample segments exhibited some differences. Note, however, that there were only two Car-loving Rejecters in the BEV sample:

- The Uninterested Rejecters and Cost-conscious Greens were disproportionately more likely to charge their BEVs at their place of work or education, and Unmet Needs much less likely. This was after controlling for levels of employment in each segment.
- The Cost-conscious Greens were already much more likely to adopt a BEV with a 50 mile AER than any other segment, but the differences between segments disappear above this range.
- There were some differences on the level of satisfaction with the amount of Savings Points available through the charging tariff (see Figure 46). It would seem that the Cost-conscious Greens and the Pragmatists were comparatively satisfied, the Car-loving Rejecters were the most satisfied, and the Unmet Needs were the least satisfied.

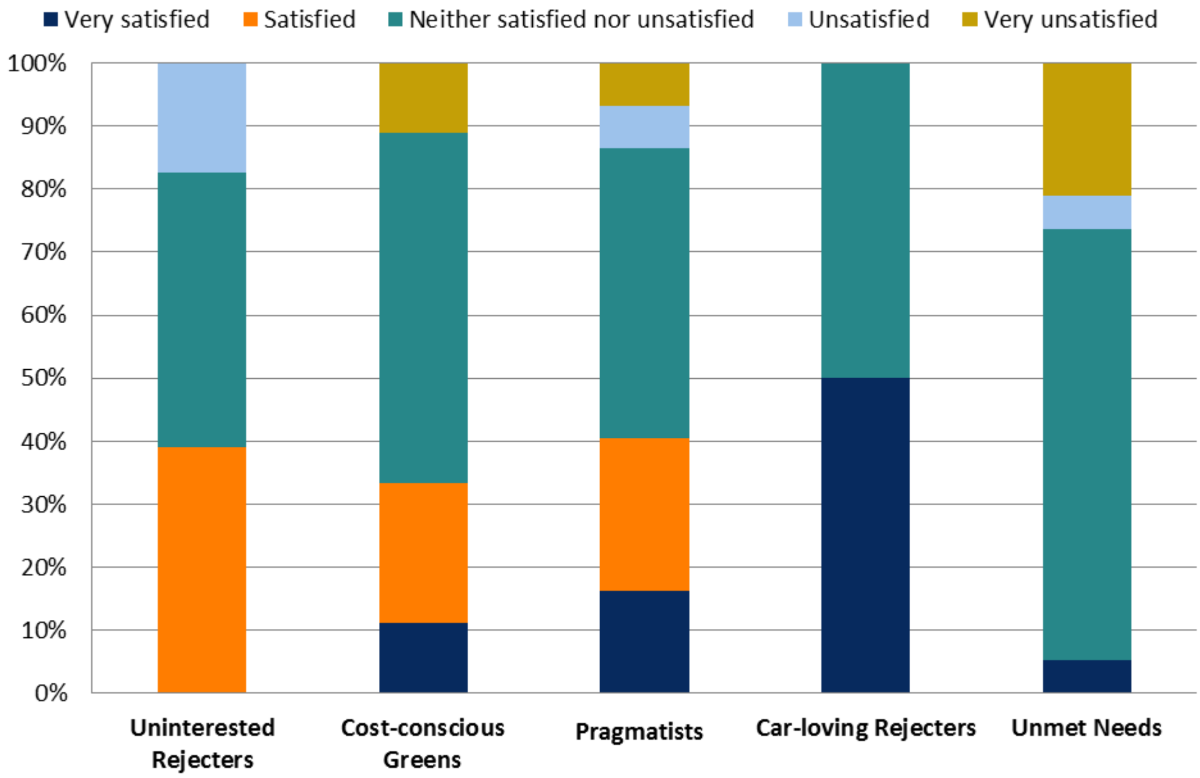


Figure 46: Proportion of level of satisfaction with the amount of Savings Points available through the charging tariff by segment

B.3.4 *PHEV Charging Trial sample*

There were a couple areas on which the PHEV sample segments had some differences based on self-reported data from the trial questionnaires:

- The PHEV sample differed significantly across segments with respect to travel patterns. The Car-loving Rejecters and the Unmet Needs had the highest annual total car mileage, and the Cost-conscious Greens the least (Figure 47).
- Over a fifth of all Car-loving Rejecters claimed to undertake journeys of more than 80 miles every day compared to no-one claiming this every day in any other segment. The Uninterested Rejecters and Cost-conscious Greens report the least frequent trips of this length.
- The Cost-conscious Greens undertake notably greater proportion of their journeys in urban areas, with the Pragmatists having a much more even proportion across each different type of area
- Cost-conscious Greens and Car-loving Rejecters have greater awareness of charging at workplaces even after accounting for employment levels.
- The Cost-conscious Greens were far more likely to say they had accelerated/ decelerated smoothly with their PHEV. Interestingly, the Pragmatists were the least likely.
- The Uninterested Rejecters were less likely to say they are likely to adopt a PHEV even as the range option is increased above 100 miles and charging reduces to 2 hours.

They are even less likely than the Car-loving Rejecters (the second least likely group to adopt).

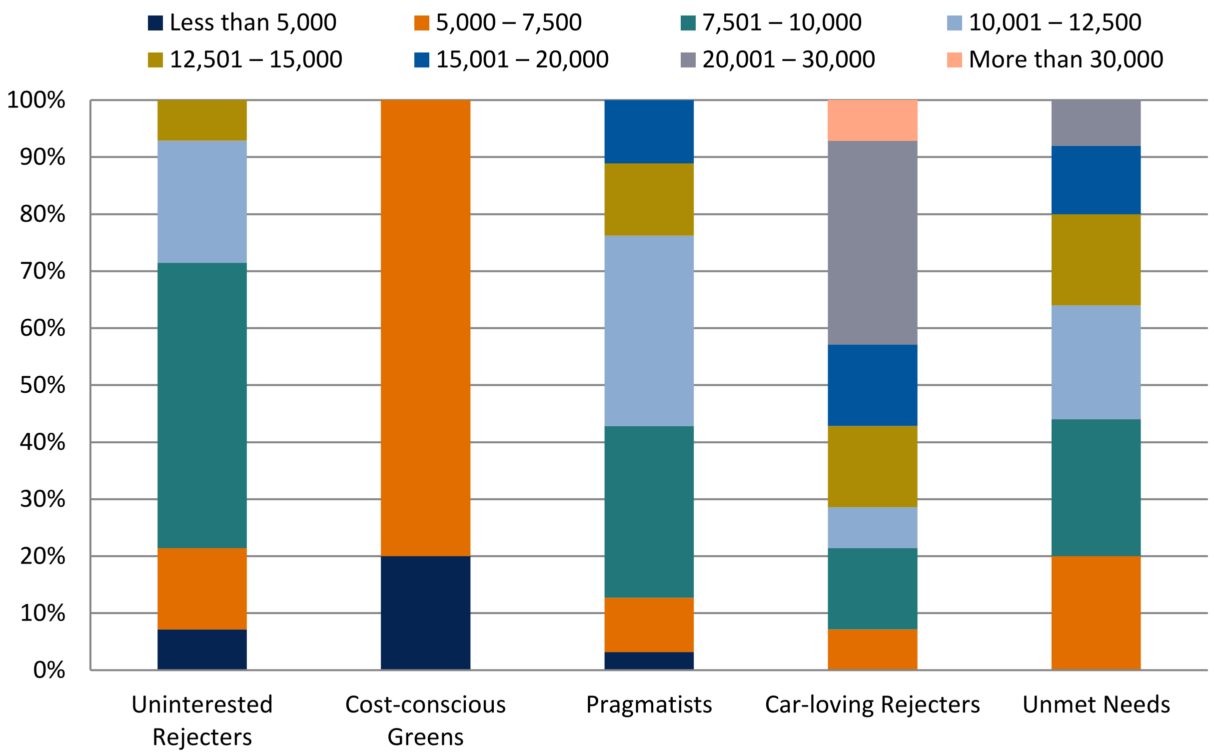


Figure 47: PHEV Trial sample - proportion of annual car mileage by segment

B.4 BEV Charging Trial results

B.4.1 *Core analyses*

B.4.1.1 *What is the charging behaviour of mainstream consumers when not participating in a managed charging scheme?*

- → **In unconstrained conditions (without a managed charging scheme), weekday charges at home most commonly started in the late afternoon and early evening (3pm-10pm).**
- → **Weekday charges away from home most commonly started in the morning (6am-10am).**
- → **Weekend charges at home followed a similar pattern to home weekday charges, with most charges starting in the evening (3pm-10pm).**
- → **Weekend charging away from home was more variable, although the small sample of events means caution is needed in interpretation.**

The focus of this analysis was to understand the charging behaviours of BEV participants in the control group, i.e. those who were free to charge as they wished without particular incentives for engaging with a managed charging scheme. Section B.4.1.2 then discusses the impact of managed charging on mainstream consumer charging behaviour. The analysis used data from vehicle telematics and the CPMS, supplemented by questionnaire data where relevant.

Charging at home

In the BEV Charging Trial there were 3,788 home charge events, accounting for about 78% of all charge events recorded during the trial. All BEV participants charged at home during the trial. Around 76% of BEV participants also charged away from home.

In the Control group, home charges began straight away after plugging in; there was no option to set a schedule for the charge as there was for participants in the UMC or SMC groups. Figure 48 shows the proportion of home charge events by charge start time (in 1-hour time intervals) for weekday and weekend charge events.

There was a statistically significant difference in the distribution of charge start times between weekdays and weekends ($\chi^2 = 14.081$, $p = 0.003$). The majority of home BEV charges started in the evening; a clear peak is visible from 15:00 to 20:00, which is more pronounced on weekdays compared with weekends.

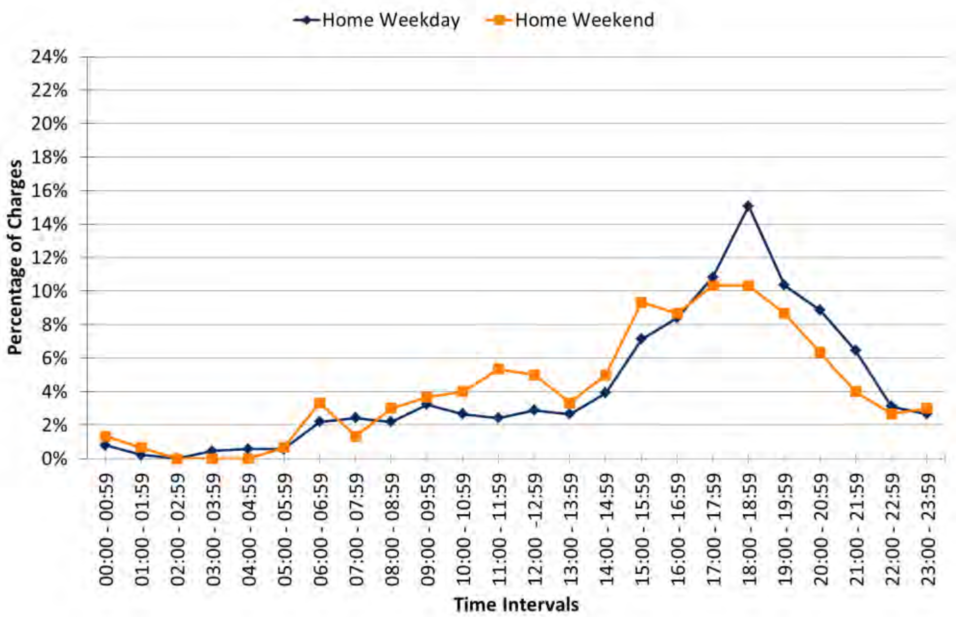


Figure 48: Proportion of weekday and weekend home charge events by charge start time for BEV Control group participants (N = 1,169)

Figure 49 shows the average energy delivered per control group participant for each hour of the day. This shows that peak energy usage for both weekends and weekdays was in the late evening (around 20:00-22:00).

For the purposes of this calculation, a consistent charging rate was applied over the duration of each charge event; e.g. a 2.5kWh charge over 5 hours resulted in an hourly charge rate of 0.5kWh. This assumption was necessary to calculate energy delivered (kWh) per hour.

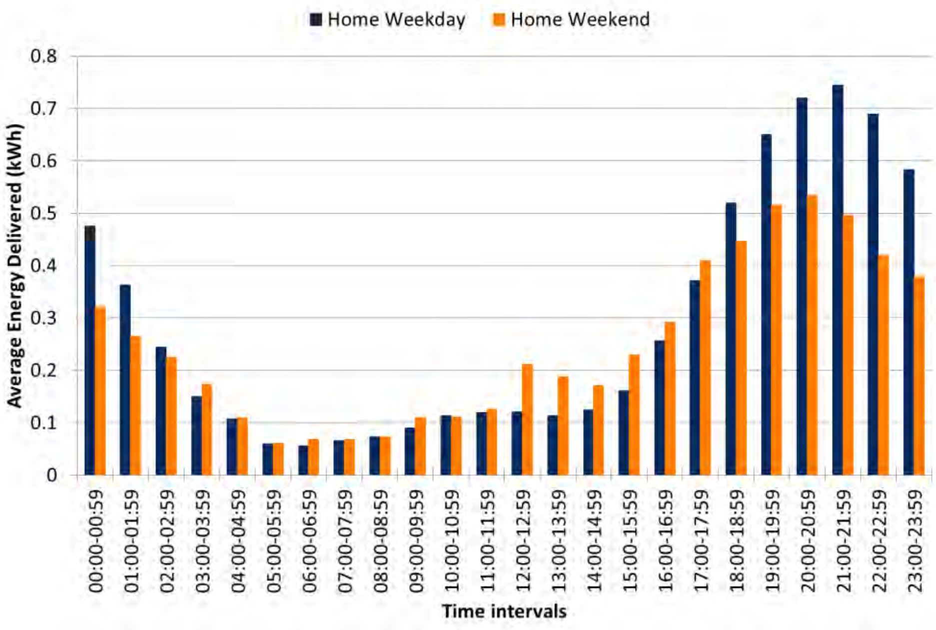


Figure 49: Average energy delivered per participant per hour of the day for home change events in the BEV control group

Charging away from home

A total of 984 charge events away from home were recorded in the BEV Charging Trial. In the Control group, there were 274 weekday charges and 137 weekend charges away from home. Expressed as energy delivered, the total amount of charging completed by Control group participants across home and away events amounted to 21,299kWh. Charge events away from home accounted for about 5,456kWh; around 25% of all charging that took place.

A comparison of the weekday and weekend charge events at home and at locations away from home is shown in Figure 50. There was a statistically significant difference in the distribution of charge start times between home and away charge events on both weekdays ($\chi^2 = 186.30$, $p < 0.001$) and weekends ($\chi^2 = 21.543$, $p < 0.001$). The profile of charges away from home on weekdays shows a clear peak in the early morning between 06:00 and 10:00. For weekend charge events, a pattern can still be observed for home charges in the evening, and charges away from home in the morning; however, there is greater variability on weekends than weekdays. This is consistent with activity patterns at the weekend differing from those on a typical weekday.

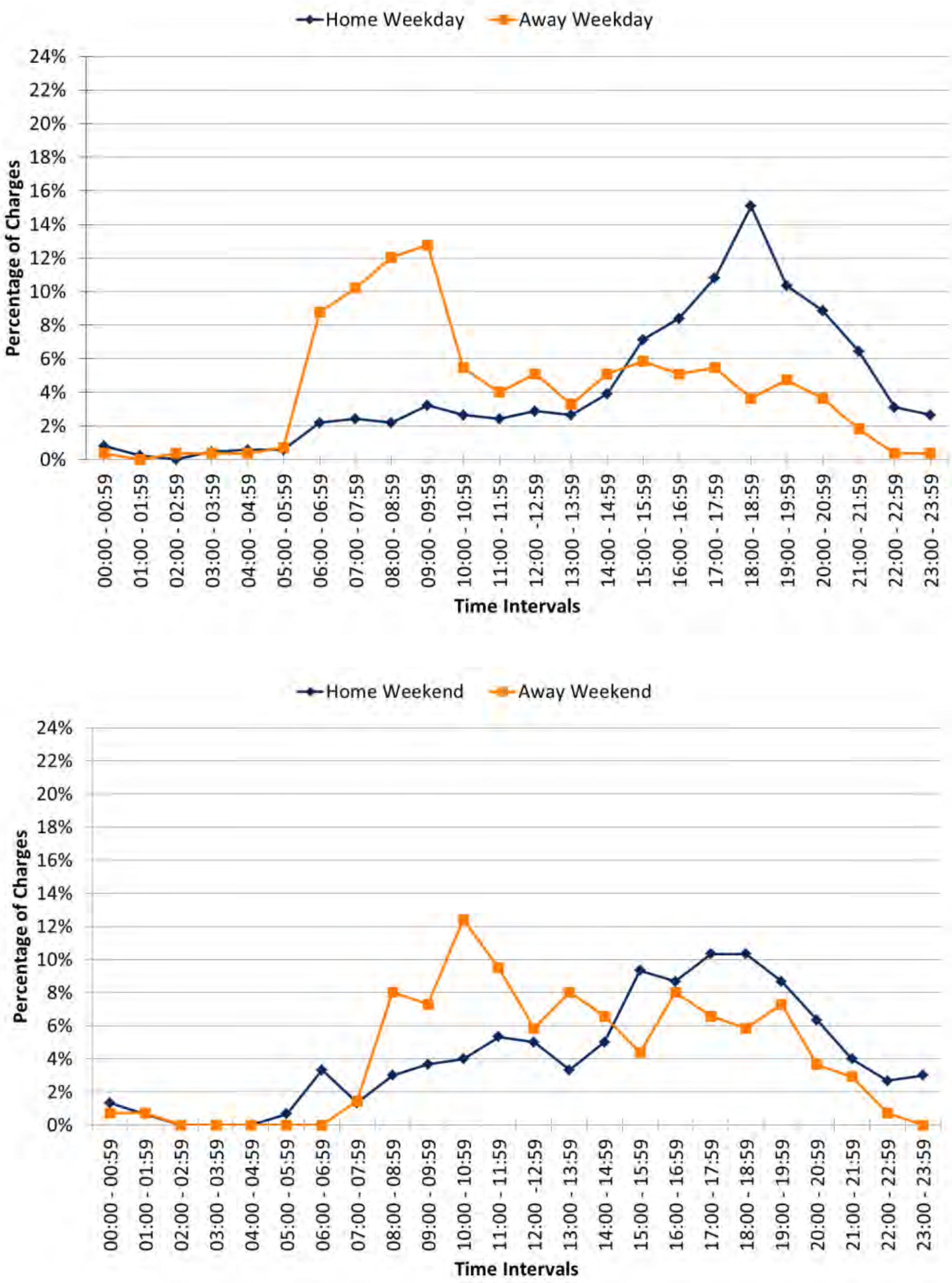


Figure 50: Proportion of weekday and weekend charge events at home and away from home by charge start time for Control group BEV participants (N = 1,580) (Top – Weekday; Bottom – Weekend)

Figure 51 shows the percentage of participants who reported (in the TP2 questionnaire) that they had access to a chargepoint at various locations away from home. The most commonly reported place where a chargepoint was available was at motorway service areas, followed by fee-charging car parks and supermarkets. Around a third of the BEV participants reported that they had access to a chargepoint at work.

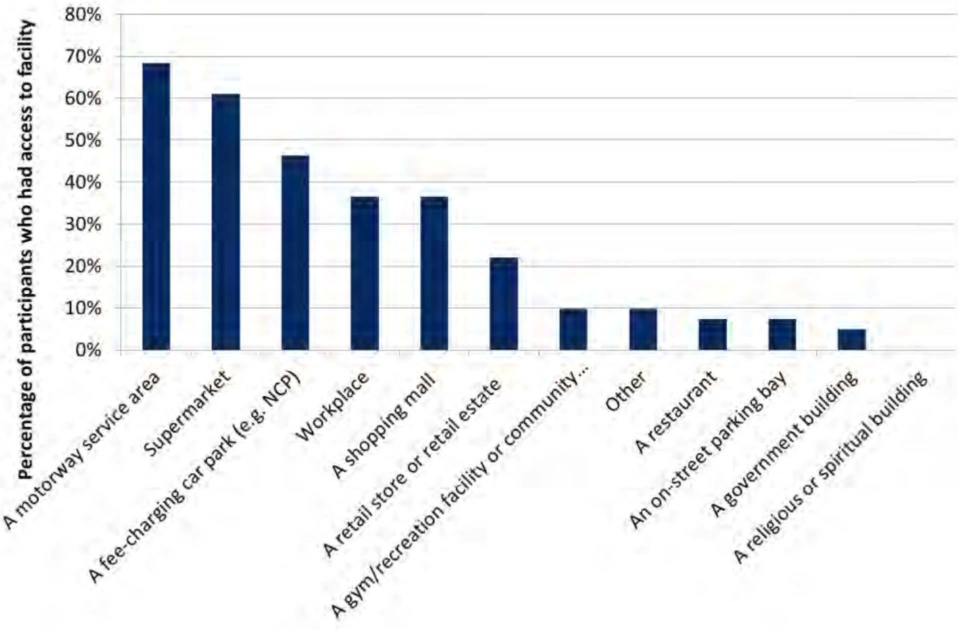


Figure 51: Proportion of Control group BEV participants who reported they had access to chargepoints at various locations (N = 127)

Figure 52 shows the self-reported frequency at which BEV participants charged at various locations away from home.

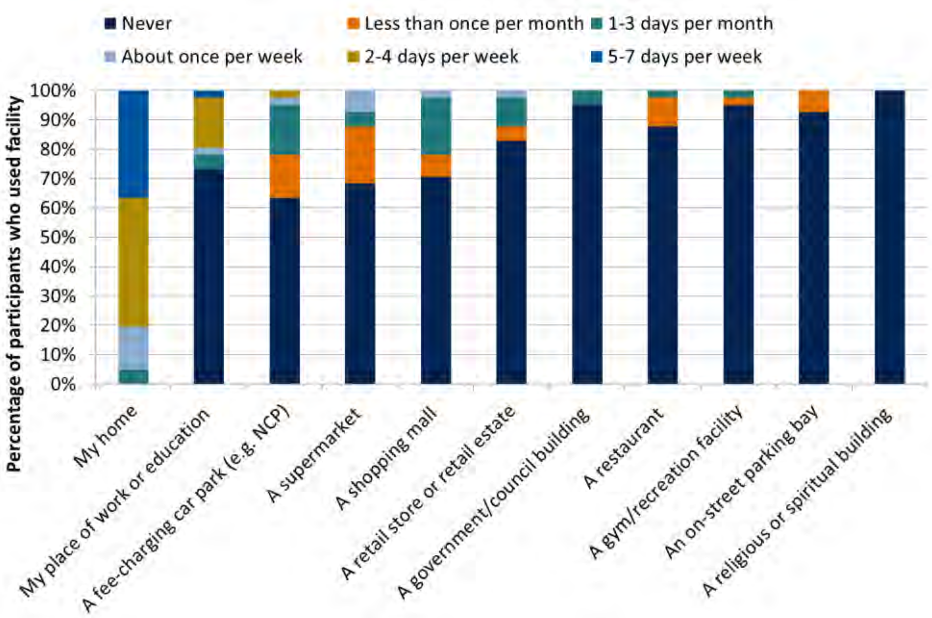


Figure 52: Self-reported frequency of charging at home and locations away from home for Control group BEV participants (N = 127)

The greatest share of participants (more than 30%) reported charging at fee-charging car parks and supermarkets less than once per month or more frequently. The greatest share of regular charging was reported to be at participants' places of work or education; around 20% of the sample reported charging 2-4 times per week or more.

B.4.1.2 *How does the charging behaviour of mainstream consumers when participating in an unmanaged charging scheme compare with when participating in a Supplier-Managed or User-Managed Charging scheme?*

→ **Plug-in times at home were not greatly influenced by participation in managed charging schemes.**

→ **The times at which home charges started, however, were substantially influenced by participation in a managed charging scheme.**

→ **The UMC scheme shifted home charge start times to later in the evening relative to the Control group (6pm-10pm); this shift was in line with the Low tariff period.**

→ **The SMC scheme shifted home charge start times into the overnight period (9pm-5am); as a result, the charging profile for this group was considerably flatter than the other groups.**

This section combines together results to the following two research questions:

- How does the charging behaviour of mainstream consumers when participating in a managed charging scheme compare with their behaviour when they are not?
- How does the charging behaviour of mainstream consumers when participating in a Supplier-Managed Charging scheme compare with their behaviour when participating in a User-Managed Charging scheme?

The focus of this analysis was to understand the charging behaviours of BEV participants in the Control group compared with those in the UMC and SMC groups. The analysis used data from vehicle telematics and the CPMS.

Charging at home

Figure 53 shows the proportion of home charge events by plug-in time for the Control, UMC and SMC groups. The majority of home plug-ins occurred in the evening between about 5pm-8pm. Plug-ins on weekends were more spread out than on weekdays, but still showed peaks in the evening period. Statistical analysis showed there were significant differences in the distribution of weekday plug-in times between the UMC and SMC groups (χ^2 = 12.14, p = 0.001), between the UMC and Control groups (χ^2 = 46.75, p < 0.001) and between the SMC and Control groups (χ^2 = 16.23, p = 0.001). There were also significant differences in the distribution of weekend plug-in times between the UMC and Control groups (χ^2 = 8.37, p = 0.039). SMC participants plugged their vehicle in proportionally more often during the morning and afternoon, and less often during the evening and overnight[28], compared with UMC participants.

Weekday and weekend plug-in times differed significantly for both UMC (χ^2 = 30.90, p < 0.001) and SMC (χ^2 = 14.59, p = 0.002) groups, with clear peaks in the evening on weekdays compared with weekends.

[28] See section A.15.3 for explanation of morning, afternoon, evening and overnight periods.

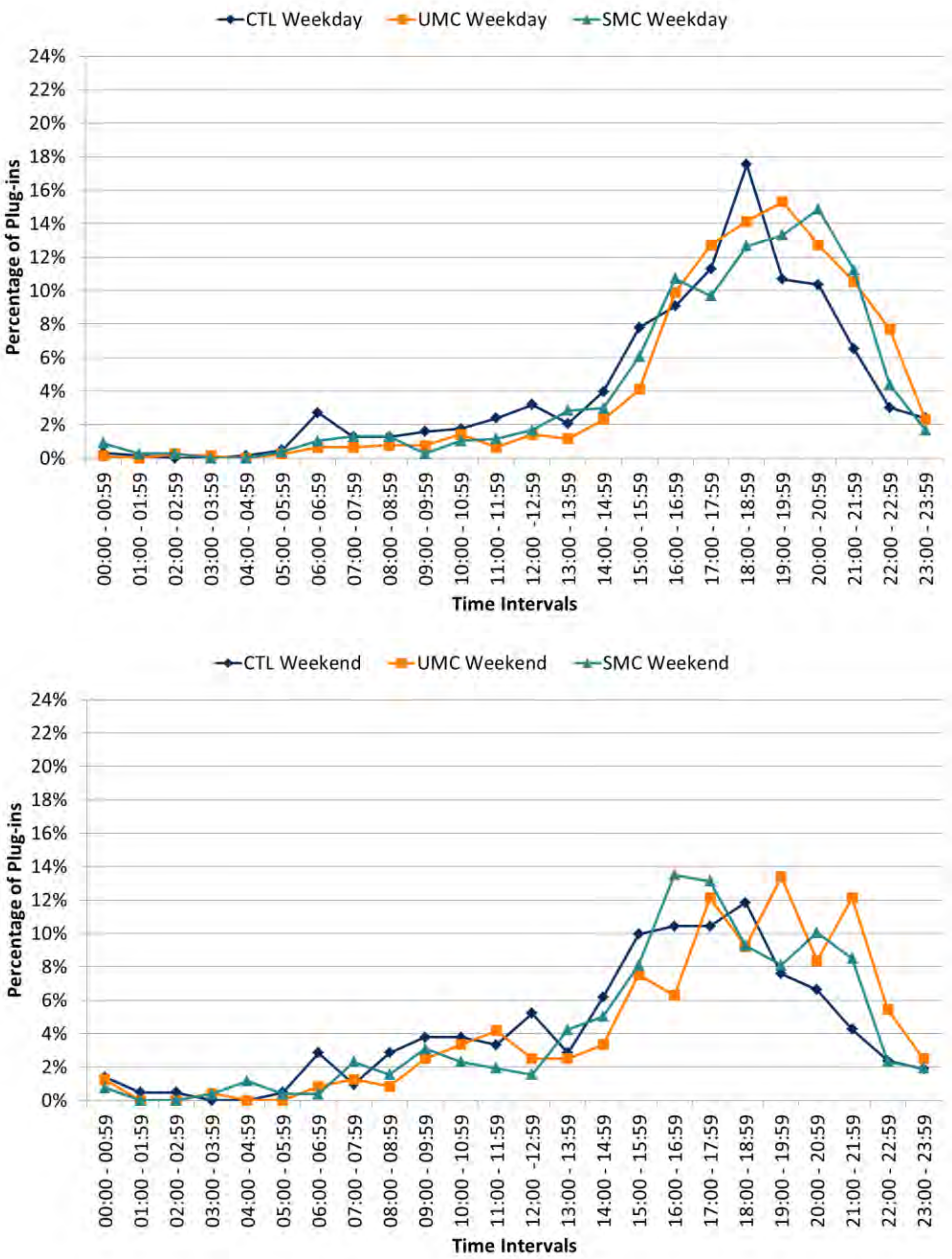
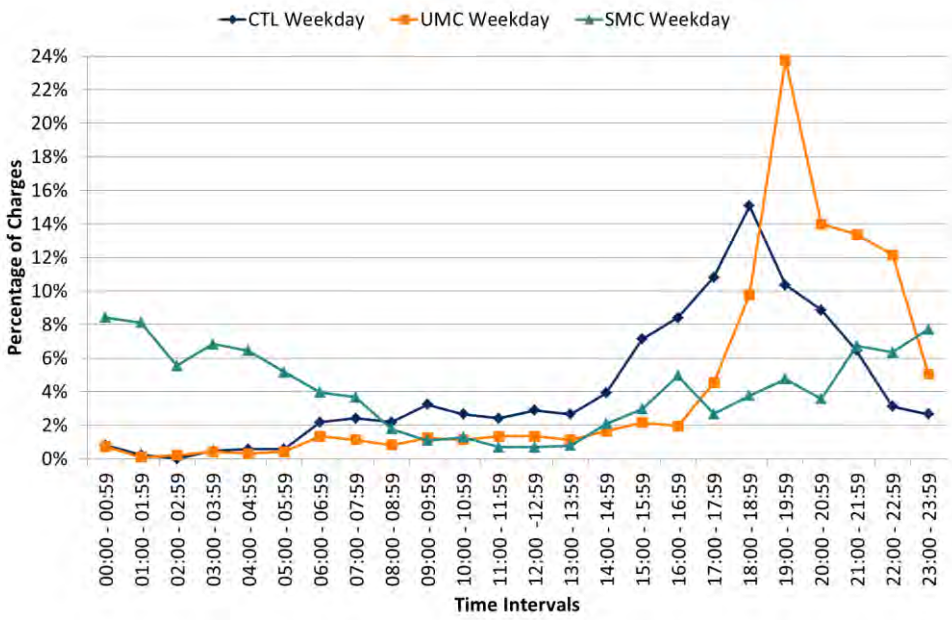


Figure 53: Proportion of home charge events by plug-in time for Control, UMC and SMC BEV participants (N = 2,889) (Top – Weekday, Bottom – Weekend)

There were significant differences in the distribution of weekday charge start times between the UMC and Control ($\chi^2 = 114.08$, $p < 0.001$), between the SMC and Control ($\chi^2 = 469.16$, $p < 0.001$) and between UMC and SMC ($\chi^2 = 358.53$, $p < 0.001$). Likewise the weekend charge start profiles also differed significantly (UMC vs. Control: $\chi^2 = 34.09$, $p < 0.001$; SMC vs. Control: $\chi^2 = 140.29$, $p < 0.001$; UMC vs. SMC: $\chi^2 = 126.15$, $p < 0.001$).

These differences are clearly illustrated in Figure 54, which shows the proportion of home charges by charge start time for the three groups.



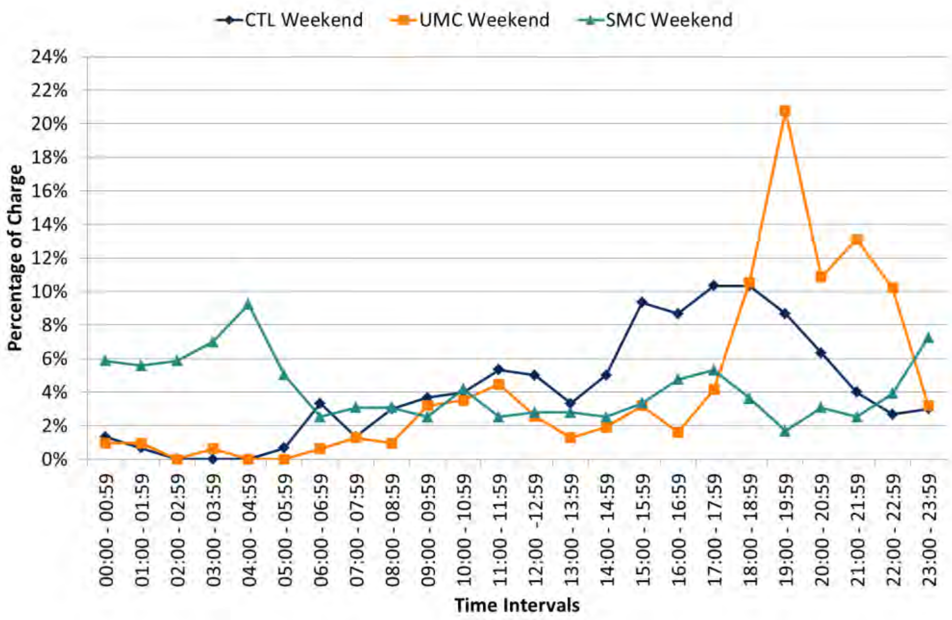


Figure 54: Proportion of home charge events by charge start time for Control, UMC and SMC BEV participants (N = 3,822) (Top – Weekday, Bottom – Weekend)

There is a clear impact of managed charging on the charging profiles. In the Control group, there was a peak in weekday charge events starting between 6pm-7pm. In comparison, the majority of charge events in the UMC group were shifted to later in the evening, with a peak between 7pm-8pm in line with the Low tariff band. For the SMC group, on the other hand, most of the charging events occurred in the overnight period, starting between 12am-5am. The profile for BEV SMC charge start times was in fact considerably flatter than that of both Control and UMC groups, showing that SMC was highly effective at shifting charging demand.

There were also statistically significant differences in the charge start times between weekday and weekend charge events for both the UMC ($\chi 2 = 18.889$, $p < 0.001$) and SMC ($\chi 2 = 18.067$, $p < 0.001$) groups. In both cases, weekday charge events were less likely to start in the morning or afternoon and more likely to start evening or overnight, compared with weekend charge events.

The charge start times in the SMC group were governed by the way the SMC system was configured for the purposes of the trial (see section A.9). If, for example, participants set a Departure Time in the early morning at 7am (as might be typical for commuters) then the system started the charge so as to deliver the Desired SOC by 6am (i.e. one hour before the Departure Time). This was a necessary set-up for the trials since it avoided system complexity whilst ensuring the user experience of an SMC scheme was adequately simulated. A real-world SMC scheme would likely administer charging in a slightly different way; more closely mapping charge start/stop times against real-time fluctuations in whole-sale energy prices and supply. As such, the charging profiles in a real-world SMC scheme may be more spread out than those observed in this trial. Nevertheless, even where charging takes place in a single continuous block as was the case in this trial, the data shows that SMC can be an effective means of shifting charging demand into the overnight period.

Figure 55 shows the average energy delivered per participant for each experimental group. These data support the patterns seen in the profile of charge start times, with the two managed charging schemes shifting peak energy demand to later in the evening (in the UMC group) and into the overnight/early morning period (in the SMC group). It should be noted, as described above, that this calculation assumed a consistent charging rate over the duration of each charge event.

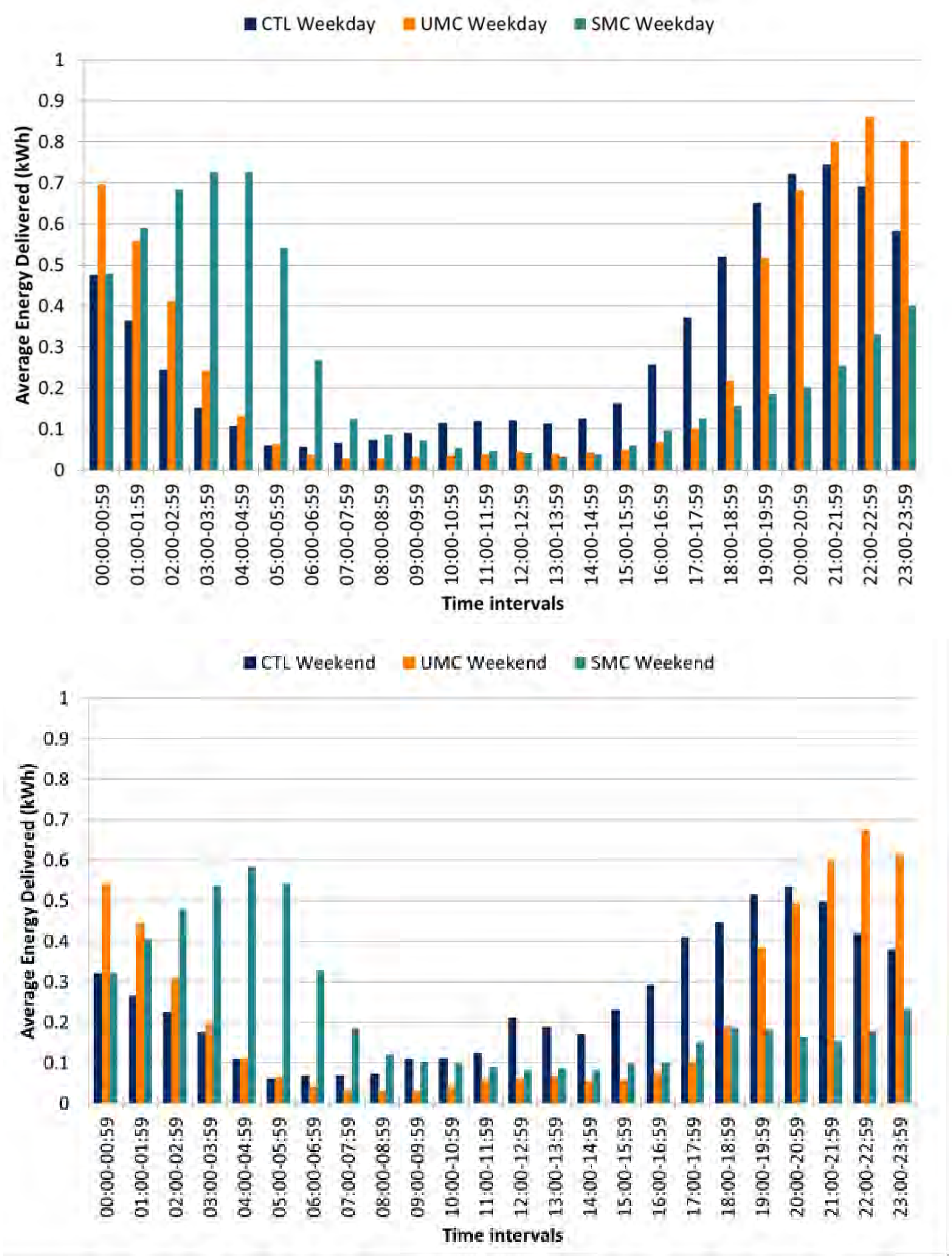


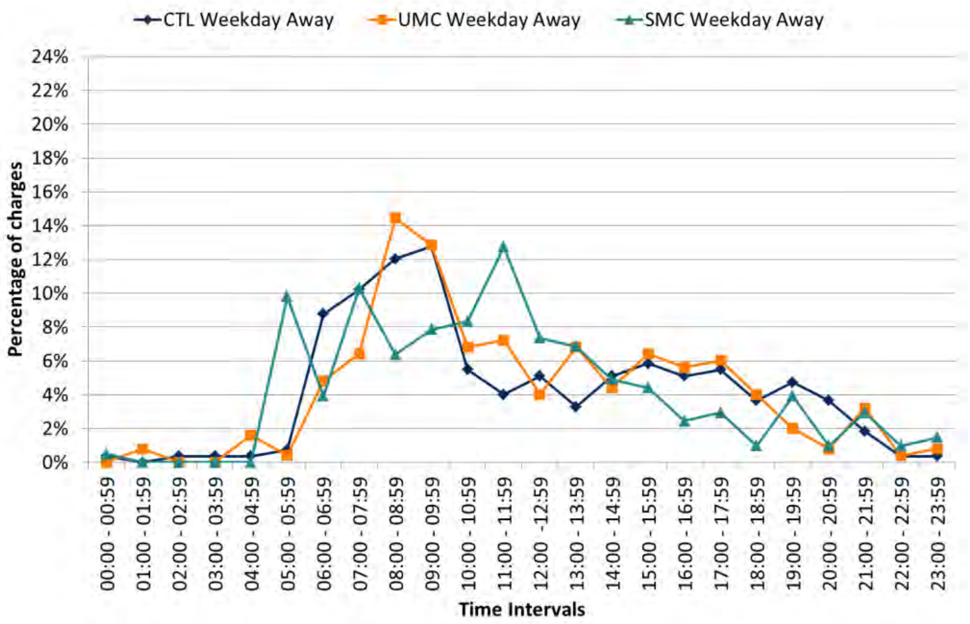
Figure 55: Average energy delivered per participant per hour of the day for Control, UMC and SMC BEV participants (N = 3,822) (Top – Weekday, Bottom – Weekend)

Charging away from home

The managed charging schemes experienced by participants in the trial only applied to charge events at home; as such, the most important comparisons for understanding the impacts of managed charging are with home charge events. However, it may be hypothesised that experience with managed charging at home could also impact behaviours when charging away from home. As such, this section compares the charging behaviours away from home between participants in the Control group and participants in the managed charging groups. When considering the results of this analysis it is important to note that the sample of away from home charge events (N = 984) was considerably smaller than that for home charge events (N = 3,788).

Figure 56 shows the proportion of away from home charge events by charge start times for the Control group and the two managed charging groups. Statistical analysis showed there were significant differences in weekday charge start times between the Control group and the two managed charging groups combined ($\chi^2 = 11.19$, $p = 0.011$). For managed charging participants, a larger proportion of weekday away charges started in the afternoon (12pm-4pm), and a smaller proportion started in the morning (4am-10am), compared with Control charging participants. On weekdays, charge start times peaked between 8am-10am for both Control and managed charging participants. On weekends, the peak is a bit later in the morning (10am-11am) and is less pronounced, with a greater share of charge events starting later in the day.

Examination of the UMC and SMC groups separately showed a significant difference in the distribution of weekday away from home charge start times between the UMC and SMC groups ($\chi^2 = 28.55$, $p < 0.001$) and between the SMC and Control groups ($\chi^2 = 23.27$, $p < 0.001$). For SMC participants, there were more away from home charges which started in the afternoon or overnight, and fewer which started in the morning or evening, compared with UMC participants, and more away charges which started in the evening or overnight, compared with Control participants.



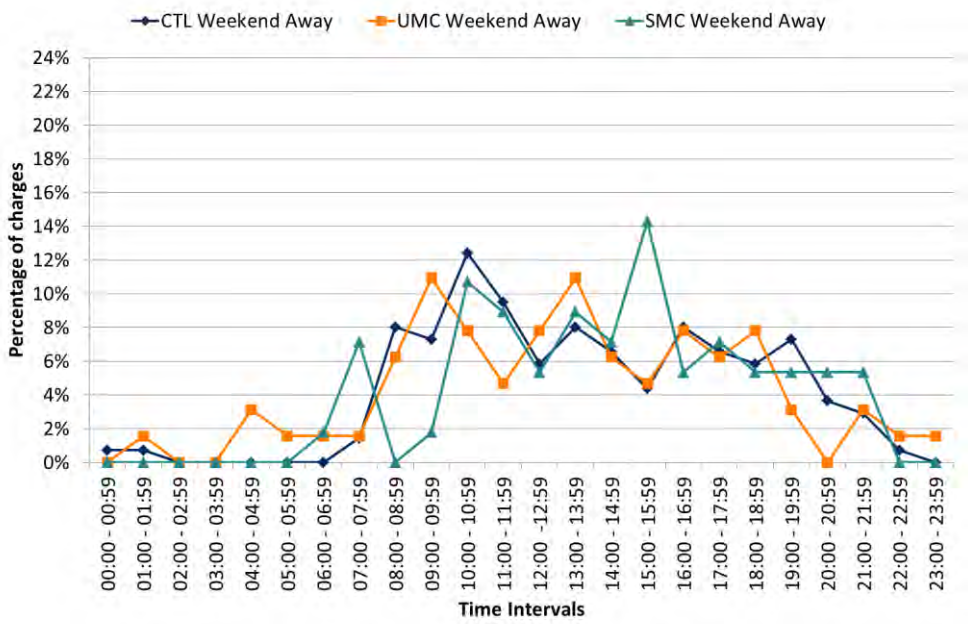


Figure 56: Proportion of away from home charge events by charge start time for Control, UMC and SMC BEV participants (Top – Weekday (N=727), Bottom – Weekend (N = 257)

There was also a statistically significant difference in the charge start times between weekday and weekend away from home charge events for both the UMC ($\chi^2 = 9.29$, $p = 0.026$) and SMC ($\chi^2 = 22.43$, $p < 0.001$) groups. In both cases, weekday charge events were less likely to start in the afternoon or evening, and more likely to start overnight or in the morning, compared with weekend charge events.

B.4.1.3 *What are the diurnal, weekly and seasonal time profiles of charging when participating (or not) in a given managed charging scheme?*

- **Most charging events started in the Low tariff band; charging profiles did not significantly vary between the UMC-Summer and UMC-Winter sub-groups.**
- **The distribution of charge start times did not differ significantly between the SMC-Summer and SMC-winter sub-groups**
- **There were no substantial differences in the frequency of charging between real-world seasons**

The focus of this analysis was to understand how the charging behaviours of BEV participants varied between the Summer and Winter sub-groups of UMC and SMC, and between the real-world seasons experienced by participants in the trial (approximately winter, spring and summer). Analysis of the diurnal and weekly variation in BEV charging profiles is provided in sections B.4.1.2 and B.4.1.5 respectively. The analysis used data from vehicle telematics and the CPMS.

Comparisons between Summer and Winter sub-groups

This analysis compares the charging behaviours of participants assigned to the SMC-Summer, SMC-Winter, UMC-Summer, UMC-Winter and Control charging groups. Home and away from home charges have been analysed separately.

UMC Summer and Winter

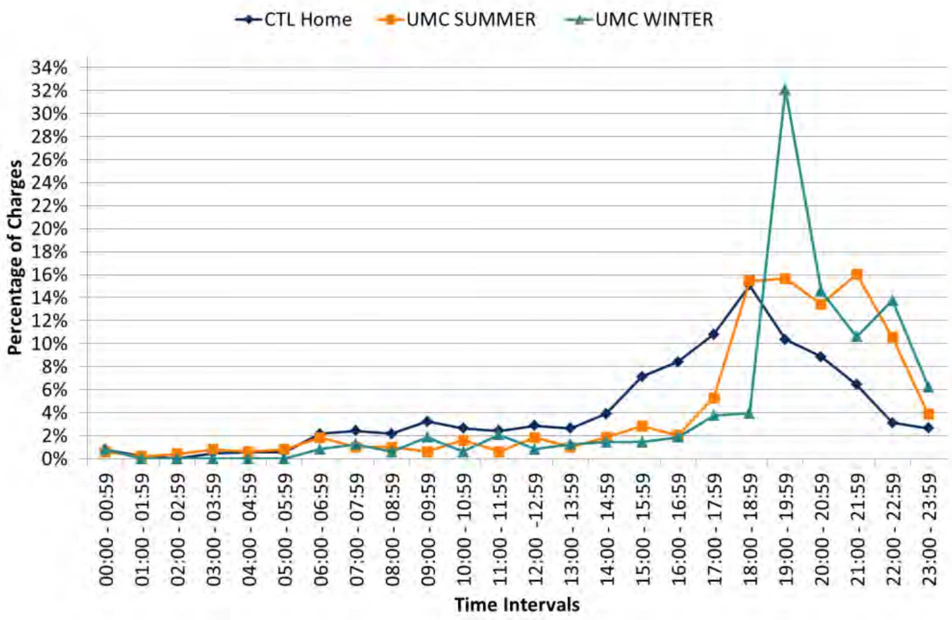
The proportion of UMC charge events starting in each of the Tariff bands is shown for weekend and weekday events in Table 32.

Table 32: BEV charge start times for home charges on weekdays by tariff band

	Weekdays		**Weekends**	
Tariff Band	**UMC-SUMMER**	**UMC-WINTER**	**UMC-SUMMER**	**UMC-WINTER**
Low	77.03%	78.13%	69.33%	70.00%
Standard	5.28%	4.58%	4.91%	4.00%
Medium	5.69%	6.25%	12.88%	15.33%
High	11.99%	11.04%	12.88%	10.67%

In all cases, the majority of charge events started in the Low tariff band; showing a good level of engagement with the managed charging scheme. The proportions of charge events starting in each band were similar between UMC-Summer and UMC-Winter. There was a slightly, but significantly, higher proportion of charge events at the weekend starting in the Medium band, and a slightly lower proportion in the Low band. This may be reflective of activity patterns at the weekend differing from that on weekdays. There were no significant differences found when comparing between the UMC-Winter and UMC-Summer groups..

Figure 57 shows the proportion of home charge events by charge start time for Control, UMC-Summer and UMC-Winter charging groups.



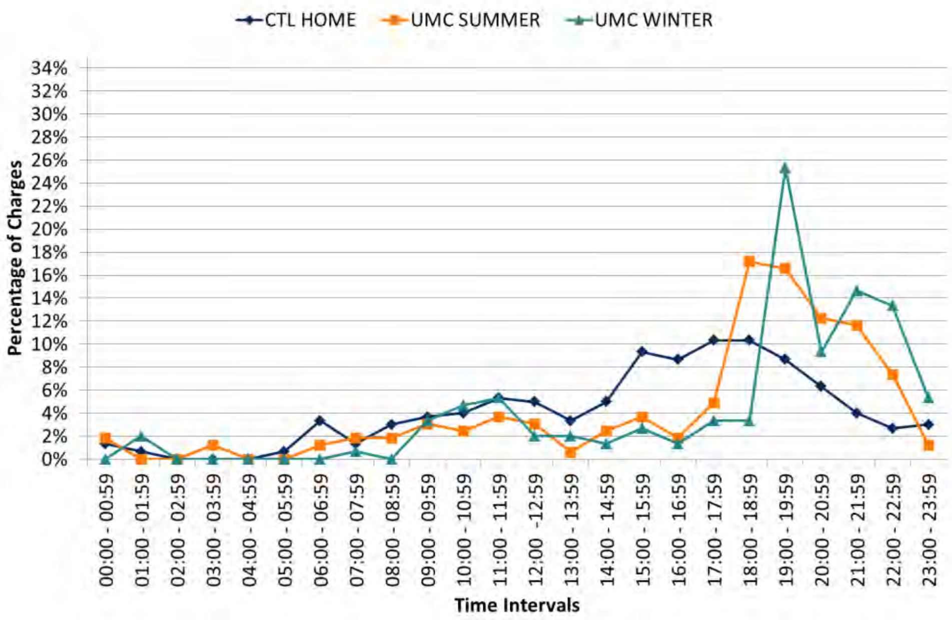


Figure 57: Proportion of home charge events by charge start time for control and UMC BEV participants (N = 2454) (Top – Weekday, Bottom – Weekend)

Both on weekdays and weekends, it can be seen that the peaks in charge start times were broadly in line with the start of the Low tariff band; 7pm for UMC-Winter participants and 6pm for UMC-summer participants. In the UMC-Summer group, the peak extended to later in the evening (7pm-10pm). There no significant difference between the UMC-summer and UMC-winter groups on weekdays or on weekends.

SMC Summer and Winter

There was a significant difference in the distribution of plug-in times between the SMC-Summer and SMC-Winter charging groups on weekdays ($\chi^2 = 10.80$, $p = 0.013$). SMC-Summer participants were proportionally more likely to plug in their vehicle during the evening (4pm-10pm), and less likely to plug it in during the afternoon (12pm-4pm), compared with SMC-

Winter participants. Most of the time, participants in all groups tended to plug in their vehicles in the evening, but the charges usually started overnight. This impact can be seen thanks to the SMC scheme that the participants are involved in.

Figure 58 shows the distribution of the charge start times between SMC-Summer, SMC-Winter and Control participants.

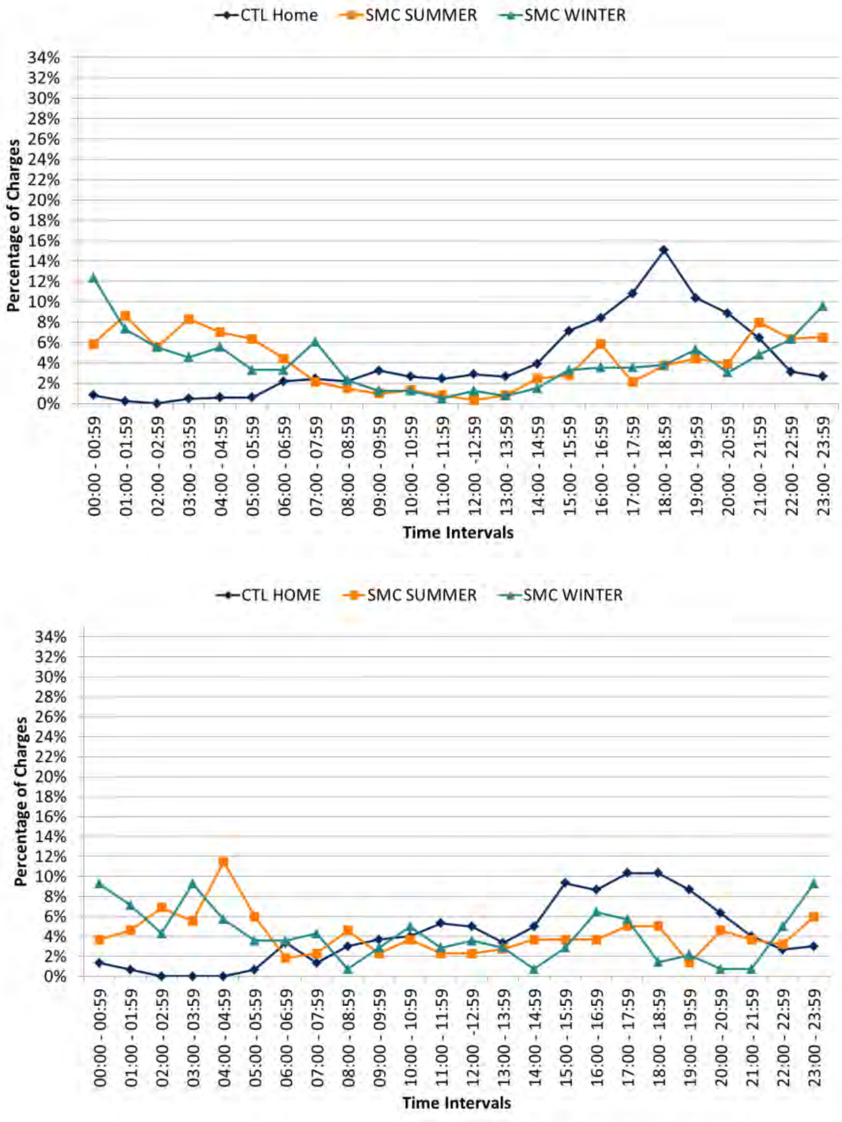


Figure 58: Proportion of home charge events by charge start time for Control and SMC BEV participants (N = 2454) (Top – Weekday, Bottom – Weekend)

SMC charges occurred mostly in the overnight period. There was no significant differences between the charge start times SMC-Summer and SMC-Winter groups on weekdays or weekends.

Comparisons between real-world seasons experienced in the trial

In order to gain a deeper understanding of charging patterns, participants' behaviours through the seasons were also analysed. All charge events from November 2017 to February 2018 were classified as Winter events. Charge events in March, April and May 2018 were classified as Spring, and events occurring from June 2018 to the end of the trial (mid-September 2018) were classified as Summer.

Figure 59 shows the average number of charging events per participant by season. From this graph, we can see that there was little variation in the average number of charges per participant between the seasons.

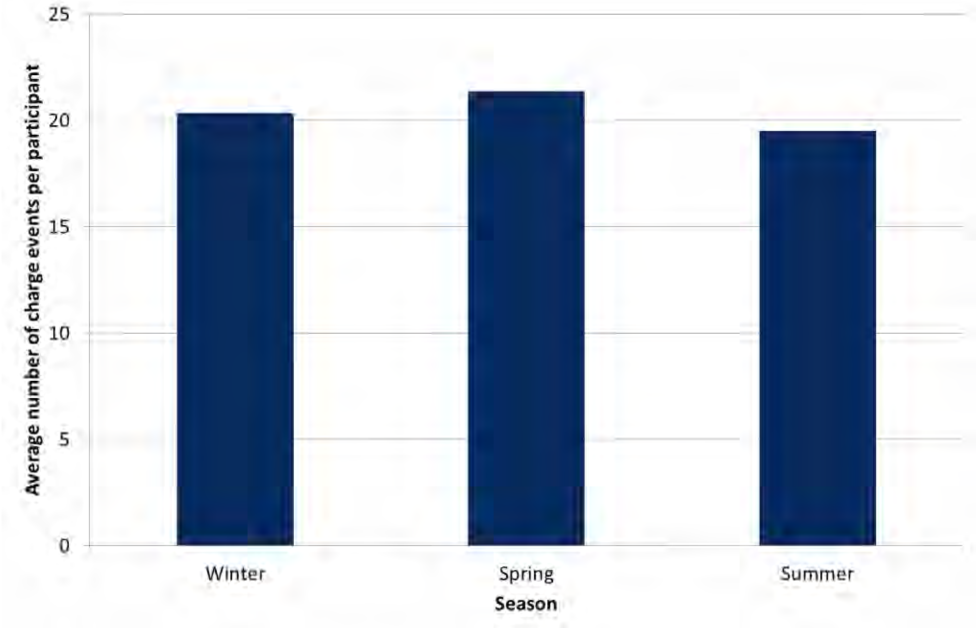


Figure 59: Average number of BEV charging events per participant by season

Figure 60 shows the average energy added per participant by season. From this graph, we can see that there was little variation in the energy added per participant between the seasons. In line with Figure 59, participants in Spring (who charged most frequently) added the most amount energy as well. While participants in Winter charged more frequently than participants in Summer, more charging energy was added per participant by participants in Summer than participants in Winter.

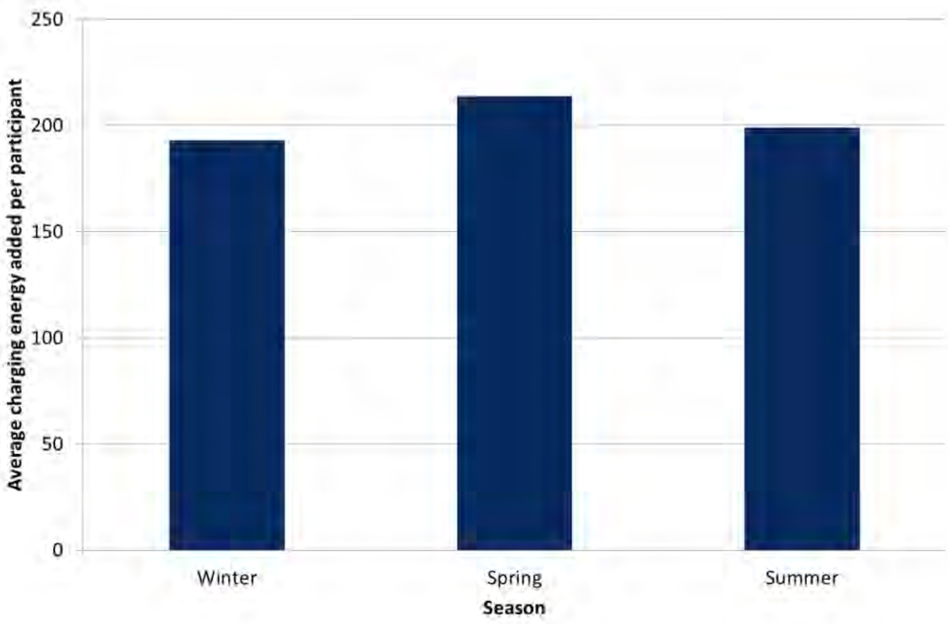


Figure 60: Average energy (kWh) added per BEV participant by season

B.4.1.4 *What are the between-participant variabilities in mainstream consumer charging behaviour when participating (or not) in a given managed charging scheme?*

- → **Start times of home charge events were more variable among participants in the SMC group than those in the Control or UMC groups; in line with the configuration of the SMC scheme in this trial.**
- → **The SOC at plug-in time varied substantially between participants; but the majority of the time SOC was between 40% and 60%. No differences between groups were observed.**
- → **There was very little variability in the SOC at plug-out; particularly for the UMC and Control groups which almost always finished on 100%. Greater variability was observed in the SMC group. This has important implications for the electricity system as it suggests that SMC may allow for greater inter-day and inter-location flexibility.**
- → **Home plug-out times were most consistent between participants in the SMC group. Across groups, participants consistently unplugged their vehicle during the early-mid morning period.**

The focus of this analysis was to understand how the level of between-participant charging behaviours varied within each experimental group. The analysis used data from vehicle telematics and the CPMS.

For the purposes of this analysis per-participant median values were calculated for the following charging metrics: plug-in time, charge start time, SOC at plug-in and plug-out, charge stop time and plug-out time. For example, the median plug-in time for each participant was calculated, averaging across all charge events undertaken by a given participant, and thus removing any *within*-participant variability from the metrics. In the case of charge and plug-in/out times, medians were calculated for each one-day period from midday-midday, as the vast majority of home charges started in the evening or overnight.

To understand *between*-participant variability, these per-participant values have been presented using boxplots. The boxplots are shown for each experimental group to illustrate the distribution of charging data across the participant sample. Within each boxplot, the solid line in the middle of the box represents the median value, and the upper and lower edges of the box represent the inner boundaries of the upper and lower quartiles, respectively. The difference between the upper and lower quartiles is known as the inter-quartile range (IQR); a measure of variability in the data. The lines extending from the edge of the box (known as 'whiskers') represent data that is within ±1.5 x IQR from the upper or lower quartile. Any data falling outside this range are plotted as outliers; represented by the black dots.

Plug-in and charge start times

Figure 61 presents the distribution of median home plug-in times for each group. Median plug-in times were slightly later in the managed charging groups than the Control group, in line with the patterns in charging profiles discussed earlier.

All of the experimental groups had similar inter-quartile ranges; this suggests that differences in charging profiles observed between the groups were due to a shift in charging behaviour, rather than an increase in variability in charging.

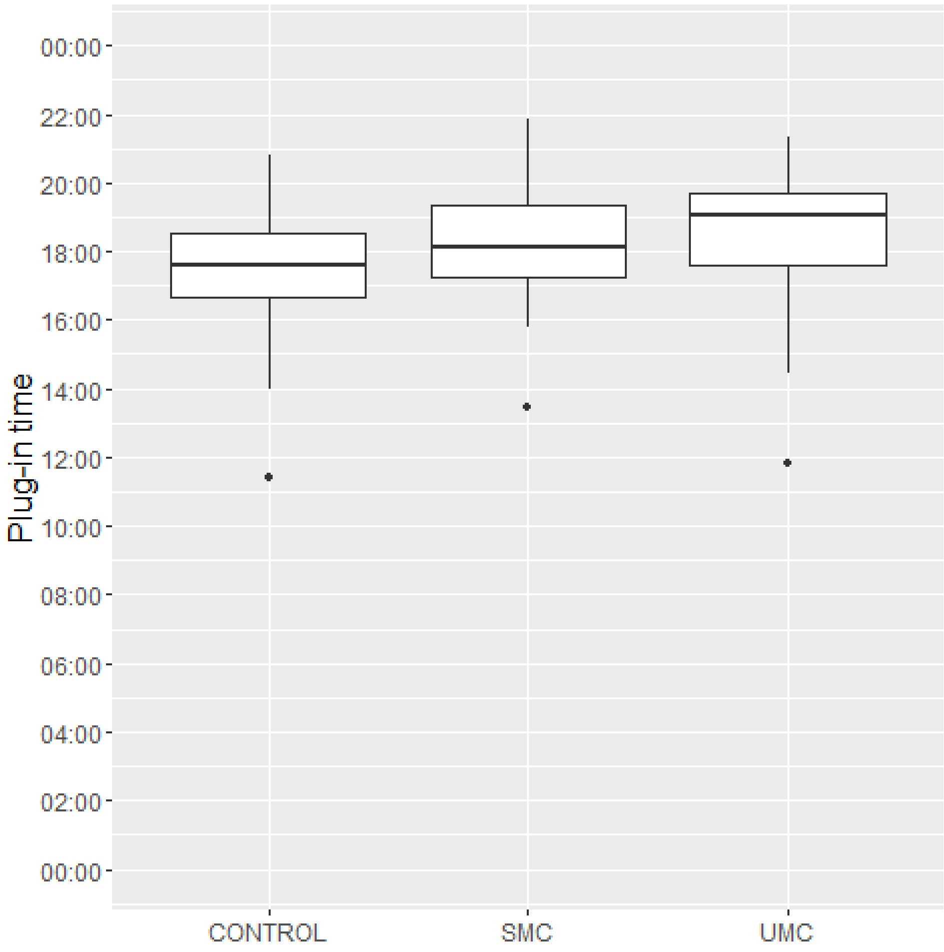


Figure 61: Boxplot showing median and IQR home plug-in times for BEV participants in each trial group (N = 127)

Figure 62 presents the distribution of median charge start times for home charges in each trial group. The results show that there was much greater variability among participants in the SMC trial group, compared with other trial groups. This is likely due to the configuration of the SMC scheme; whereby charge start was governed by user inputs (the Desired SOC and the Departure Time) and the SOC of the vehicle at the point of plug-in. The narrowness of UMC distribution compared to SMC can be explained by charge start times clustering around the start of the Low tariff band in the UMC group.

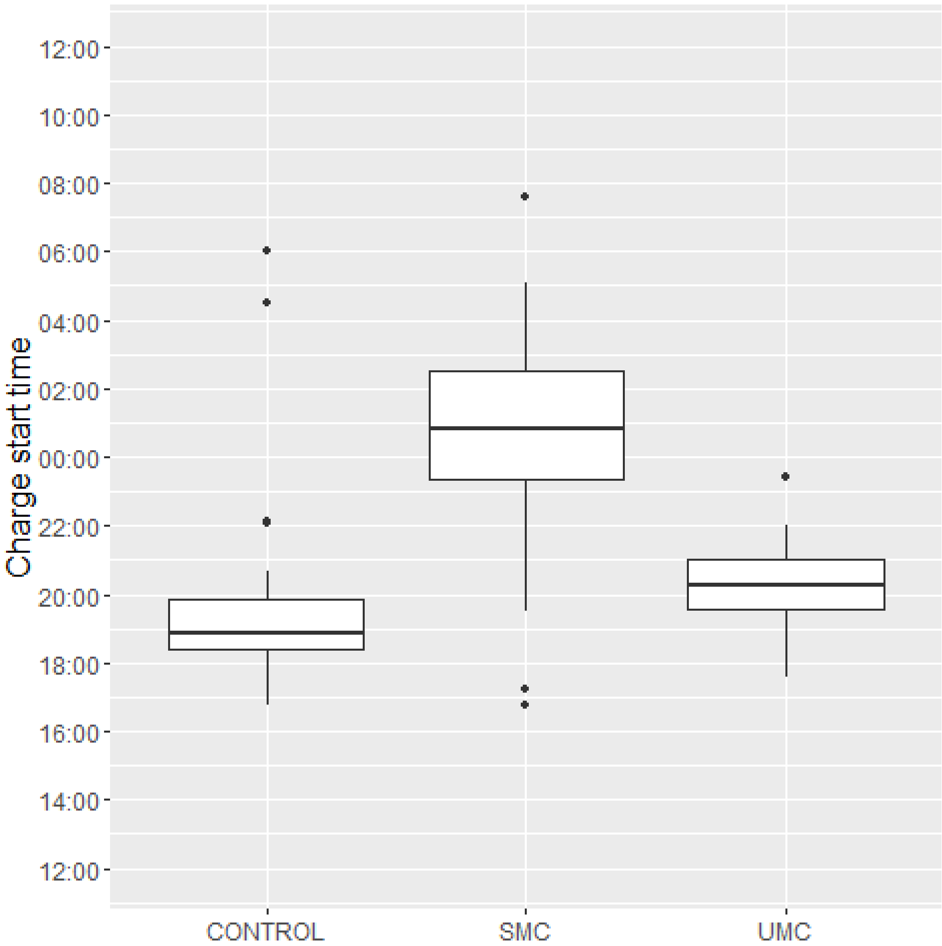


Figure 62: Boxplot showing median and IQR home charge start times for BEV participants in each trial group (N = 127)

SOC at plug-in and plug-out

Figure 63 presents the distribution of median SOC at plug-in for each trial group. The results show that there was a similar level of variability between participants' in each trial group. Median SOC at plug-in was around 50% for all groups. The distribution of SOC at plug-in suggests that most participants engaged in top-up charging (with SOC typically between 40% and 60%) rather than waiting until SOC was low before recharging – hardly any charging events began with an SOC less than 20%.

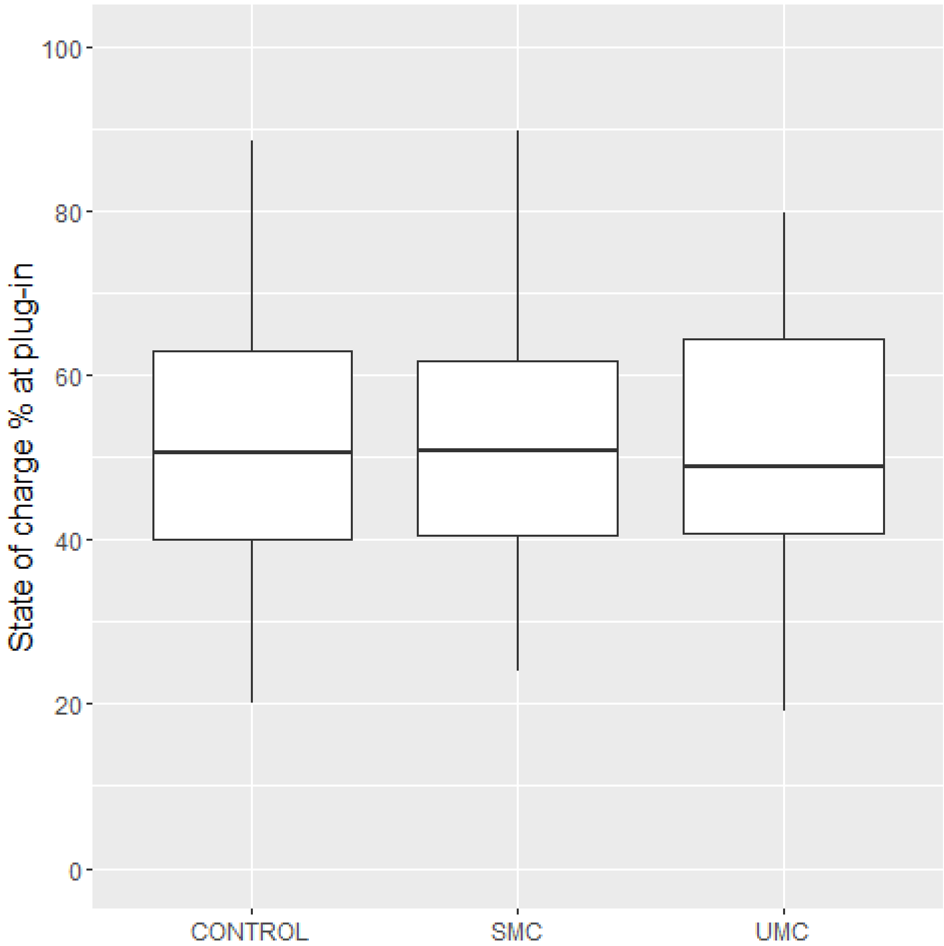


Figure 63: Boxplot showing median and IQR SOC at plug-in for BEV participants in each trial group (N = 127)

Figure 64 presents the distribution of median SOC at plug-out for each trial group. The results show that for participants in the control and UMC trial groups, the median state of charge (99%) was equal to both the upper and lower quartiles, which is why the three left hand boxplots do not contain a box. In both of these groups, almost all participants routinely charged to 100% SOC. For the participants in the SMC trial groups, there was some variability in final SOC between participants as well as a lower median. This suggests that some participants were requesting Desired SOCs of less than 100%, in line with the incentives for the SMC scheme which encouraged users to only request the amount they needed.

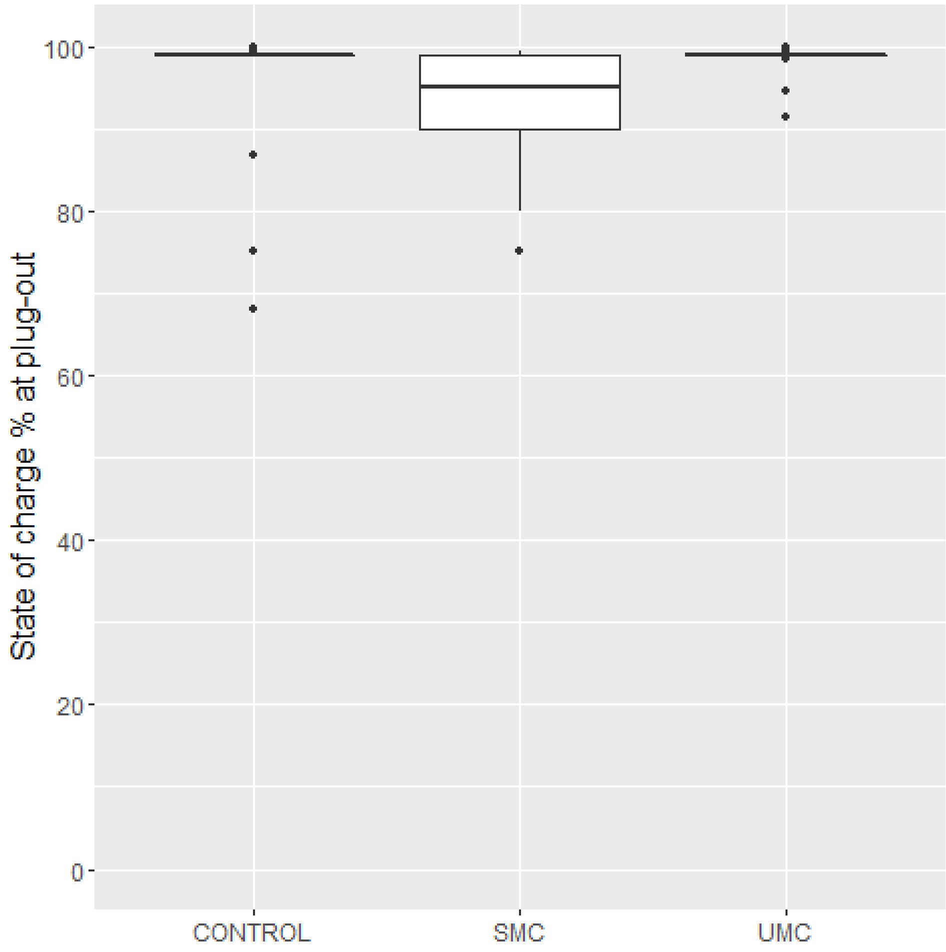


Figure 64: Boxplot showing median and IQR SOC at plug-out for BEV participants in each trial group (N = 127)

Figure 65 presents the distribution of median SOC at plug-in for each trial group for charges that occurred away from home. Most away from home charges began with an SOC around 50% indicating that these charges were also top ups.

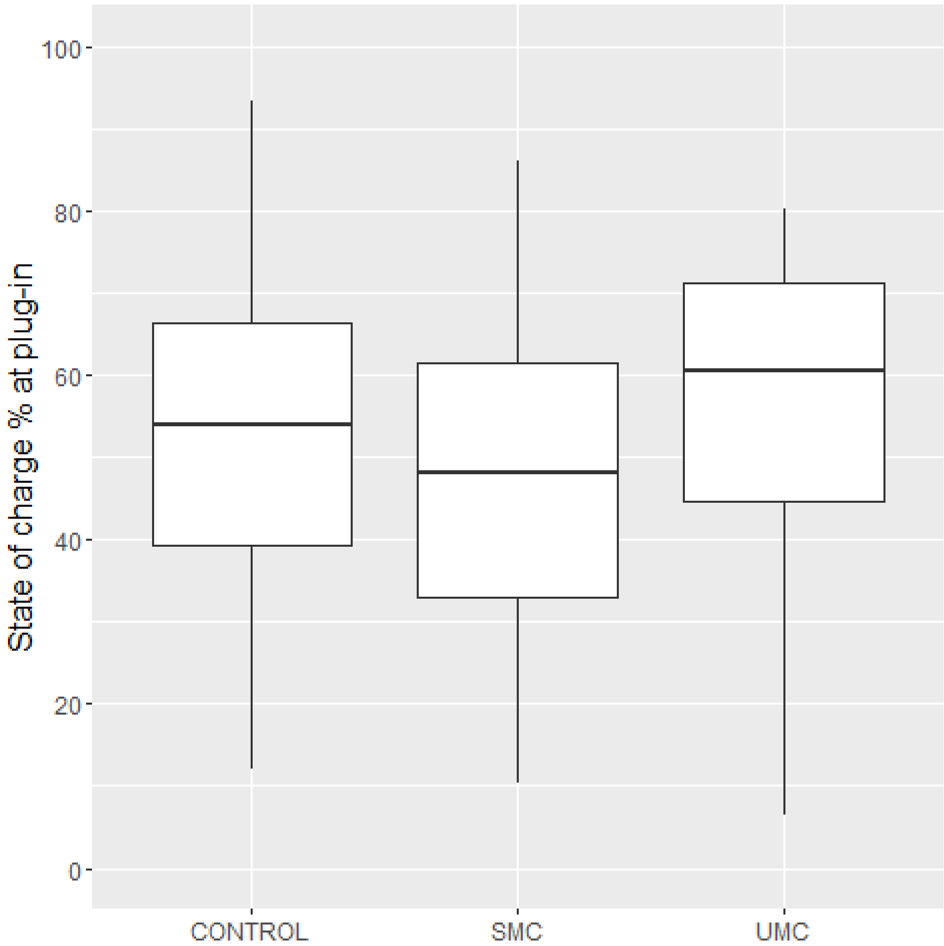


Figure 65: Boxplot showing median and IQR SOC at charge start for charges away from home for BEV participants in each trial group (N = 86)

Figure 66 shows the distribution of median SOC added for each trial group for charges that occurred away from home. Most away from home charges added 20-30% SOC to the battery, supporting the earlier assertion that these types of charges were used to top-up the battery rather than completely refill it.

Figure 67 shows the distribution of median energy delivered during charging for away charge events across all participants. The VW e-Golf had a 35.8 kWh nominal capacity; the median kWh added to the battery during away from home charges was about 10 kWh. The precise location of these charges is unknown, but some may have been at POLAR network chargepoints which participants could use for free during the trial.

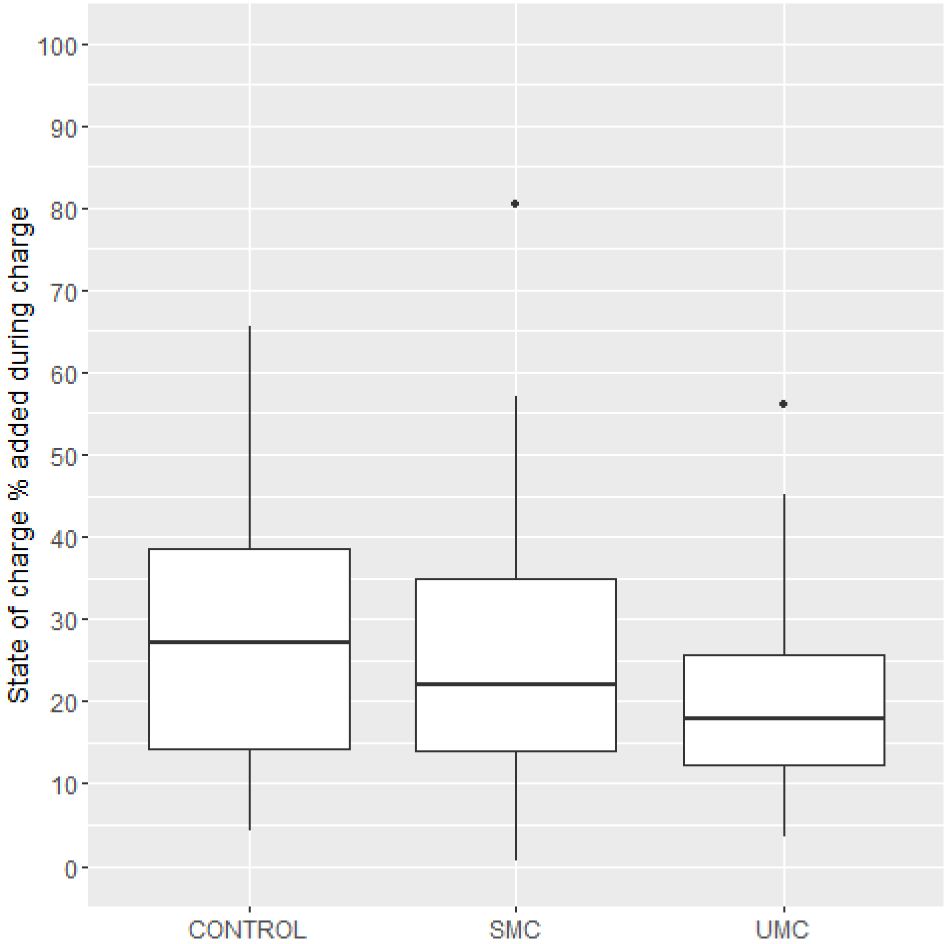


Figure 66: Boxplot showing median and IQR SOC added for away charges among BEV participants in each trial group (N = 86)

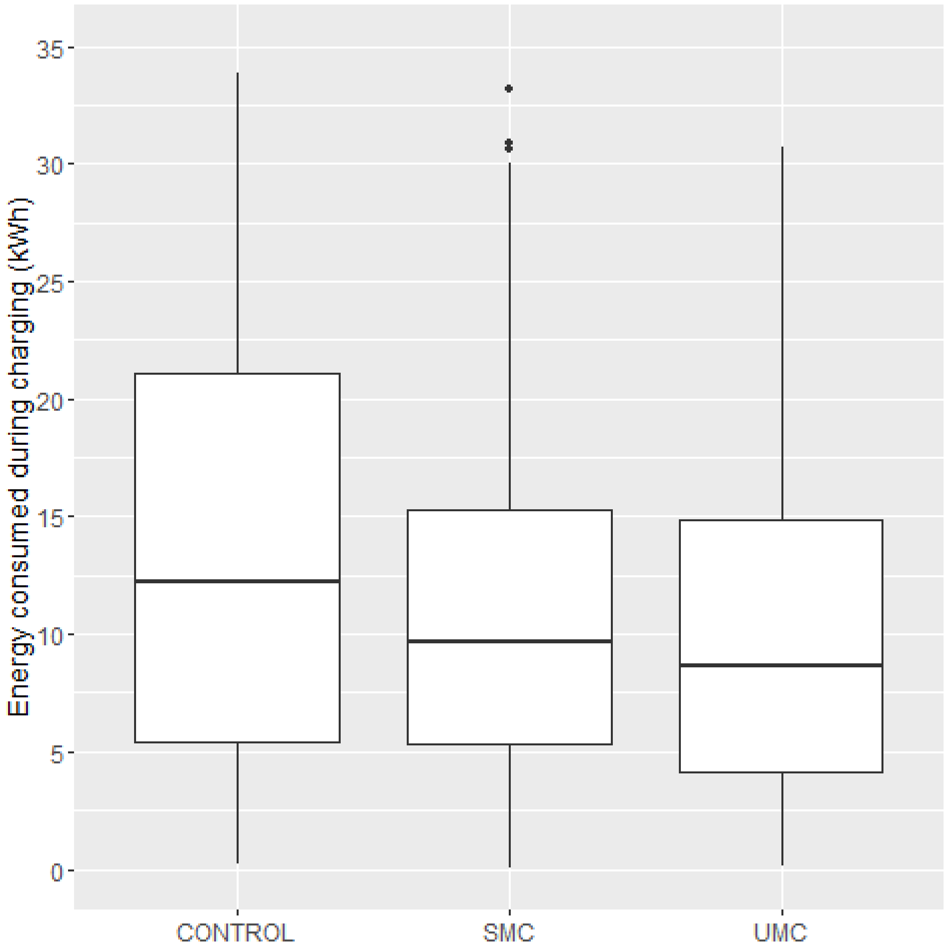


Figure 67: Boxplot showing median and IQR energy delivered during away charges among BEV participants in each trial group (N = 86)

Plug-out and charge stop times

Figure 68 presents the distribution of median charge stop times for each trial group. The figure shows that the greatest level of variability was in the Control group with the SMC group having the least. This is likely due to the configuration of the SMC system whereby charging was scheduled to finish one hour before the Departure Time requested by participants. The majority of Departure Times requested by participants were between 5am and 9am; confirming this explanation of the narrow distribution in charge stop times.

For the other groups, the variability in charge stop time is a function of both charge start times and starting SOC; hence the greater overall variability compared with SMC charges.

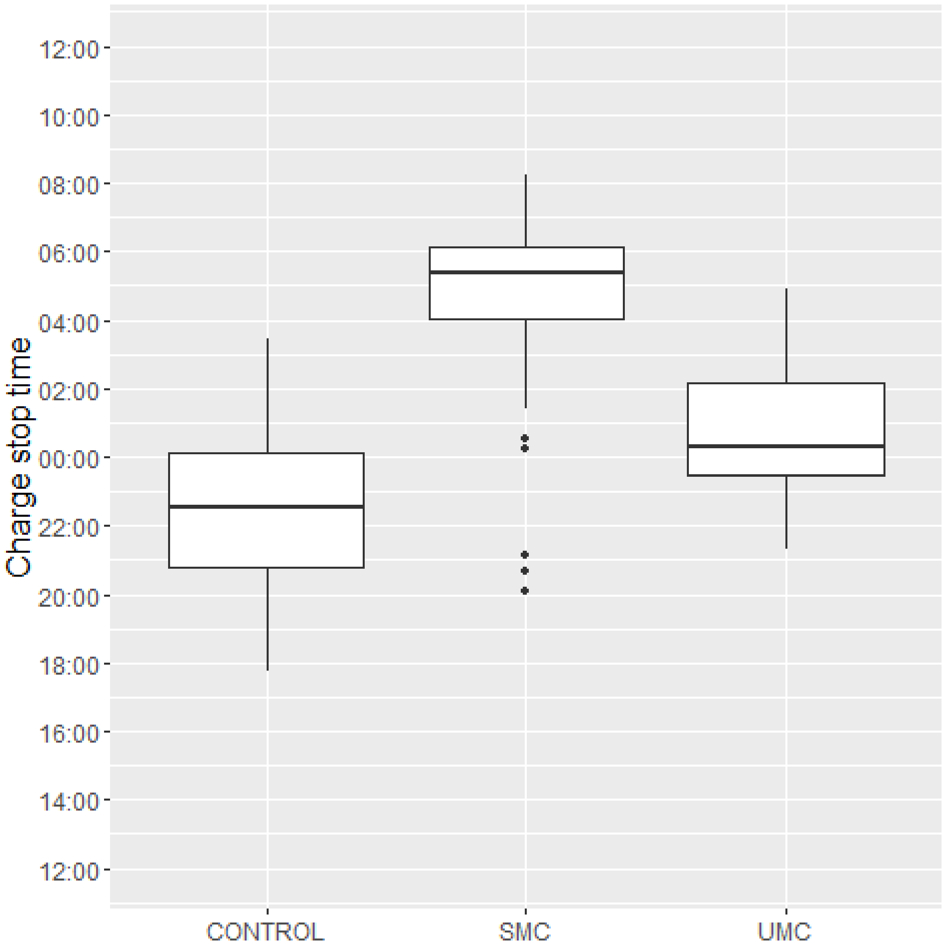


Figure 68: Boxplot showing median and IQR charge stop times for BEV participants in each trial group (N = 127)

Figure 69 presents the distribution of median plug-out times for each trial group. The figure shows that participants typically unplugged their vehicle in the morning, with the greatest level of variability among the Control group and the smallest level of variability among participants in the SMC trial groups. Possibly, participants in the SMC group, who set a Departure Time through the smartphone app for most charge events, felt prompted to unplug the car around the same time, which may explain the reduced variability observed. However, this is speculation and the precise reasons for these differences are unknown.

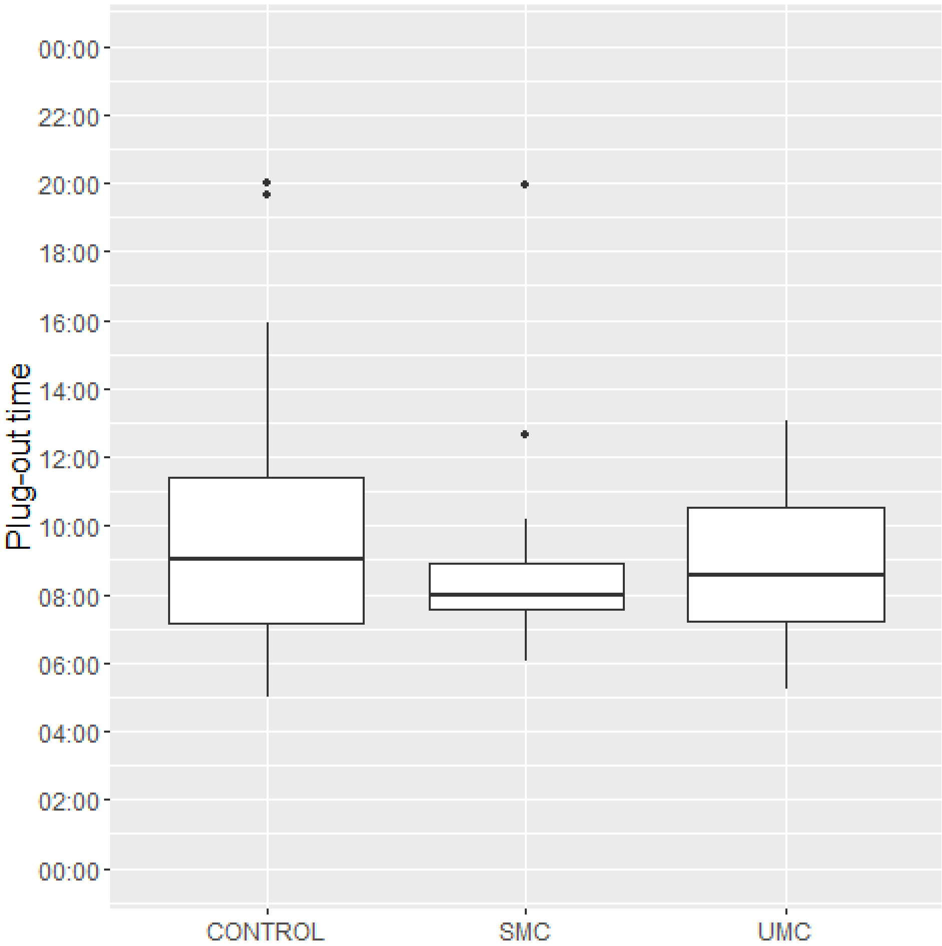


Figure 69: Boxplot showing median and IQR plug-out times for BEV participants in each trial group (N = 127)

B.4.1.5 *How does charging behaviour vary with time over the first eight weeks of using and charging a PiV, whether participating in a managed charging scheme or not?*

→ **There were no statistically significant differences in the average number of charges per participant per week across the 8 weeks of the trial period.**

Using data from vehicle telematics and the CPMS, this analysis investigated the extent to which charging behaviour varied between different weeks of the trial.

Figure 70 presents the average number of home charge events per participant for each week of the trial. The data shows that the frequency of charging was relatively stable across the eight weeks, although there were was a slightly higher frequency during the first two weeks, compared with the other six. However, there were also large standard deviations in the number of charges per participant per week; as such there were no statistically significant differences in the mean number of charges.

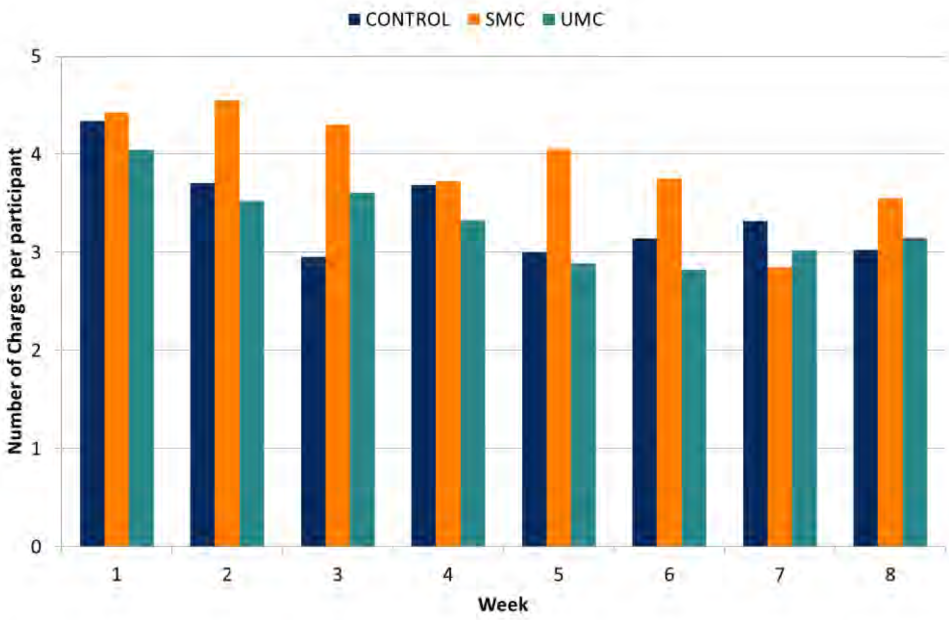


Figure 70: Average number of BEV home charges per week per participant across all groups

Figure 71 shows the proportion of home charges by UMC/SMC driver input method, split across the 8 weeks of the trial.

These data show a general trend of decreasing use of 'Charge Now' and setting a new schedule in the SMC group, and an increase in use of the default settings. A similar trend, of decreasing incidence of setting a new schedule can also be seen in the UMC group; in the latter half of the trial participants very rarely used this function in the app..

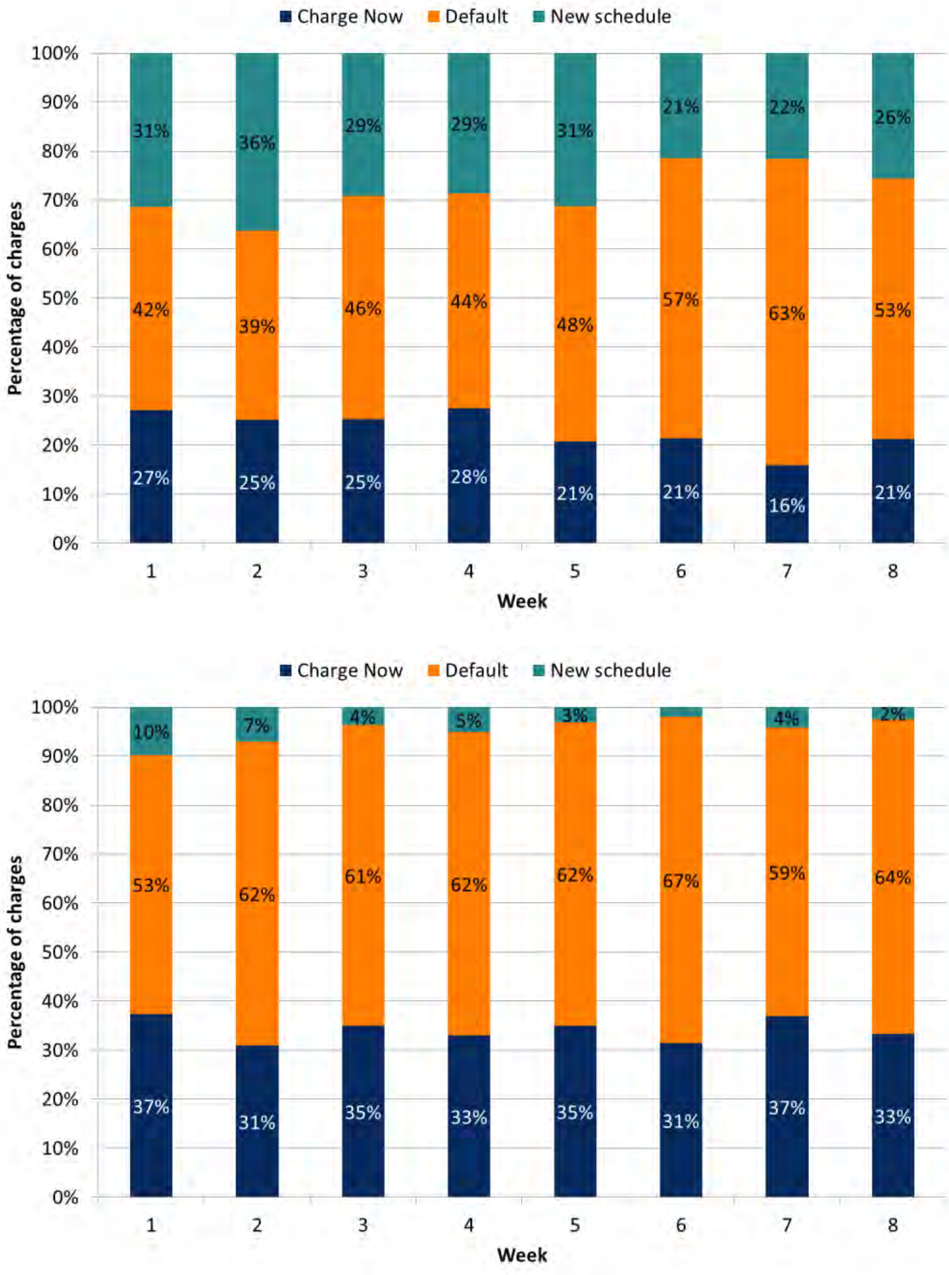


Figure 71: Proportion of BEV charges by driver input method for each week in the trial (Top – SMC; Bottom – UMC)

In addition to the measures explored above, weekly differences in the SOC at plug-in and plug-out, and the amount of SOC added per charge, were also explored. However, no notable trends were established which suggested that these metrics changed over the course of the trial.

B.4.1.6 *How do mainstream consumers interact with specific features of User- and Supplier-Managed Charging?*

- **The average number of home charges per participant over the eight weeks was similar in the two groups (21 charges per participant in UMC group, and 25 in SMC group).**
- **There were significant differences between the SMC and UMC groups in how they interacted with the app:**
  - **Participants in the SMC group set a new charge schedule more frequently (28% of home charges) than the UMC group (5% of home charges).**
  - **For the UMC group, 61% of charges were initiated using the default settings compared with 48% for the SMC group.**
  - **For UMC, 34% of charges were initiated using 'Charge Now', compared with 24% in SMC.**
- **The Control group reported interacting with the app relatively infrequently (22%) compared with the UMC (46%) and SMC groups (45%).**
- **The proportion of charges where the participant used the default settings increased over the eight week trial period.**

Using data from vehicle telematics and the CPMS, this analysis investigated whether there were differences in the way SMC and UMC participants engaged with the managed charging schemes.

On average, participants charged a similar number of times at home in the two groups (21 times in the UMC group and 25 times in the SMC group). For each charge event the driver could either 'Charge Now', use the 'Default' settings in the app, or apply a 'New schedule' where they selected new settings for that specific charge session. Figure 72 presents the proportion of charge events undertaken via each of these options.

The SMC group set a new schedule more frequently (28% of charge events) compared with the UMC group (5% in the UMC group). For the UMC group, nearly two-thirds of charges were initiated using the default settings and over one-third of charges were initiated using the 'Charge Now' function. Chi-squared tests showed that the differences between groups were statistically significant ($p < 0.001$). Examination of use of the various driver input methods across the 8 week trial period showed a tendency for the use of defaults to increase between week 1 and week 8.

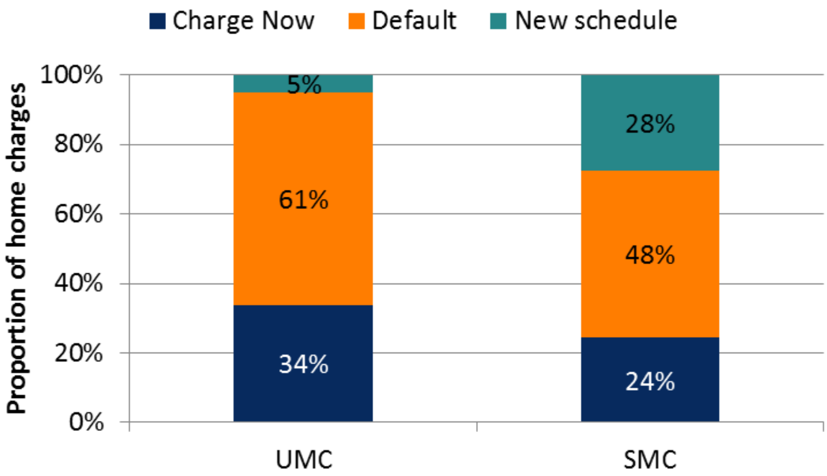


Figure 72: Proportion of home charges in UMC and SMC group by driver input method (N = 1,978)

UMC and SMC charge events which were initiated by the default settings, or by a new schedule setting, were found to have significantly longer plug-in durations than 'Charge Now' events and control group charges. This suggests that when the BEV participants were engaging in the Managed Charging schemes, they tended to plug-in for longer. However, when BEV drivers chose to 'opt out' of managed charging by using the 'Charge Now' function, the plug-in durations were reduced. Greater plug-in durations are likely to offer greater opportunity for flexible charging, so this finding supports the conclusion that engagement with Managed Charging is successful in shifting charging behaviour and increasing the opportunity for flexibility, except on occasions when overriding is required.

Participants were also asked about how frequently they interacted with the smartphone app during the trial; responses for each of the three groups are shown in Figure 73.

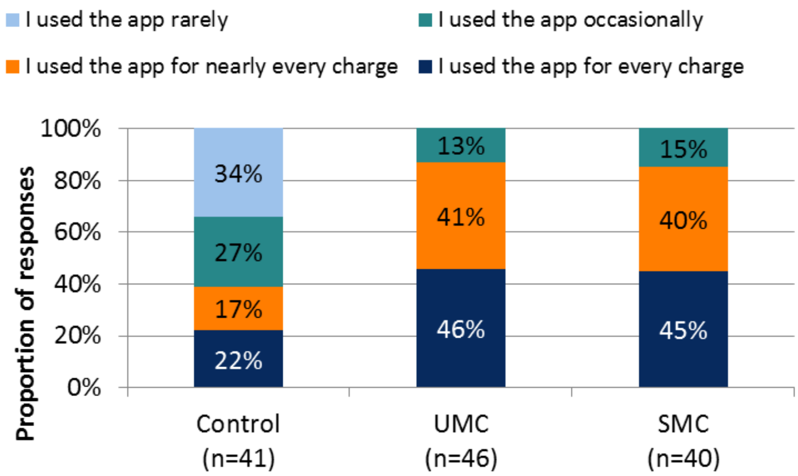


Figure 73: Proportion of responses to TP2 questionnaire "How often did you make use of the features on the smartphone app when charging the vehicle during the trial?" by trial group

The results show that the Control group interacted with the app relatively infrequently (for this group, the app provided information only; e.g. SOC and charging status) compared with the UMC and SMC groups (who used the app to set when the vehicle should charge, or the level of charge required and by when respectively). An independent samples Kruskall-Wallis test showed there was a significant difference between the three groups ($p < 0.001$) and pairwise Mann-Whitney tests showed that this difference was between the UMC and Control group ($p < 0.001$) and the SMC and Control group ($p < 0.001$).

Participants ratings of satisfaction with the smartphone app – reported on a scale of very satisfied to very unsatisfied – are shown in Figure 74.

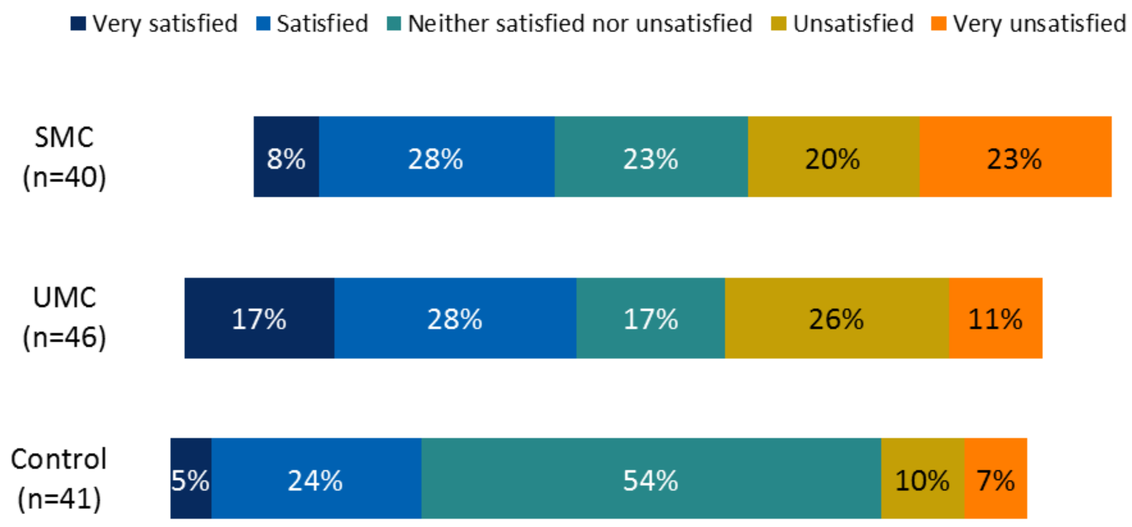


Figure 74: Proportion of responses to TP2 questionnaire "How would you rate your level of satisfaction with the charging tariff smartphone application?" by trial group

A higher proportion of the SMC (43%) and UMC groups (37%) were unsatisfied or very unsatisfied with the smartphone application compared with the Control group (17%); the UMC and SMC groups also appeared to be more polarised in their opinions than the Control group, of which 54% indicated that they were neither satisfied nor unsatisfied. However, an independent samples Kruskall-Wallis test showed that the differences between groups were not statistically significant ($p = 0.373$).

B.4.1.7 *What preferences do mainstream consumers have between Supplier-Managed Charging, User-Managed Charging, and no managed charging?*

- → **The majority of participants reported being very satisfied, satisfied, or neither satisfied nor unsatisfied with the scheme they experienced in the trial (97% for SMC, 98% for UMC and 91% for Control); there were no significant differences between groups.**
- → **A greater share of the UMC group was likely to choose the charging scheme they experienced than the SMC or Control groups.**
- → **When given a choice between the three different types of charging scheme, UMC was the preferred option for most participants in both the Control and UMC groups. In contrast, a higher proportion of participants in the SMC group were more likely to pick SMC, suggesting that experience of the scheme may have influenced their decision.**

This analysis examined data from the TP2 questionnaires to understand participants' preferences for the three types of charging scheme.

Participants were first asked to indicate their level of satisfaction with the charging scheme they experienced in the trial. Figure 75 presents the distribution of these responses for each experimental group.

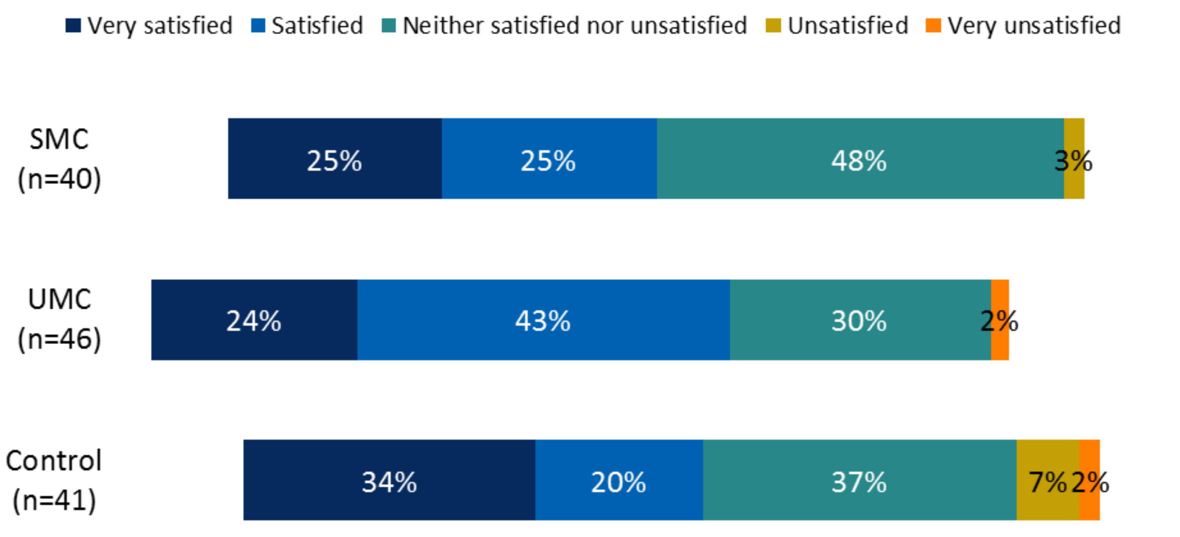


Figure 75: Proportion of participants who reported they were satisfied or unsatisfied with the charging scheme they experienced in the trial (N = 127)

The vast majority of participants reported being very satisfied, satisfied, or neither satisfied nor unsatisfied with the scheme they experienced. Independent samples Kruskall-Wallis tests showed that there were no significant differences in satisfaction between the three groups ($p = 0.637$).

Figure 76 shows how likely or unlikely the participants were to choose the charging scheme they experienced if they owned a BEV or PHEV in future. The UMC group were significantly more likely to choose the scheme they experienced than the SMC group (if they owned a BEV;

p = 0.049; or if they owned a PHEV; p = 0.036) and the Control group (BEV; p = 0.002; PHEV; p = 0.011).

The results also suggest that both the SMC and UMC groups were more likely to choose the charging scheme they experienced if they had a BEV compared to if they had a PHEV. For both the BEV and PHEV questions, almost two-thirds of the Control group were undecided whether they would choose an unmanaged charging scheme (as experienced in the trial).

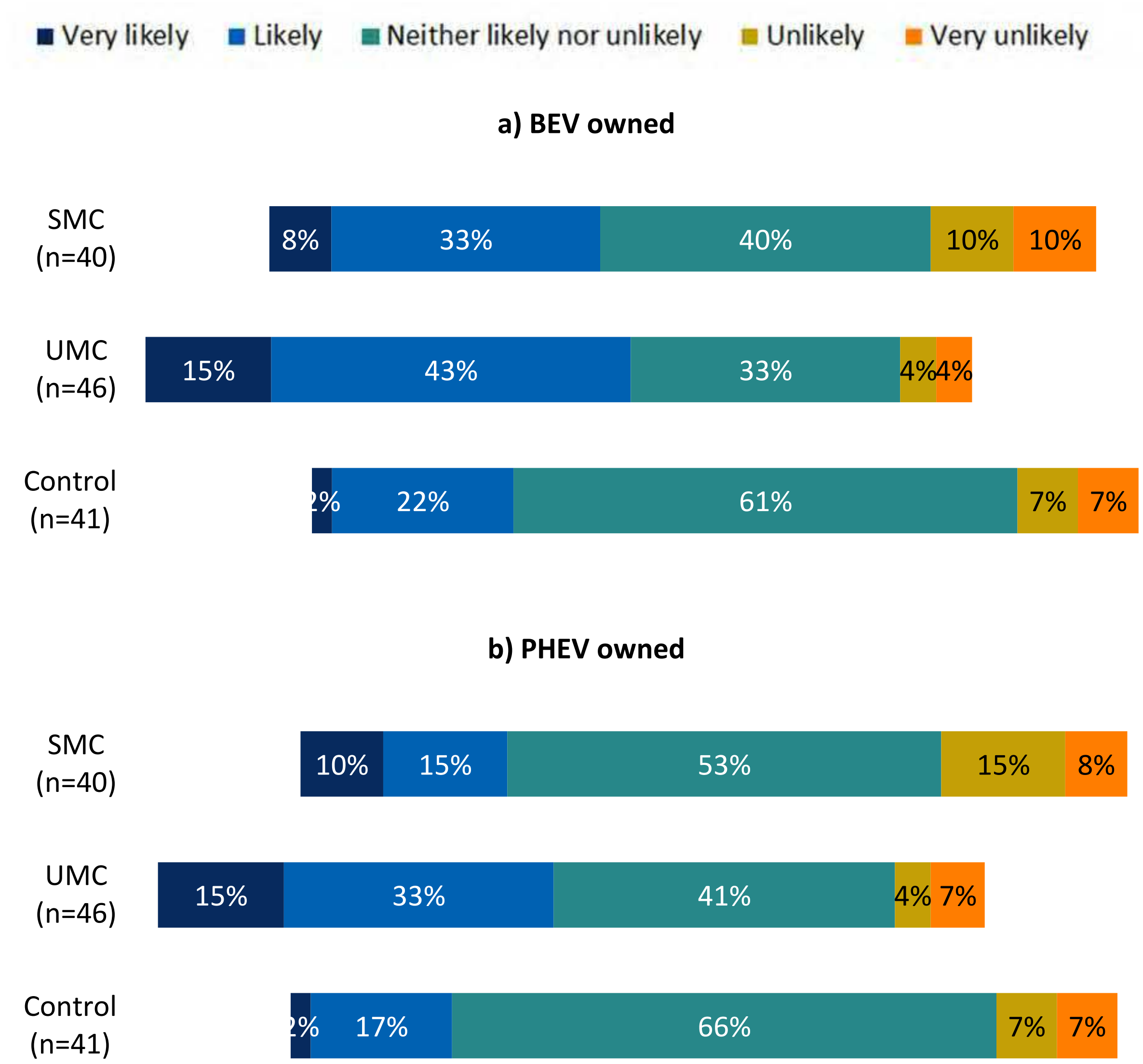


Figure 76: Proportion of participants likely or unlikely to choose the charging scheme they experienced in the trial if they owned a BEV (a) or PHEV (b) (N = 127)

Participants were then given a description of the three different types of charging scheme and asked which they would choose in future if they owned a BEV or PHEV (Figure 77).

Chi-squared tests showed there were significant differences in the responses between the three groups (BEV owned: p = 0.002; PHEV owned: p = 0.006). For Control group and UMC participants, the UMC scheme was chosen by the majority of participants, both if they had a

BEV in future or a PHEV. In contrast, the SMC group were more likely to pick SMC in future, suggesting that their experience of this tariff may have influence their decision.

Additional analysis on mainstream consumer preferences for managed charging was undertaken using the Alternative Specific Constants (ASC) from the choice experiment; the results of this are presented in the following section.

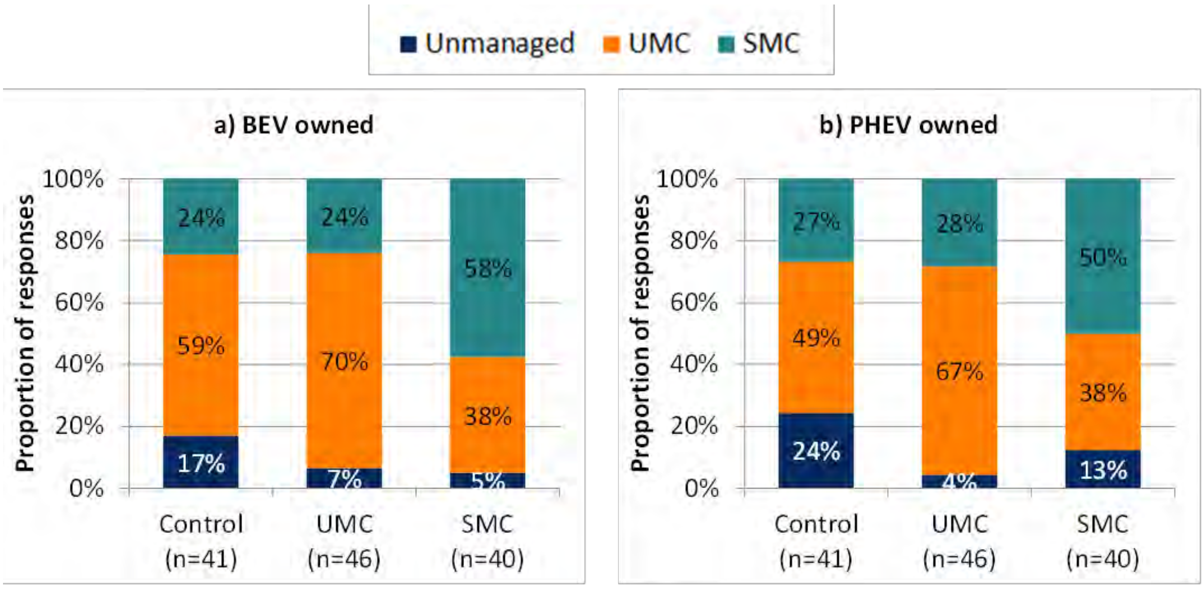


Figure 77: Proportion of participants likely or unlikely to choose unmanaged, UMC or SMC schemes by experimental group if they owned a BEV (a) or PHEV (b) (N = 127)

B.4.1.8 *What factors influence preferences between Supplier-Managed Charging, User-Managed Charging, and no managed charging?*

- → **Participants' choice of charging scheme was dependent on expected annual savings.**
- → **Managed charging was less attractive if peak electricity costs were high, even if the expected annual savings remained the same. This may be due to a perceived risk of needing to charge during peak times which would erode annual savings. A larger effect was observed for SMC users, possibly because they felt they had less control and ability to avoid peak rates.**
- → **Provision of an override function increased the share of participants predicted to choose SMC. This was even true of an override function where the user bears all the financial penalty of changing settings in a particular charging session.**
- → **Participants showed greater willingness to pay for managed charging, particularly SMC, if there is a rapid chargepoint within five minutes of their home.**
- → **Participants' underlying attitudes towards UMC and SMC were positive, particularly if there is nearby public charging. Even with no annual savings, the majority of participants would choose managed over unmanaged charging. BEV participants' experience of a managed charging scheme appeared to make their underlying attitudes towards that scheme more positive.**
- → **Participants' ratings of the importance of having control over when the vehicle charges had an impact on managed charging preferences. Those who viewed control as more important were more likely to choose UMC or unmanaged charging than SMC.**

Choice experiment analysis

Table 33 presents the choice coefficients derived for the BEV trial participants, according to the utility equation shown in Table 19.

These choice coefficients provide quantification of how trial participants traded-off different aspects of managed charging against one another when choosing between MC schemes. All coefficients, other than the expected annual savings, can be expressed in terms of willingness-to-pay (WTP). This shows the expected annual savings that participants are willing to forgo in order to choose a scheme with that particular attribute. The WTP for each attribute is discussed in more detail in the following section.

Table 33: Choice coefficients from the choice experiment for BEV trial participants

Attribute	Choice Coefficient	Standard Error	*p*-value[29]
Estimate of annual savings (£/yr)	0.009952	0.000562	0
Additional cost of SMC charging during peak hours (£/kWh)	-2.33754	0.246929	0
Additional cost of UMC charging during peak hours (£/kWh)	-1.07711	0.232892	0
5 minutes to nearest rapid chargepoint (SMC)	1.448075	0.126836	0
15 minutes to nearest rapid chargepoint (SMC)	1.103596	0.123764	0
30 minutes to nearest rapid chargepoint (SMC)	0.724161	0.122036	0
5 minutes to nearest rapid chargepoint (UMC)	0.475882	0.103191	0
Override available, but changing configuration results in loss of all financial reward for that charge event	0.503831	0.103806	0
Override available, complete flexibility to change configuration	1.013744	0.104134	0
Alternative Specific Constant (SMC)	-0.54056	0.155324	0.0005
Alternative Specific Constant (UMC)	0.739566	0.116083	0

<u>Additional cost of charging during peak hours</u>

Figure 78 shows how higher cost of peak time charging relative to unmanaged charging affected the BEV trial participants' WTP for SMC and UMC schemes. In both cases, WTP was found to be negative and linear: As the peak cost increases, participants require greater annual savings to compensate.

[29] As reported by N-Logit

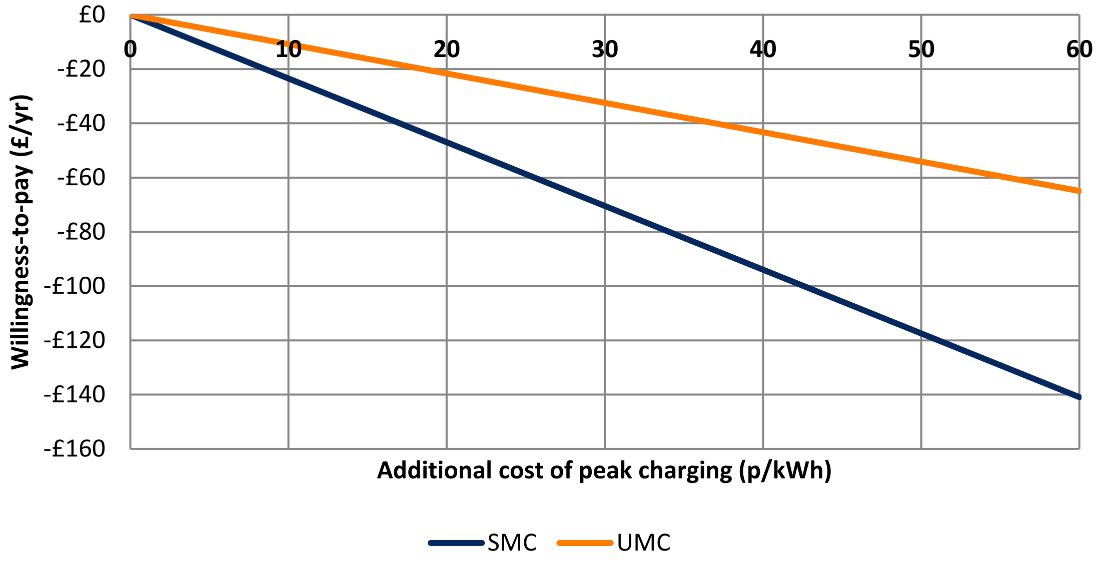


Figure 78: BEV trial participants' willingness to pay for additional cost of peak charging compared with unmanaged charging

Willingness-to-pay was found to be more negative for SMC (-£2.35/yr per p/kWh) than UMC (-£1.08/yr per p/kWh), indicating that BEV trial participants placed more value in a low peak charging cost for SMC compared with UMC. This may be because with UMC participants perceived that they would have more control over when they charge and therefore they would be more able to avoid peak charging costs. Under SMC, an element of trust is required between participant and supplier that the vehicle will indeed be charged during the lowest cost hours. It appears that participants require a greater level of compensation to mitigate the risk that the supplier might not deliver the lowest cost.

<u>Override Function</u>

The choice experiment revealed that BEV trial participants placed high value in the ability to override their SMC charging settings once set. Figure 79 shows the WTP for an SMC tariff with different levels of override functionality. The two override functions tested were:

1. User can change settings once set, but this results in loss of all savings from that charging event.
2. User has full flexibility to change settings and savings for that event are still passed through.

Participants showed a willingness to forgo £102/yr in charge cost savings to have full flexibility to change settings without financial penalty. Even if overriding the settings resulted in participants losing all savings from that event, this function was still valued at £51/yr. Since the financial reward to the user is lost in the latter form of override, such a system is unlikely to incur a net cost for the charging supplier, and so could provide a cost-effective way of encouraging consumers to switch to SMC.

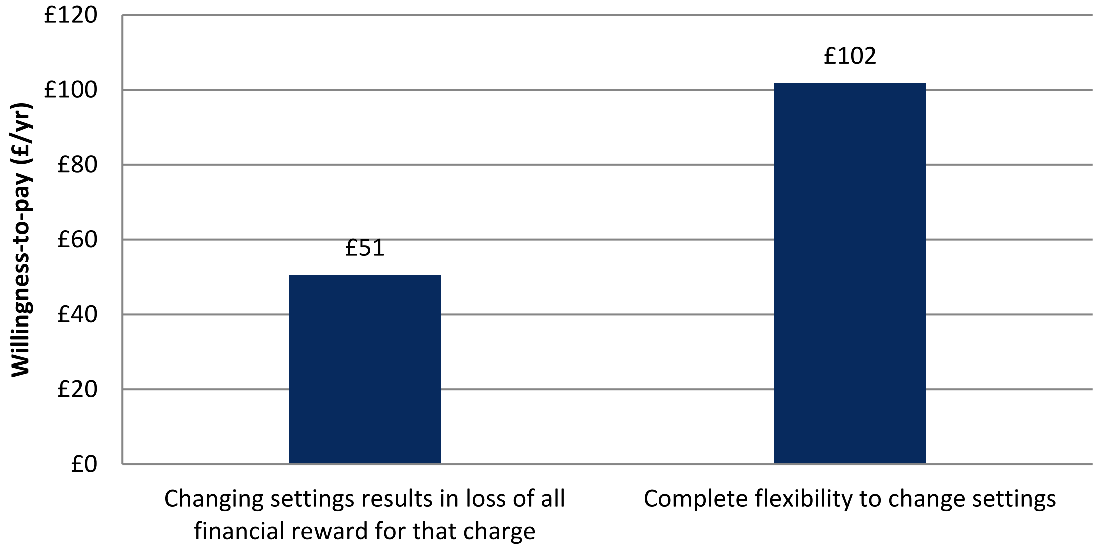


Figure 79: BEV trial participants' willingness to pay for override function in SMC tariffs.

__Proximity of Rapid Charging__

Since managed charging involves delaying charging to some extent, there is an increased risk that if the car is needed earlier than expected, the state of charge may be lower than is required. Having access to a 50kW rapid chargepoint nearby mitigates this risk. Figure 80 shows the BEV trial participants' additional WTP for SMC and UMC tariffs depending on travel time to the nearest rapid chargepoint.

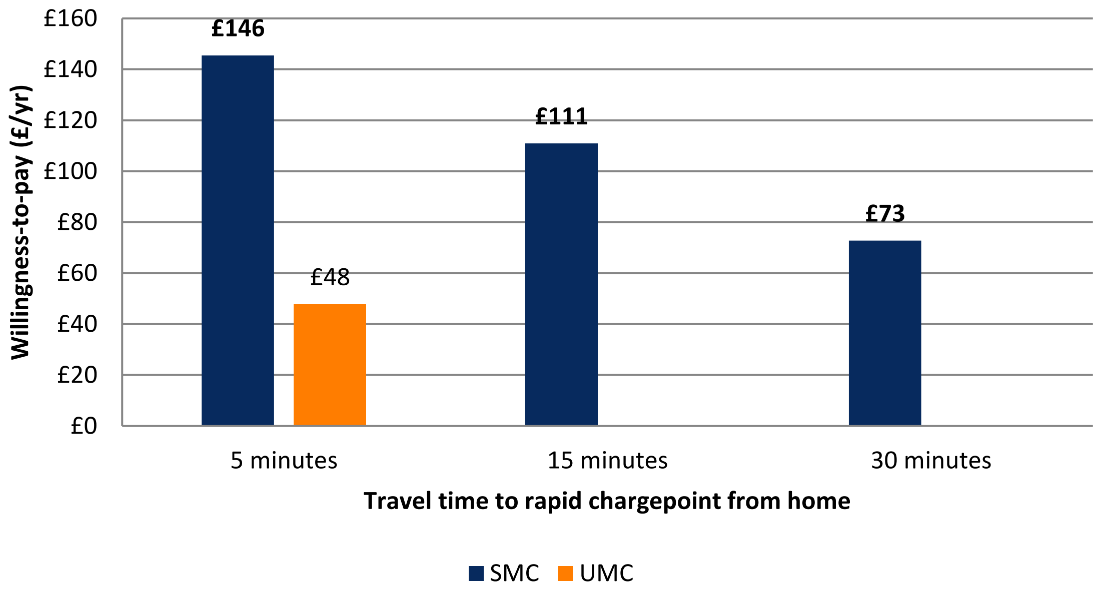


Figure 80: BEV trial participants' willingness to pay for SMC and UMC tariffs at different proximities of rapid chargepoints to home, relative to no access to nearby rapid chargepoints

An initial observation is that all values were positive, which shows that participants recognised the benefits of a nearby rapid chargepoint in the context of their ability to adopt a managed charging tariff.

For the UMC option, statistically significant choice coefficients could only be identified when the rapid chargepoint was within five minutes of home. The null hypothesis (that the perceived utility was zero) therefore could not be rejected when the nearest rapid chargepoint was either 15 minutes or 30 minutes away and consequently it was assumed that the WTP at these levels was zero. This suggests that, under UMC, participants perceive a benefit from a rapid chargepoint only when it was very close by.

If the nearest rapid chargepoint was five minutes away, the additional WTP for SMC was £146/year, which was approximately three times larger than it was for UMC. In addition, for SMC, statistically significant choice coefficients were identified at all three levels of rapid chargepoint proximity. Figure 80 illustrates how this WTP appeared to follow a linear relationship against proximity, falling by approximately £2.90/yr for every additional minute to the nearest rapid chargepoint.

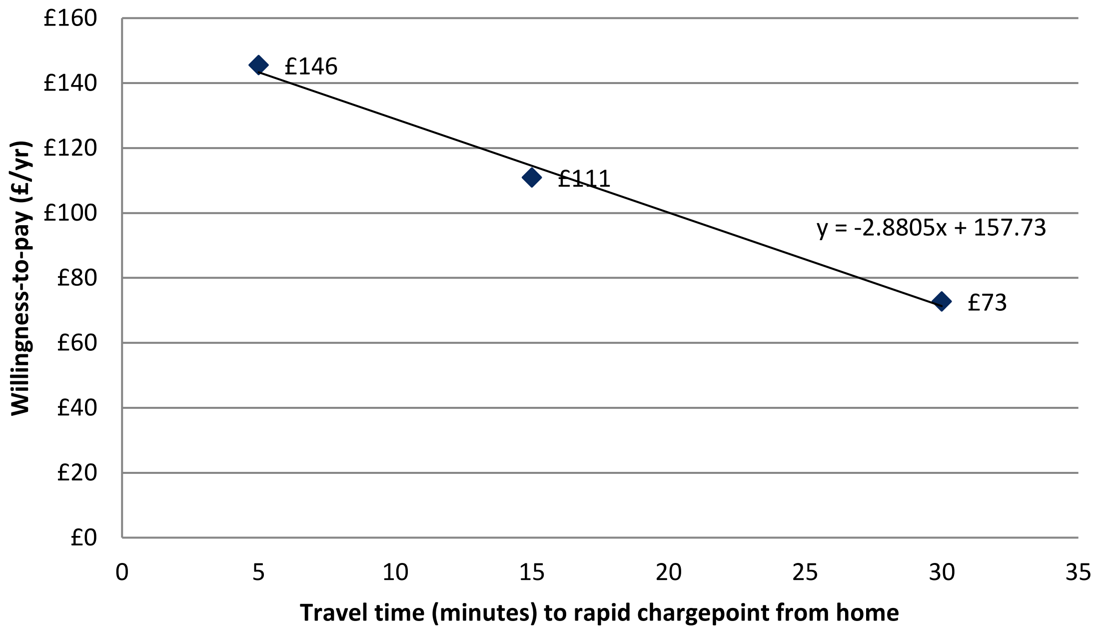


Figure 81: Illustration of linear relationship between BEV trial participants' WTP for SMC tariff and proximity of rapid chargepoints to home.

The results, therefore, show that BEV trial participants placed much higher value on there being nearby rapid chargepoints when considering SMC compared with UMC. Furthermore, they continue to attribute value even when the chargepoint required significant travel time (i.e. 30 minutes) to reach. This may be due to a perception of greater risk of receiving too little charge with SMC and therefore greater need for a back-up charging option.

Anticipatory Charging and Accuracy of Annual Savings Estimate

For BEV trial participants, statistically significant choice coefficients could not be identified for either anticipatory charging, or the accuracy of annual savings estimates, and thus the null hypothesis could not be rejected. The 'accuracy of savings estimate' attribute had the potential to increase or decrease savings in equal measure, and so any perception of risk that savings may be lower than expected may have been offset by an equal opportunity for larger than expected savings. For anticipatory charging, it appears that participants on average placed little value on its availability. Participants were made aware in the description of anticipatory charging that if they regularly set their desired end state of charge to 100%, they would receive very little, if any, of the additional savings that the anticipatory charging attribute offered. Figure 82 shows that most BEV participants in the SMC charging group on average set the Desired SOC to at least 90%. In fact, only 6 out of 40 participants set the desired state of charge to less than 90% for more than half of their home charge events. It is likely, therefore, that participants considered that with their typical charging behaviour they would not realise much of the additional benefit available.

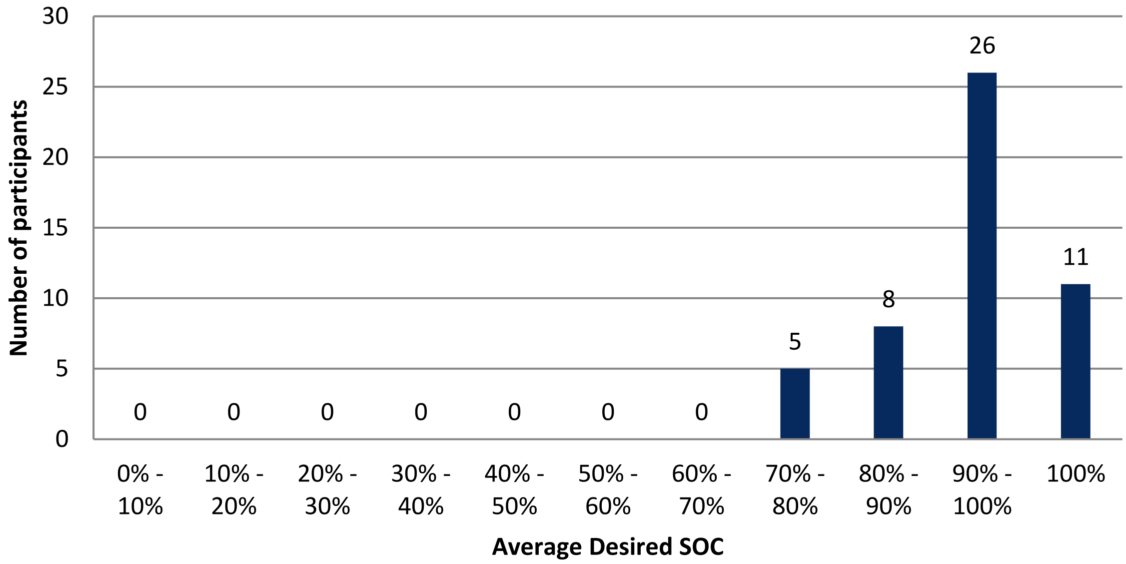


Figure 82: Number of BEV participants in SMC charging group by average Desired State of Charge.

As a result, it was assumed that these attributes did not influence tariff choice and so they were excluded from the final utility equations shown in Table 19.

Net attitudes towards UMC and SMC

While the choice coefficients can provide a view on how participants value specific vehicle attributes, the Alternative Specific Constants (ASC) can also be used to quantify the underlying attitudes towards UMC and SMC. Recall the general equation for utility from Appendix A.12.1:

$$U_i = \sum_{j=1}^{j=T} \beta_j x_{ij} + \varepsilon_i$$

The constant, ε_i, is represented by the ASCs for UMC and SMC in the utility equations shown in Table 19. Figure 83 shows the ASCs derived from the choice experiment:

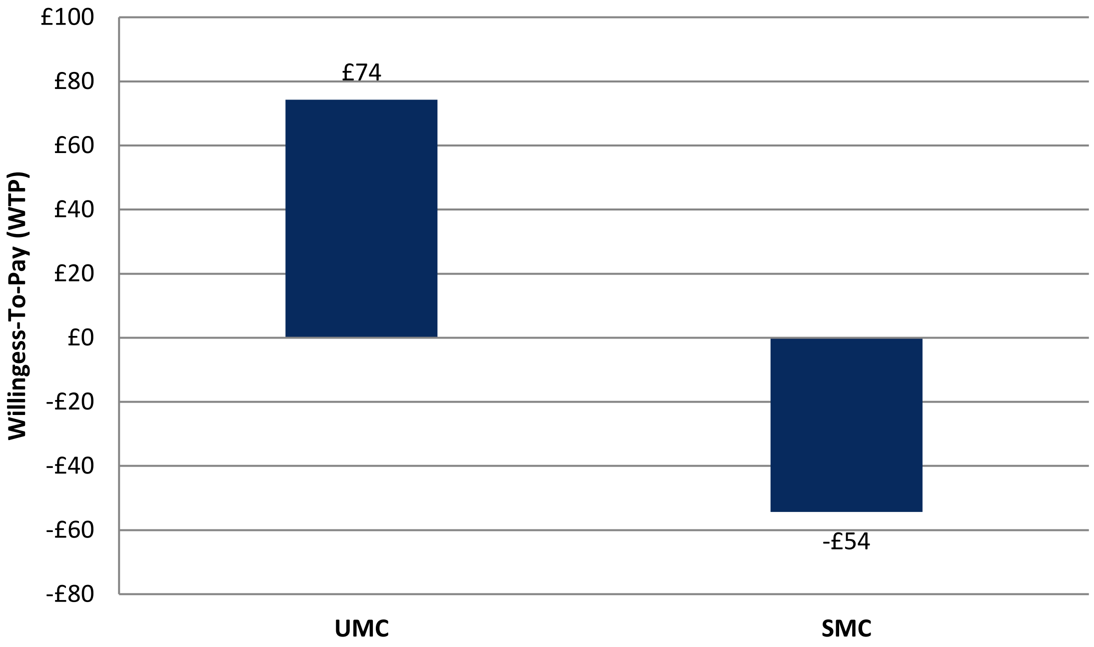


Figure 83: Alternative Specific Constants for BEVs and PHEVs derived from the choice experiment, expressed in terms of WTP

At first glance, the ASCs suggest a strong negative bias against SMC, and a positive bias towards UMC. However, before conclusions can be drawn from the ASCs it is necessary to understand exactly what they represent. In the utility equations ASCs serve two purposes:

1. To correct for the fact that each of the three alternatives have a different set of attributes. For example, consider the following simple set of utility equations describing a SMC and unmanaged charging (NMC):

   $$U_{NMC} = \beta_{cost} \times Annual\ Electricity\ Spend_{NMC}$$

   $$U_{SMC} = \beta_{cost} \times Annual\ Electricity\ Spend_{SMC} + \beta_{override} \times Override\ available + ASC_{SMC}$$

   The utility of the SMC tariff in this case is dependent on the availability of an override function, while the NMC tariff is not. If the annual electricity costs were the same for both NMC and SMC, then without ASC_{SMC} the presence of an override would make the utility of SMC larger than NMC. This is clearly incorrect as a user already has completely free choice to change when their EV charges under NMC. Therefore, ASC_{SMC} must be negative to compensate for the override attribute not found in the NMC utility equation.

2. The ASC also accounts for the utility of the unobserved factors not explicitly investigated in the choice experiment. For example, this could be the perceived risk associated with allowing someone else to manage a user's charging, or concerns surrounding increased battery degradation. In the example above, this would be the difference in utility between a SMC and NMC tariffs that have identical attributes.

An ASC of alternative, i, can therefore be expressed as the sum of its two component parts:

$$ASC_i = ASC_{i,correction} + ASC_{i,unobserved}$$

$ASC_{i,correction}$ corrects for the fact that not all attributes apply to all alternatives. $ASC_{i,unobserved}$ accounts for the unobserved factors not directly investigated in the choice experiment. Derivation of both components can be demonstrated with the following example:

Consider the simple choice model from above between the SMC and NMC tariffs. If both tariffs are identical in respect of their observed attributes, then $ASC_{i,unobserved}$ can be isolated as the difference in utility:

$$ASC_{SMC,unobserved} = U_{SMC} - U_{NMC}$$

Substituting in the utility equations yields:

$$\begin{aligned} ASC_{SMC,unobserved} &= \big(\beta_{cost} \times Annual\ Electricity\ Spend_{SMC} + \beta_{override} \times Override\ available \\ &\quad + ASC_{SMC,correction} + ASC_{SMC,unobserved}\big) \\ &\quad - \beta_{cost} \times Annual\ Electricity\ Spend_{NMC} \end{aligned}$$

And rearranging for $ASC_{SMC,correction}$:

$$\begin{aligned} ASC_{SMC,correction} &= \big(\beta_{cost} \times Annual\ Electricity\ Spend_{NMC}\big) \\ &\quad - \big(\beta_{cost} \times Annual\ Electricity\ Spend_{SMC} + \beta_{override} \times Override\ available\big) \end{aligned}$$

Since the observed attributes of the two powertrains are the same, the annual electricity spend for both tariffs are equal. Consequently:

$$ASC_{SMC,correction} = \beta_{override} \times Override\ available$$

In this case, $Override\ available$ is equal to 1 as this would make the SMC tariff equivalent to NMC in terms of functionality.

The above example can be generalised to say that the $ASC_{i,correction}$ is the utility value of the attributes not considered for the base tariff (i.e. NMC) that would make that alternative equivalent to the base tariff:

$$ASC_{i,correction} = -\sum_{k=1}^{k=M} \beta_k x'_{ik}$$

- k denotes the attributes of alternative i that are not included in the utility equations of all alternatives.
- x' denotes the values of these attributes which make all alternatives identical across their observed attributes.

For the utility equations derived for this study (see section A.15.5) that would be:

$$\begin{aligned} ASC_{SMC,correction} &= -\big(\beta_{savings} \times Annual\ Savings_{SMC} + \beta_{peak,SMC} \times Additional\ Peak\ Cost_{SMC} \\ &\quad + \beta_{charging\ prox\,=\,5mins,SMC} \times Charging\ Prox[5mins]_{SMC} \\ &\quad + \beta_{charging\ prox\,=\,15mins,SMC} \times Charging\ Prox[15mins]_{SMC} \\ &\quad + \beta_{charging\ prox\,=\,30mins,SMC} \times Charging\ Prox[30mins]_{SMC} \\ &\quad + \beta_{partial\ override} \times Override_{partial} + \beta_{full\ override} \times Override_{full}\big) \end{aligned}$$

$$ASC_{UMC,correction} = -\Big(\beta_{savings} \times Annual\ Savings_{UMC} + \beta_{peak,UMC} \times Additional\ Peak\ Cost_{UMC} + \beta_{charging\ prox\,=\,5mins,UMC} \times Charging\ Prox[5mins]_{UMC} + \beta_{charging\ prox\,=\,15mins,UMC} \times Charging\ Prox[15mins]_{UMC} + \beta_{charging\ prox\,=\,30mins,UMC} \times Charging\ Prox[30mins]_{UMC}\Big)$$

The attribute values to equate SMC and UMC to unmanaged charging, and therefore calculate $ASC_{SMC,correction}$ and $ASC_{UMC,correction}$, are:

- Annual savings of £0, such that the total electricity costs are equivalent to unmanaged charging.
- Additional peak cost of £0/kWh, to equate the SMC and UMC tariffs to a flat unmanaged tariff.
- Full override functionality for SMC, as this is already possible with UMC and unmanaged charging.
- No access to nearby rapid chargepoints, since the utility of unmanaged charging does not benefit from having a rapid chargepoint nearby.

Once $ASC_{i,correction}$ has been estimated, $ASC_{i,unobserved}$ is calculated as:

$$ASC_{i,unobserved} = ASC_i - ASC_{i,correction}$$

Figure 84 shows a graphical example of how $ASC_{SMC,unobserved}$ is estimated for the BEV participants. $ASC_{SMC,correction}$ is equal to the sum of the dark grey components. This analysis reveals that $ASC_{SMC,unobserved}$, expressed in terms of WTP, is £47.50/yr. This can be interpreted to mean that BEV drivers are willing to give up £47.50/yr in savings in order to charge via supplier managed charging.

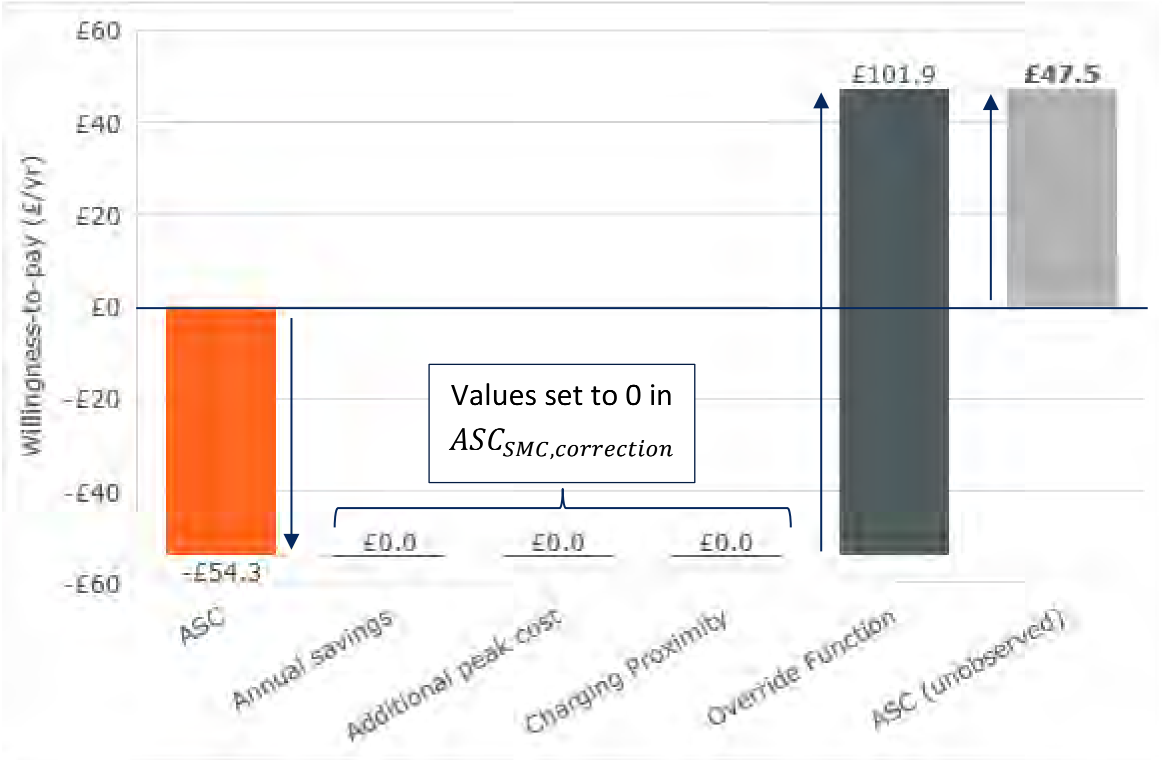


Figure 84: Waterfall diagram illustrating the derivation of $ASC_{SMC,unobserved}$ for BEV participants, shown in terms of WTP

In the case of UMC, which does not have an override function attribute, the value of $ASC_{UMC,correction}$ is zero. Therefore $ASC_{UMC,unobserved}$ is equal to the ASC value derived from the choice experiment, which is £74.30/yr when expressed in terms of WTP. Since both WTP values are positive, this suggests that BEV drivers have positive underlying attitudes towards supplier-managed and user-managed charging. In other words, the positive aspects of managed charging not directly investigated in the choice experiment outweigh the negative. This suggests that a large share of participants will still choose managed charging even if it provides no annual savings, or indeed if savings are negative (i.e. they are willing to pay for it). However, it is worth noting that the choice experiment only tested participant choice between annual savings of £20 and £500, and so the ASCs are strictly only valid between these bounds. Furthermore, incentives are still likely to be necessary to shape charging behaviour to preferred times of day.

The calculation of the unobserved utility above considered a scenario where there was no nearby rapid chargepoints. The proximity of rapid charging attribute cannot be equated to unmanaged charging in the same way as the other attributes because it serves to provide a back-up only to managed charging. However, proximity of rapid chargepoints has a positive utility value for both UMC and SMC and so in a scenario with rapid chargepoints within 5 minutes of home the utility of the unobserved factors is even more positive. The values for both scenarios are shown in Figure 85, and in both cases is positive for UMC and SMC.

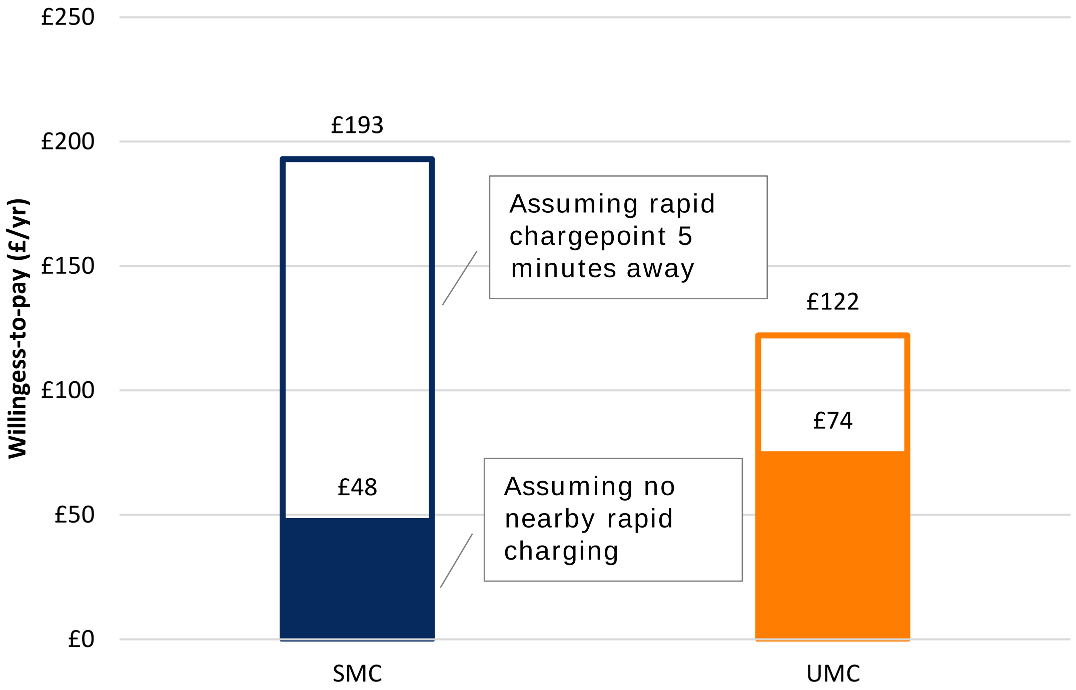


Figure 85: $ASC_{SMC,unobserved}$ and $ASC_{UMC,unobserved}$ derived for BEV trial participants, assuming tariffs are equivalent to unmanaged charging with no nearby rapid chargepoint as well as nearest rapid chargepoint is 5 minutes away

An attempt was also made to derive choice coefficients for each of the charging groups (UMC, SMC and Control group) within the BEV sample. The intention was to understand how experience of a particular tariff during the trial influenced attitudes towards managed charging attributes. However, in doing this the sample sizes were reduced to roughly 40, and the Control group outputted coefficients with generally high *p*-values and therefore low statistical significance. This meant exploring how experience of managed charging in general impacts the choice coefficients was not possible. However, statistically significant choice coefficients were derived for the UMC and SMC charging groups and these are presented in Figure 86. Here it can be seen that experience of a tariff in general makes attitudes towards that tariff more positive, however, the exact extent of this effect depends on whether access to nearby charging is assumed to make the tariffs equivalent to unmanaged charging.

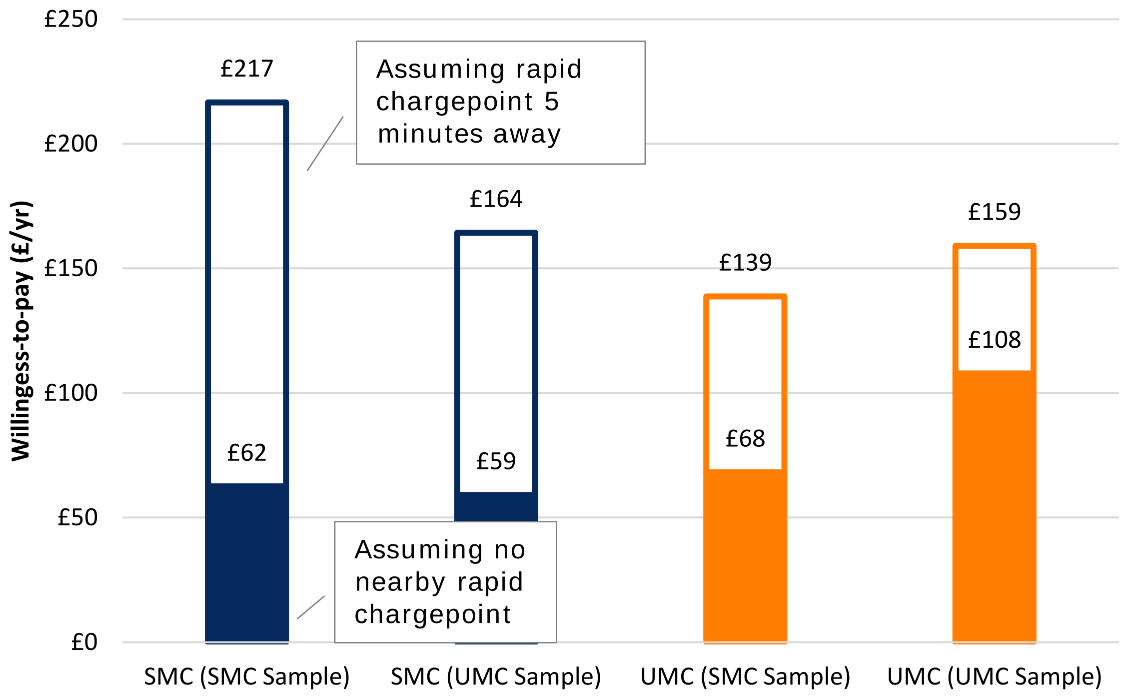


Figure 86: $ASC_{SMC,unobserved}$ and $ASC_{UMC,unobserved}$ derived for SMC and UMC charging groups within the BEV trial participants, assuming tariffs are equivalent to unmanaged charging with no nearby rapid chargepoint as well as nearest rapid chargepoint is 5 minutes away

Questionnaire analysis

To supplement the data from the choice experiment, analysis of the TP2 questionnaire data was also undertaken to explore the factors which influenced mainstream consumer preferences for managed charging. Two regression models were built; one to explore the impact of a series of factors on likelihood to choose managed charging if consumers owned a BEV, and another for if they owned a PHEV. These models used data from the TP2 questionnaire which asked participants to rate how important or unimportant the following factors would be if they owned a BEV or PHEV and were choosing a charging scheme:

- Cost of charging
- Convenience
- Simplicity
- Predictability of energy bill
- Compatibility with vehicle use and charging needs
- Ability to make savings
- Control over when your vehicle will charge
- Predictability of having a full charge when car is needed
- Control of charging via an app or website

The importance of each of these features was measured on a five-point scale from (1) ‘Not at all important’ to (5) ‘Extremely important’. There were no significant differences in the responses to these questions between the experimental groups. This suggests that the ratings of importance were not greatly influenced by the type of charging schemes experienced by BEV participants in the trial. The regression analyses described in the following sections were therefore undertaken to assess whether the importance of these factors depended on the type of charging scheme that participants would choose in *future*.

BEV model

Factor Analysis was first performed on the data to see if the number of items could be reduced to a smaller list of factors. This analysis met all of the required assumptions. However, only 53% of the variability in the data was explained by the factor solution[30]. Two factors were identified that did not appear to have clear interpretations; the survey items being grouped together did not appear to have any common and consistent themes. These results suggested that the factor scores were not suitable for analysis.

Therefore, instead of using factor scores to predict preferences for managed charging schemes, Kruskall-Wallis tests were performed on each individual questionnaire item to examine if there were significant differences in responses between participants who indicated they would chose unmanaged charging, UMC or SMC.

Ratings of the importance of “Control over when your vehicle will charge” differed significantly between these groups ($\chi^2(2) = 11.825$, $p = 0.003$); the distribution of responses is shown in Figure 87. None of the other items were found to differ significantly depending on the type of charging scheme participants chose.

[30] The generally accepted level of explained variance in the social sciences is 60%.

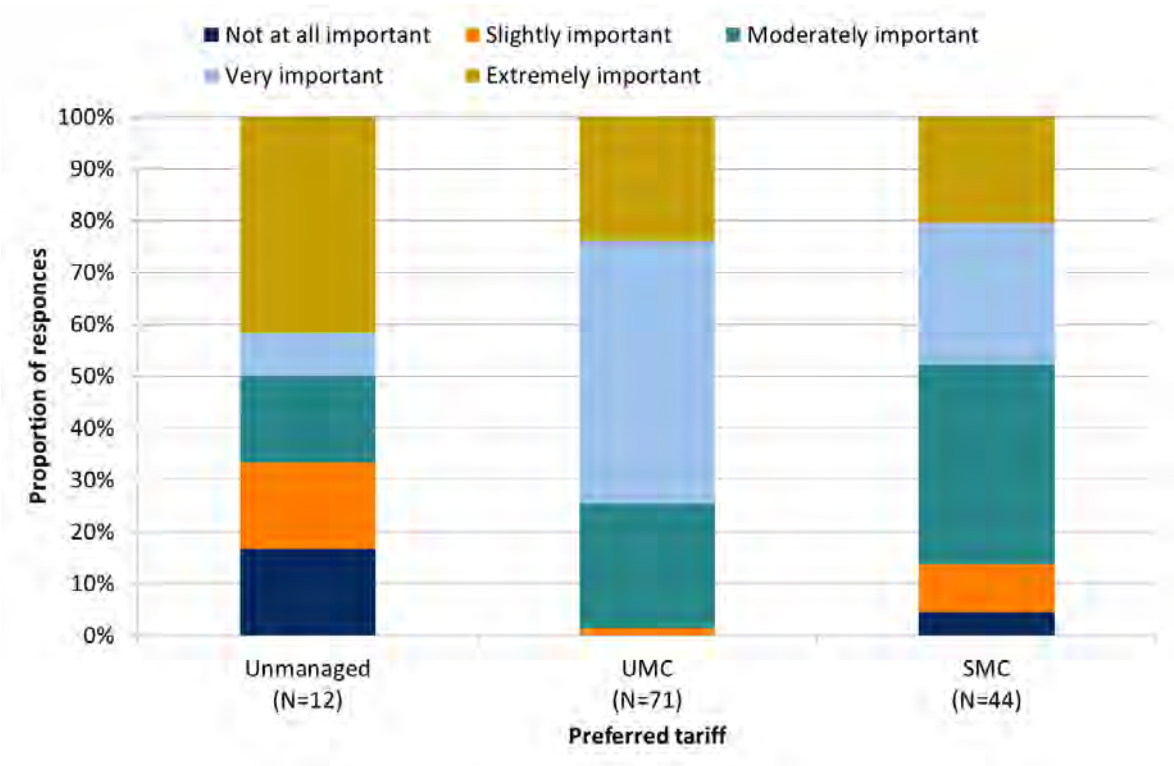


Figure 87: Proportion of participants who rated control over when the vehicle charges as important or unimportant by chosen charging scheme (if they owned a BEV)

Participants who chose UMC were more likely to rate control over when the vehicle charges as either very or extremely important than those who chose the SMC tariff. Participants who chose the unmanaged scheme were the most likely to provide extreme responses; 'Not at all important' and 'Extremely important'. This suggests that another factor may have driven participants' decisions to choose this type of charging scheme.

Ratings of importance of other factors were not found to significantly vary depending on the charging scheme chosen by participants.

PHEV model

The TP2 questionnaire also asked participants to rate how important or unimportant the factors would be if they owned a PHEV. This time the Factor Analysis returned two coherent factors that explained 59% of the variability in the data as well as meeting the required data assumptions.

The two factors identified were:

- Factor 1: Charging features and functionality ($\alpha = 0.794$)
- Factor 2: Control over charging and costs ($\alpha = 0.815$)

A high score on each of these factors means that the participant thinks these aspects of the charging scheme are important. A low score implies that the participant thought they were not important. The relative loadings of each of the questionnaire items on these factors are displayed in Table 34. A high factor loading indicates a questionnaire item that has a large input into the factor score calculation. Lower factor loading indict items that do not have a large influence on the factor score.

Table 34: Rated importance of charging scheme factors if owning a PHEV – factor loadings

	Factor loadings	
	1	2
Compatibility with vehicle use and charging needs	.790	
Convenience	.782	
Control of charging via an app or website	.613	
Simplicity	.611	
Control over when your vehicle will charge	.590	.449
Cost of charging		.878
Ability to make savings		.810
Predictability of energy bill		.699
Predictability of having a full charge when car is needed	.456	.495

Extraction Method: Principal Component Analysis

Rotation Method: Varimax with Kaiser Normalization

Loading <.4 not shown

These two factors were entered into a multinomial regression model as predictors of charging scheme preference. This model was found to be marginally significant ($\chi^2(4) = 8.267$, $p = 0.082$) suggesting that the two factors together were not strong predictors of the type of charging schemes participants would choose. When entered into the model separately, only Factor 1 was found to be significant, but only marginally ($p = 0.085$).

As the factor scores were found to be poor predictors, Kruskall-Wallis tests were run on each of the questionnaire items to test for differences in responses between participants who indicated they would chose unmanaged charging, UMC or SMC (as was done in the BEV model). Two of the items were found to significantly vary between these groups:

- Control over when your vehicle will charge ($\chi^2(2) = 14.790$, p = 0.001)
- Control of charging via an app or website ($\chi^2(2) = 9.825$, p = 0.007)

The distribution of ratings of the importance of “Control over when your vehicle will charge” is shown in Figure 88.

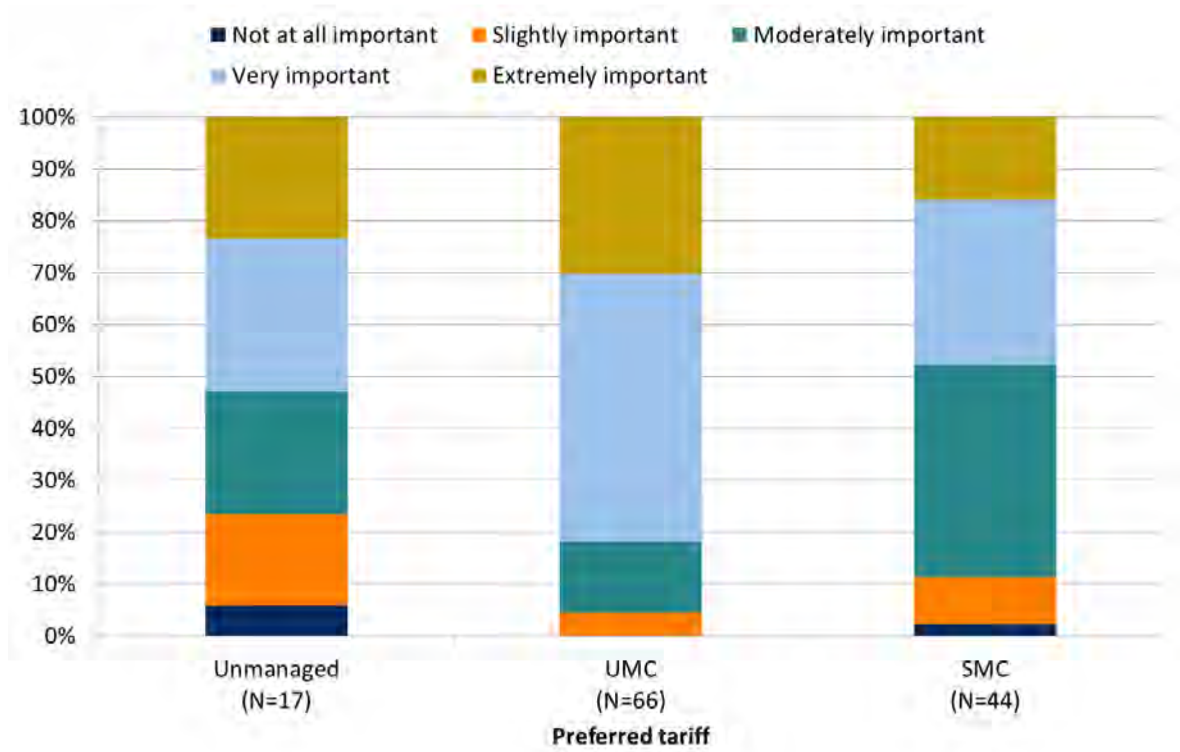


Figure 88: Proportion of participants who rated control over when the vehicle charges as important or unimportant by chosen charging scheme (if they owned a PHEV)

The majority of participants who chose UMC rated control over when the vehicle charges as being at least 'Very important' (82%) compared to around half of the participants who chose the other two schemes. This pattern is similar to that observed in the BEV model above.

A similar proportion of participants who chose the SMC and unmanaged schemes rated having control over when the vehicle charges as being at least 'Very important'. A larger proportion of participants who chose unmanaged charging gave a rating of 'Not at all important' or only 'Slightly important' (24%) compared with those who chose SMC (11%).

Figure 89 shows that the participants who chose the UMC and SMC tariffs provided very similar responses when asked to rate the importance of being able to control charges via an app or website. However, the participants who chose the unmanaged charging scheme were much less likely to rate this charging feature as 'very' or 'extremely' important (12%) compared with the UMC (44%) and SMC group (43%).

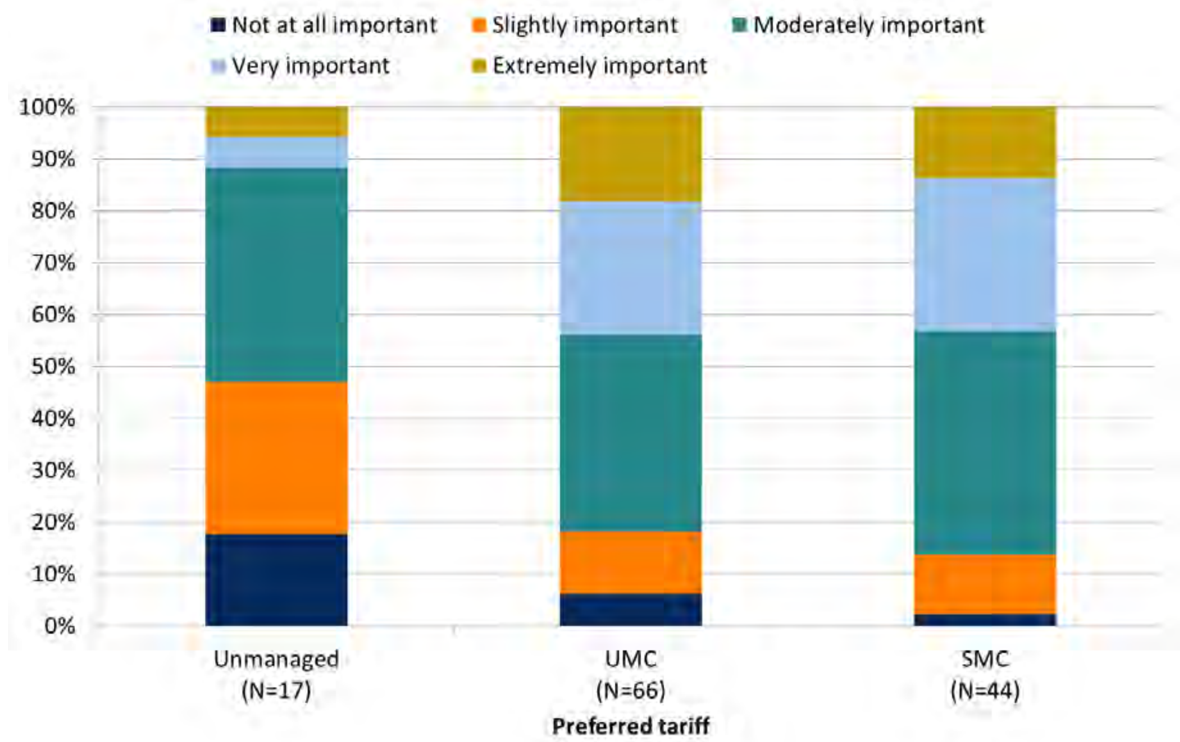


Figure 89: Proportion of participants who rated control of charging via an app or website as important or unimportant by chosen charging scheme (if they owned a PHEV)

As there was more than one survey item that had a significant relationship with the outcome, these two charging features were then used to predict participants preferred tariff[31] if they owned a PHEV using a multinomial regression model. This model was significant ($\chi^2(8)=26.332$, p = 0.001) and predicted with 60% accuracy.

Table 35: Classification accuracy for the PHEV preferred tariff model

	Predicted			
Observed	Unmanaged	UMC	SMC	Percentage Correct
Unmanaged	3	9	5	18%
UMC	1	54	11	82%
SMC	4	21	19	43%
Overall Percentage	6%	66%	28%	60%

However, only the importance of having control over when the vehicle charges was significant individual predictor of tariff preference ($\chi^2(4)=15.501$, p = 0.004). The model found that people who did not rate this item as being at least 'Very important' were less likely to choose the UMC tariff than the unmanaged tariff. In opposition to this, participants who did not rate

[31] Due to the small number of participants in some of the groups, some of the response categories were merged for this analysis to three response options instead of five. This was done by combining the 'Not at all important' and 'Slightly important' options along with the 'Very important' and 'Extremely important' options.

this item as being at least 'Very important' were more likely to choose the SMC than the unmanaged tariff. The importance rating being able to control vehicle charging via an app or website was only marginally significant as an individual predictor of tariff preference (p = 0.075). Participants who did not rate this item as being at least 'Very important' were less likely to choose both the UMC and SMC tariffs than the unmanaged tariff.

B.4.1.9 *What are the impacts of different User-Managed Charging tariffs and Supplier-Managed Charging schemes on a Consumer's likelihood to participate in these arrangements?*

- → **Annual cost savings have a very strong influence on the decision to choose a managed charging scheme.**
- → **Managed charging becomes less attractive with higher peak electricity costs, even if the expected annual savings remain the same. The impact on SMC is larger, where users may feel they have less control to avoid peak rates.**
- → **An override function, where users can changes SMC settings once input, makes SMC more attractive. This is even true of an override function where the user bears all the financial penalty of changing settings in a particular charging session.**
- → **Managed charging, particularly SMC, appears more attractive to BEV drivers if there is a nearby rapid chargepoint to act as a back-up in case their car is needed earlier than expected.**

Using the simple choice model outlined in Appendix A.15.5.1, the relative influence of each managed charging attribute on the BEV participants' choice of charging tariff can be illustrated. In each case, the value of the attribute of interest is varied, with all others held at their reference values, and the share of participants choosing each tariff is estimated in the choice model.

Expected annual charging cost savings

Figure 90 shows how the expected annual charging cost savings have a very strong influence on the share of participants predicted to choose either SMC or UMC tariffs. It was assumed that a pound per year saving is worth the same regardless of whether it is gained through UMC or SMC, and so a single choice coefficient was derived encompassing both options. Since the coefficient is the same for both schemes, their participant shares show a similar sensitivity to annual charging cost savings. Note that in both Figure 90 and Figure 91, the annual charging cost saving is varied for only one of the schemes, either SMC or UMC. In reality, the cost savings of both schemes might be expected to move in tandem, thus reducing the sensitivity of each MC scheme on an individual basis.

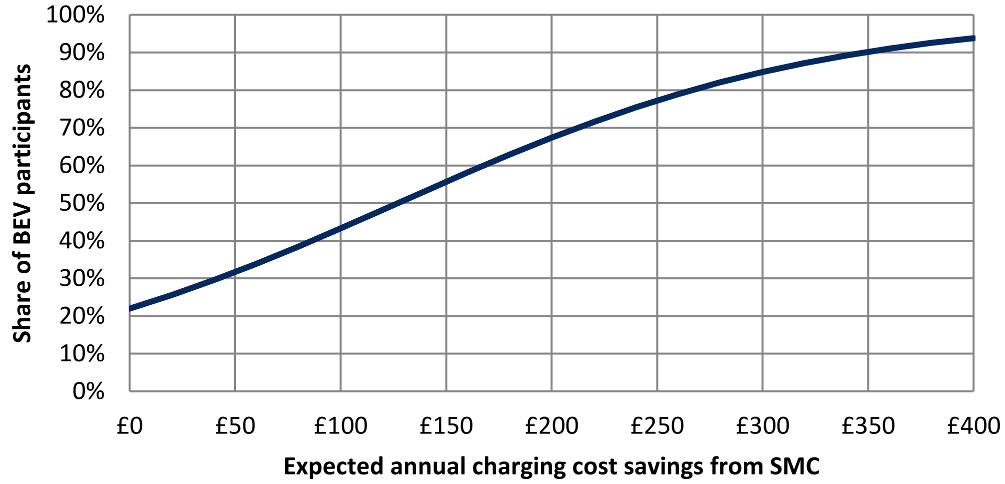


Figure 90: Share of BEV trial participants predicted to choose SMC at different levels of expected annual charging cost savings (all other attribute values are held constant at their reference values)

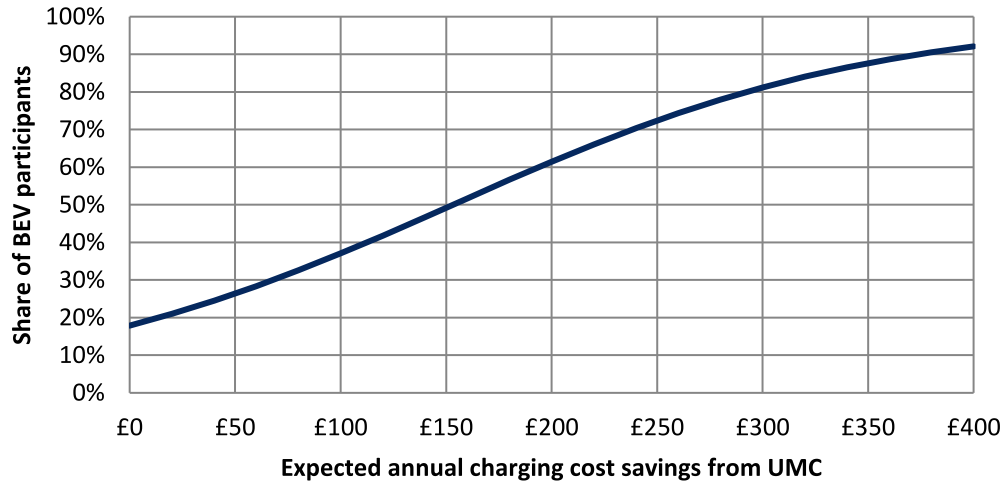


Figure 91: Share of BEV trial participants predicted to choose UMC at different levels of expected annual charging cost savings (all other attribute values are held constant at their reference values)

<u>Additional cost of charging during peak hours</u>

Figure 92 and Figure 93 illustrate how the cost of peak charging relative to unmanaged charging for SMC and UMC influences the share of participants who choose that tariff. As shown in Figure 78, the WTP for reduction in peak charging cost is greater for SMC than UMC. Thus, the share of participants choosing SMC is more sensitive to the scheme's peak charging cost than the equivalent UMC share. It can be seen in Figure 92 that reducing the SMC peak cost results in larger gains in participant share than reducing the UMC peak cost in Figure 93.

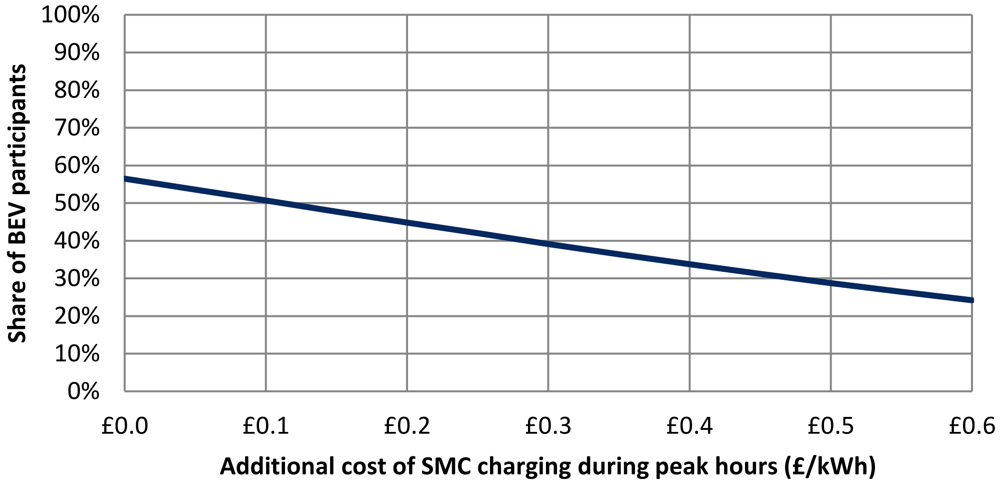


Figure 92: Share of BEV trial participants predicted to choose SMC at different levels of peak charging cost relative to unmanaged charging (all other attribute values are held constant at their reference values)

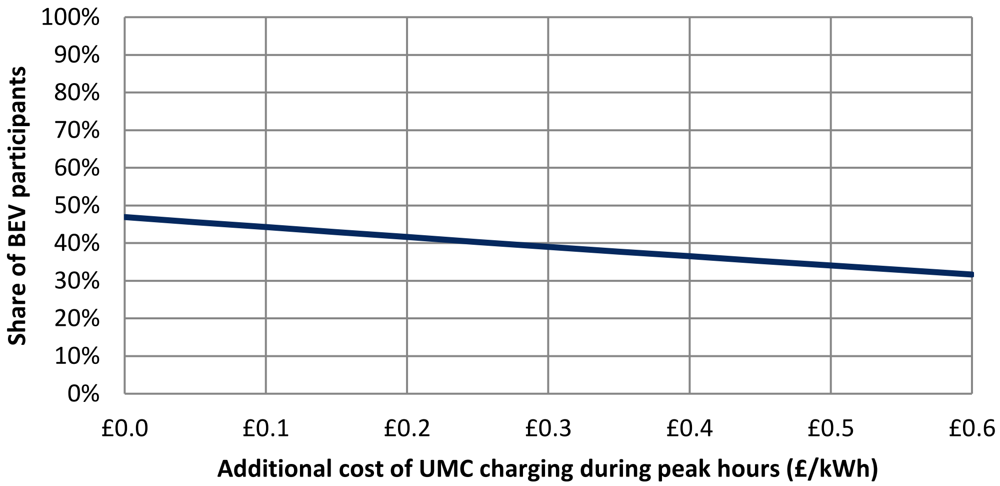


Figure 93: Share of BEV trial participants predicted to choose UMC at different levels of peak charging cost relative to unmanaged charging (all other attribute values are held constant at their reference values)

<u>Proximity of Rapid Chargepoints</u>

Unlike the estimated annual savings and peak charging cost, the proximity of rapid chargepoints cannot be varied independently for each tariff. Consequently, the influence of proximity on the share of participants choosing SMC and UMC must be considered together. This is illustrated in Figure 94.

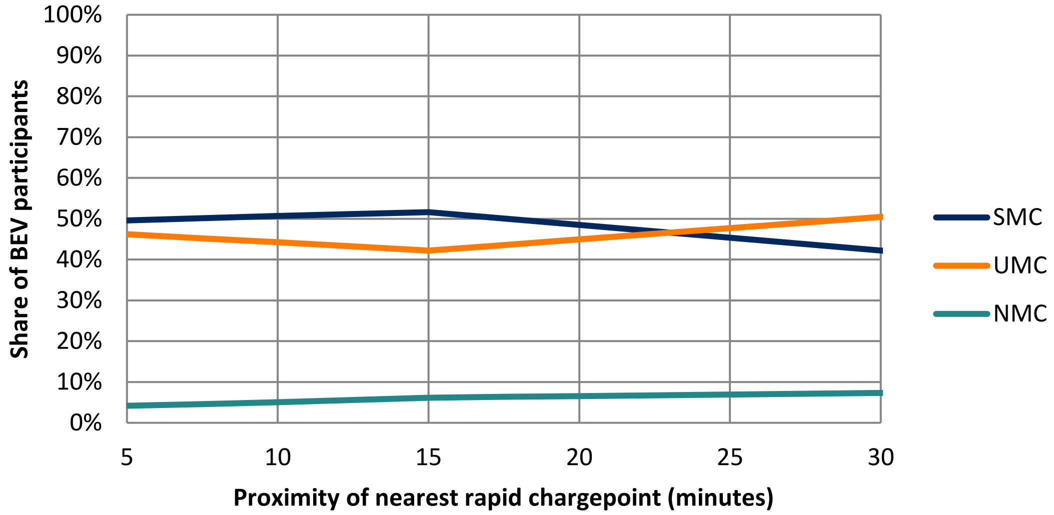


Figure 94: Share of BEV trial participants predicted to choose SMC and UMC with different proximities of the nearest rapid chargepoint (all other attribute values are held constant at their reference values)

Since no additional WTP for UMC was found when the nearest rapid chargepoint was at least 15 minutes away, reducing proximity from 30 minutes to 15 minutes increases the utility of the SMC alternative only. The result is that the share of participants predicted to choose SMC increases, while the share choosing UMC and unmanaged charging decreases. UMC loses a disproportionate share because under the reference values the share of BEV participants choosing unmanaged charging is very low. When reducing the proximity further between 15 minutes and 5 minutes, it is assumed that WTP for UMC increases linearly from zero, and this results in the share of participants choosing UMC rising. In this proximity range, WTP increases at a faster rate for UMC than SMC, and so the increase in UMC share comes at the expense of SMC.

Override Function

Figure 95 shows how the availability of an override function with SMC strongly affects the share of BEV trial participants choosing it. An override function that allows participants to change their settings mid-charge – but in principle enables the supplier to pass on all costs that this may incur – could provide significant additional uptake. If the supplier were willing to accept some of the additional cost, then uptake would be expected to grow further.

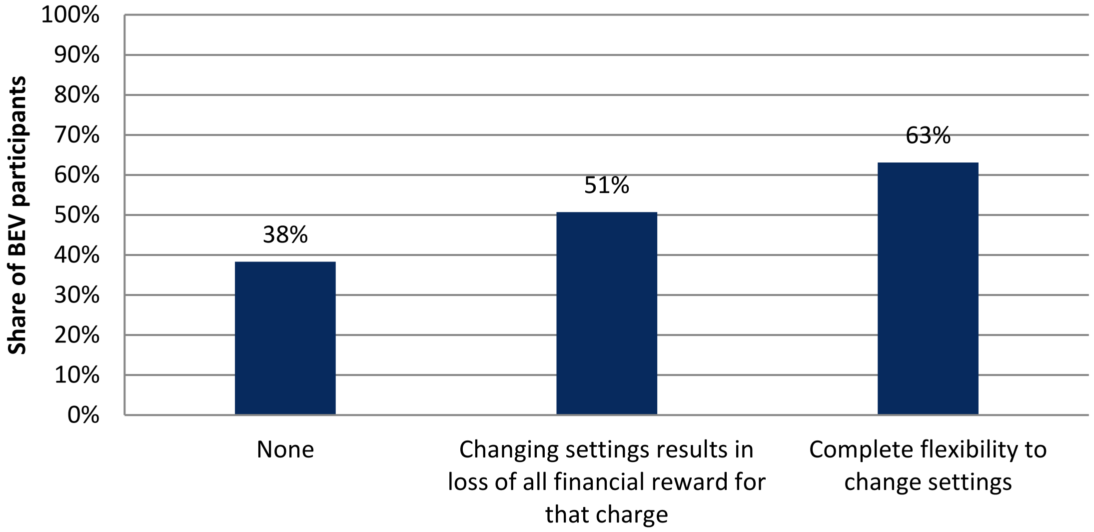


Figure 95: Share of BEV trial participants predicted to choose SMC, with different levels of override function

B.4.1.10 *What are the impacts of different User-Managed Charging tariffs and Supplier-Managed Charging schemes on the likelihood of car buyers choosing a PHEV / BEV over other powertrains?*

- → **Participants in all groups were more likely to purchase a BEV as a second car (66% at least fairly likely) than a main car (35% at least fairly likely).**
- → **There was relatively little difference in the proportion of participants likely or unlikely to purchase a PHEV as a main and second car. There were no significant differences between Control, UMC and SMC groups.**
- → **Availability of a UMC scheme made participants in the UMC and SMC groups more likely to purchase a BEV as a second car than the Control group. It did not significantly impact likelihood to purchase a BEV as a main car, or a PHEV.**
- → **Availability of a SMC scheme made participants in the SMC group more likely to purchase a BEV or PHEV than participants in the UMC or Control groups; this suggests experience with SMC was important for recognising the benefits of a SMC scheme.**
- → **When responses are combined across the three groups, availability of a SMC scheme was more likely to be rated 'not at all' likely to influence the decision to purchase a BEV or PHEV than the availability of a UMC scheme.**

The focus of this analysis was to understand how the availability of UMC or SMC schemes may impact on likelihood to purchase an electric vehicle in the future. The analysis used data from the TP2 questionnaires.

Participants were first asked to rate how likely it was that they would choose to purchase a BEV or PHEV as a main or second car in the next five years. They were then asked whether availability of a UMC or SMC scheme would make this purchase more or less likely.

Figure 96 presents the overall reported likelihood to purchase a BEV or PHEV as a main or second car in the next five years. These results were compared across the three experimental groups.

The responses show that participants in all groups were much more likely to report that they would purchase a BEV as a second car (66% at least fairly likely) in the next five years compared to a main car (35% at least fairly likely). There was relatively little difference in the proportion of participants likely or unlikely to purchase a PHEV as a main and second car.

Statistical tests (independent samples Kruskall-Wallis tests) showed that there were no significant differences in the distribution of responses across the three groups for any of these questions (BEV main car: $p = 0.274$; BEV second car: $p = 0.734$; PHEV main car: $p = 0.561$; PHEV second car: $p = 0.372$).

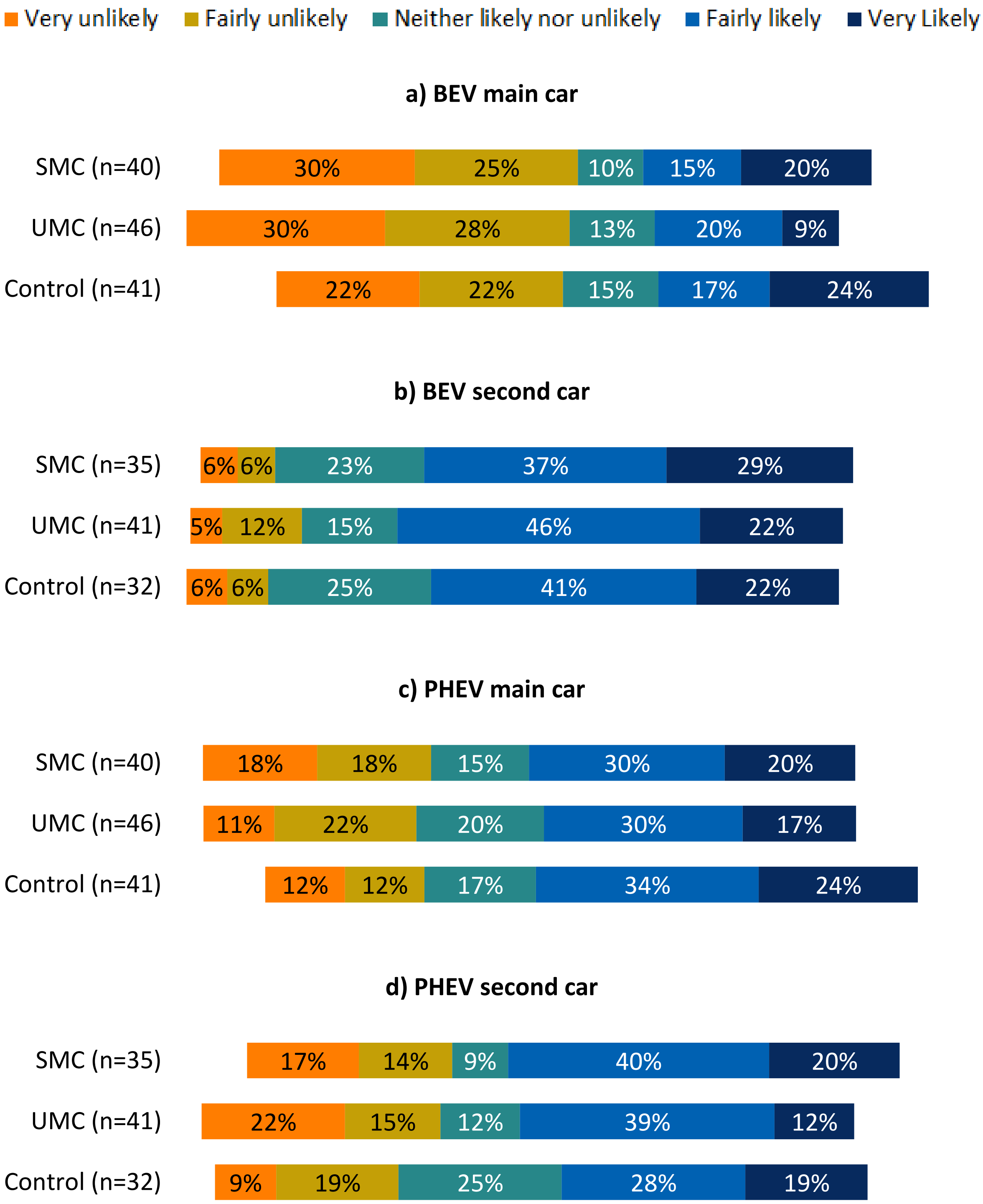


Figure 96: Proportion of responses to TP2 questionnaire "Please indicate how likely or unlikely it is that in the next 5 years, I would choose to have (a) a BEV as a main car, (b) a BEV as a second car, (c) a PHEV as a main car, (d) a PHEV as a second car"[32]

[32] N/A responses are removed from participants who do not have a second car in the household.

Figure 97 shows the distribution of each group's response to the question "If a User-Managed Charging tariff were available, would this make you more likely to have (a) a BEV as a main car, (b) a BEV as a second car, (c) a PHEV as a main car, (d) a PHEV as a second car?".

Availability of a UMC scheme made participants in the UMC and SMC groups more likely to purchase a BEV as a second car than the control group (p = 0.032). There were no significant effects found for likelihood to purchase a BEV as a main car, or a PHEV.

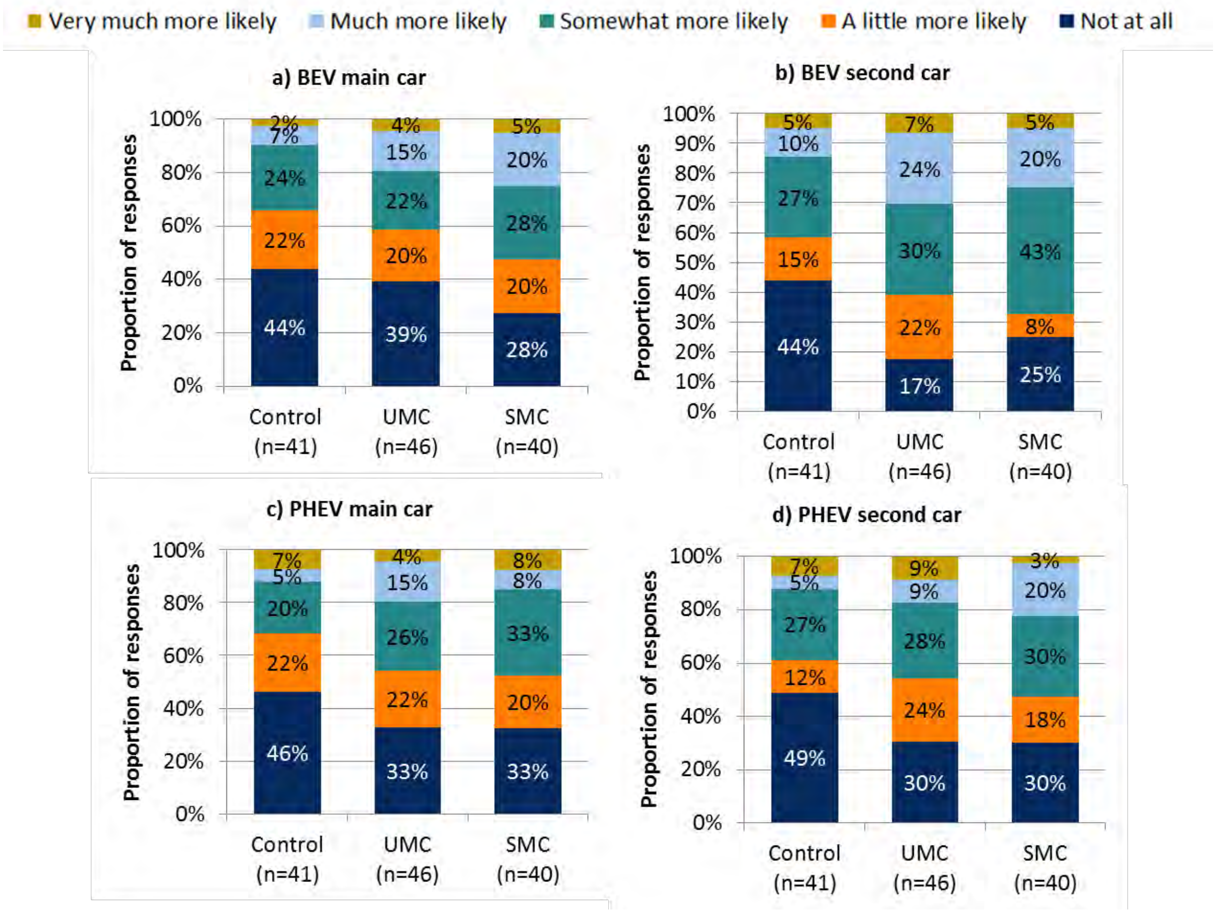


Figure 97: Proportion of responses to TP2 questionnaire "If a User-Managed Charging tariff were available, would this make you more likely to have (a) a BEV as a main car, (b) a BEV as a second car, (c) a PHEV as a main car, (d) a PHEV as a second car?"

Figure 98 shows the distribution of each group's response to the question "If a Supplier-Managed Charging tariff were available, would this make you more likely to have (a) a BEV as a main car, (b) a BEV as a second car, (c) a PHEV as a main car, (d) a PHEV as a second car?".

Availability of a SMC scheme made participants in the SMC group more likely to purchase a BEV or PHEV than the UMC and Control groups (BEV main car: p = 0.002; BEV second car: p < 0.001; PHEV main car: p = 0.030; PHEV second car: p = 0.025).

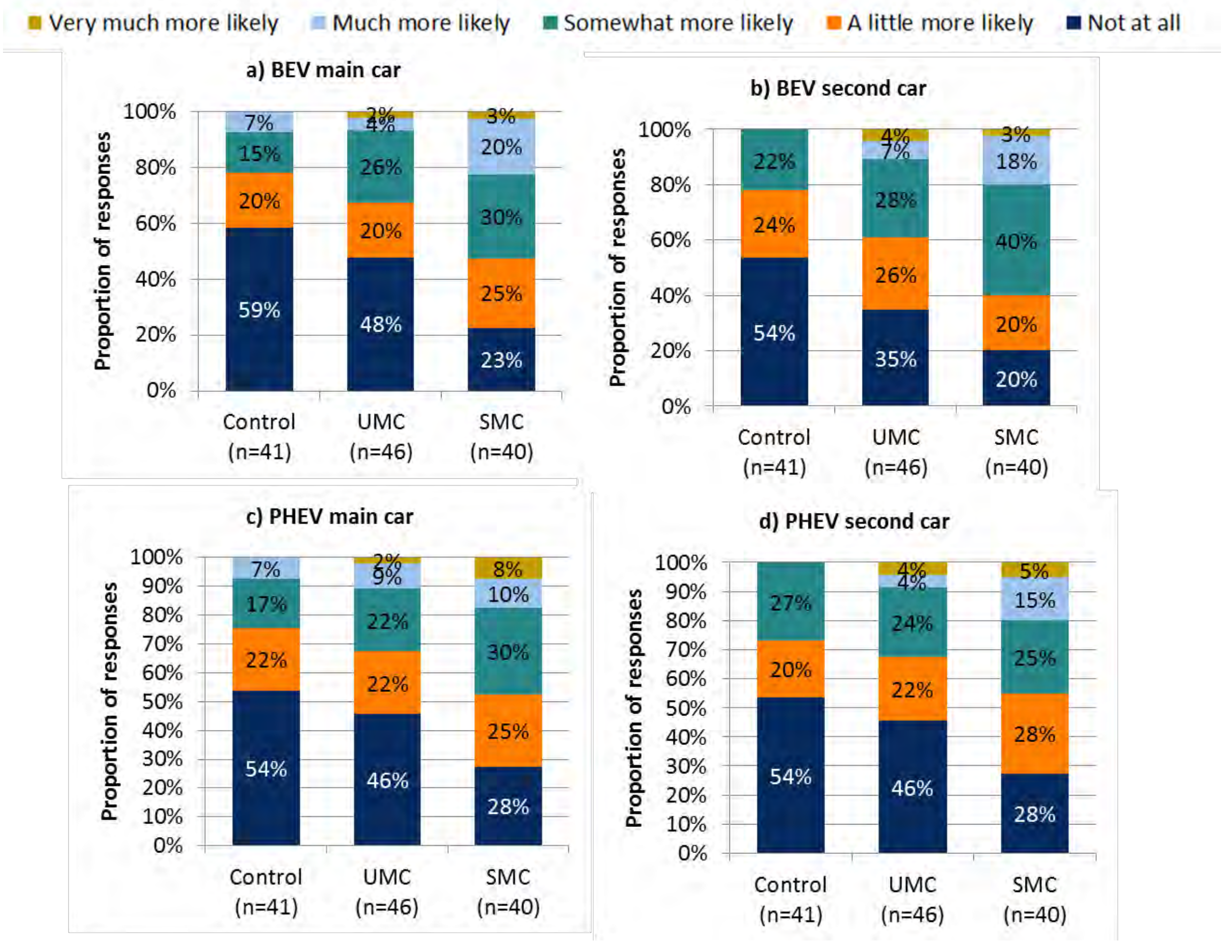


Figure 98: Proportion of responses to TP2 questionnaire "If a Supplier-Managed Charging tariff were available, would this make you more likely to have (a) a BEV as a main car, (b) a BEV as a second car, (c) a PHEV as a main car, (d) a PHEV as a second car?"

Pairwise comparisons of the results show that these differences were not consistent across groups:

- For the BEV as a main car, significant differences were found between Control and SMC ($p = 0.001$) and UMC and SMC ($p = 0.010$).
- For the BEV as a second car, the Control group differed from both SMC ($p = 0.032$) and UMC ($p < 0.001$).
- For PHEV as a main car, the Control and SMC groups were significantly different ($p = 0.001$).
- For PHEV as a second car, the Control and SMC groups were significantly different ($p = 0.007$).

These results suggest that experience of SMC in the trial meant that availability of SMC in future would increase likelihood to purchase a BEV or PHEV. Those in the UMC and control groups, who did not experience SMC, were more likely to consider availability of SMC as 'not at all' likely to influence their vehicle purchasing decisions.

Figure 99 combines the responses across the three experimental groups.

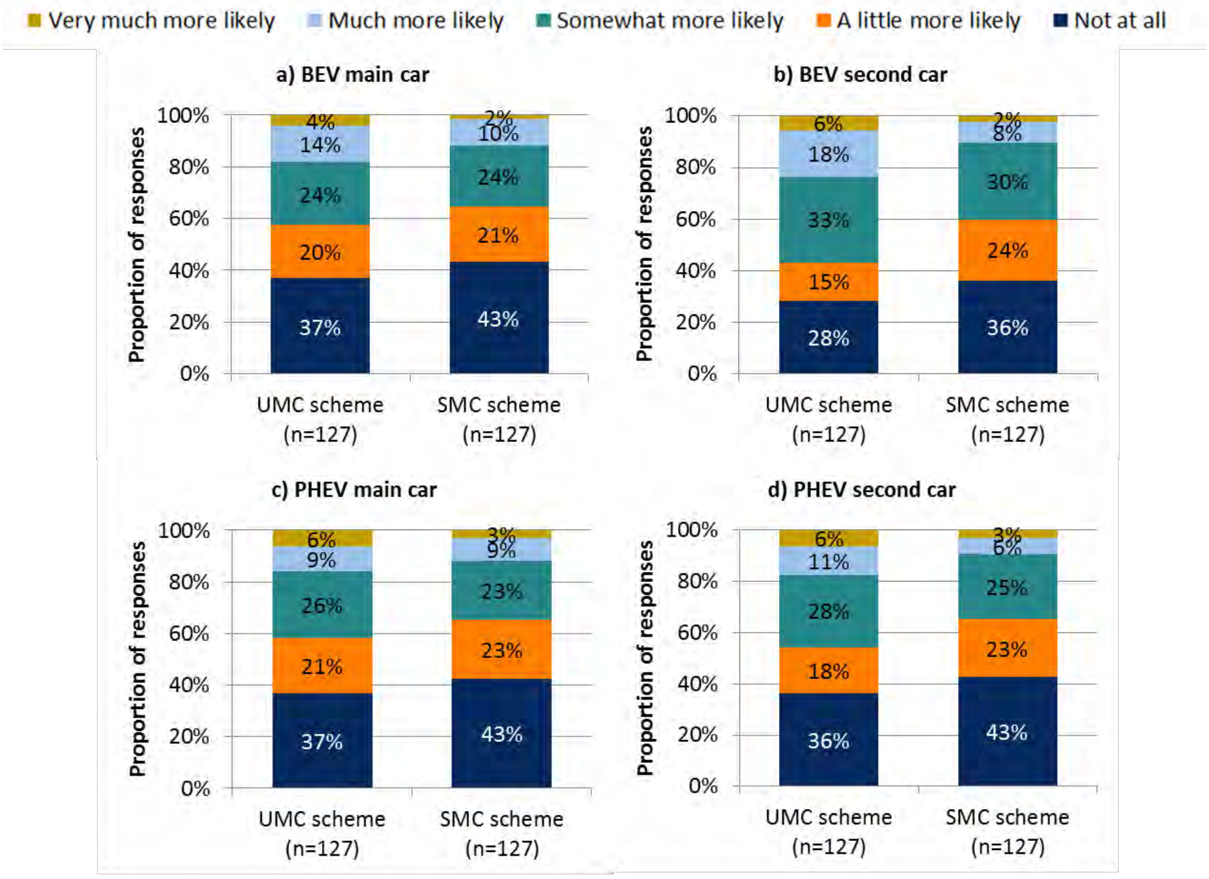


Figure 99: Proportion of responses to TP2 questionnaire “If a User- or Supplier-Managed Charging tariff were available, would this make you more likely to have (a) a BEV as a main car, (b) a BEV as a second car, (c) a PHEV as a main car, (d) a PHEV as a second car?”

The results show that availability of a SMC scheme was slightly but significantly more likely to be rated ‘not at all’ likely to influence the decision to purchase a BEV or PHEV than the availability of a UMC scheme (BEV main car: $p = 0.033$; BEV second car: $p < 0.001$; PHEV main car: $p = 0.020$; PHEV second car: $p = 0.002$).

B.4.2 *Supplementary analyses*

B.4.2.1 *Identification of factors influencing charging behaviour*

→ **Nine types of charge event were identified from a cluster analysis. The charge types were principally characterised by their location; at home, in the local area, and far from home (greater than 50 miles). For each of these locations, the charge events were further sub-divided into three different types of charge. The home charge clusters were predominantly defined by the amount of charge required to reach maximum SOC, whilst charges away from home were defined by the time of day and the availability of charging infrastructure.**

→ **Key journey variables for predicting the charge type were the start time of the journey and the SOC at the end of the journey; this was found to apply for both the last journey before the charge event and the first subsequent journey after the charge event. The data for the journey before the charge was better at predicting the type of charge than data from the subsequent journey.**

The purpose of this supplementary analysis was to identify what factors, if any, from the vehicle telematics data could be used to predict BEV charging behaviour. The analysis was split into two component parts; first, a cluster analysis was undertaken on the charging data to identify distinct categories of charge events. Second, regression analysis was used to examine the extent to which journey variables could be used to predict the different categories of charge event.

Identifying types of charging

Cluster analysis was used to group BEV charge events into distinct categories on the basis of the charging variables in Table 40.

Table 36: Variables and levels used for cluster analysis

Variable	Levels
Distance from home	• Home • Local: less than 50 miles from home • Distant: more than 50 miles away from home
Day of the week	• Weekday charges • Weekend charges
Time of day	• Morning (6am-12pm) • Afternoon (12pm-4pm) • Evening (4pm-10pm) • Overnight (10pm-6am)
Charger power	• <2 kW

Variable	Levels
	• 2-4 kW • 4-22 kW • 22+ kW
Duration of charge	• <2 hours • 2-5 hours • 5+ hours
Amount of SOC added	• <25% • 25-49% • 50-74% • 75% +

The results suggested there were different types of home charge event, and that local events away from home were distinct from those at home. However, charge events that took place further than 50 miles from home did not appear in the cluster analysis. This is likely to be due to the small number of these types of charge. As a result of this, the cluster analysis was run on the three locations separately as it was reasonable to assume that events at these locations were fundamentally different to each other. That is, the 'Distance from home' categories were prescribed, but all other variables listed above were fed into a clustering algorithm and used to elicit naturally occurring groupings in the charge events the categories emerged from the analysis. The following sub-sections report the results of the analysis of home events, local events and distant events separately.

Home events

The cluster analysis for home events found three distinct types of charge. These were predominantly defined by the charge duration (and consequently 'amount of SOC added'). The three clusters were labelled as follows:

- H1: Mid-duration charge (38%)
- H2: Short 'top-up' (28%)
- H3: Fill-up (34%)

The clusters were all of relatively equal sizes (38% of charge events were classed as H1, 28% as H2, and 34% as H3). The majority of home charge events finished with close to 100% SOC. From this we can assume that in general participants aimed to reach 100% SOC whenever they charged at home.

Table 37 summarises the characteristics of the three home charge event clusters. The longer charge events (Mid-duration and Fill up clusters) were predominantly evening and overnight, weekday charges. Short top-up charges were more evenly spread throughout the day suggesting that drivers may have been topping up between journeys, knowing that the car would be required later in the day, and ensuring sufficient range was available.

Table 37: Summary characteristics of Home charge event clusters (BEV)

	H1: Mid-duration 38% of charge events	H2: Short 'top-up' 28% of charge events	H3: Fill up 34% of charge events
Day of the week	77% on weekdays	70% on weekdays	75% on weekdays
Time of day	Majority overnight (44%) and in the evening (36%). Small proportion in the morning (11%) and afternoon (9%)	Evenly spread throughout the day: 29% overnight; 28% morning; 25% evening; 18% afternoon	Most events were overnight (55%) or in the evening (34%).
Duration of charge	2-5 hours	Less than 2 hours	>5 hours
SOC added	Most events added between 25-49%	Less than 25%	Most events added between 50-74% A quarter added >75%

__Local events__

Local events were generally clustered based on charger rate and duration. Again, three charge types were identified:

- L1: Slow 'top-up' (37%)
- L2: Fast 'top-up' (32%)
- L3: Long charge (31%)

After experience with the vehicle, participants reported that the majority of charges away from home took place at work. This suggests that the key differences in the types of local charge event are due to the availability of infrastructure and time available to charge at work. This is likely to explain the identification of a long-charge cluster away from home, and is supported by the majority of these events occurring in the morning, on weekdays, using low powered chargers (see Table 38). In general, most local charge events were during the day, as would be expected. A good proportion of events were fast 'top-ups', of short duration, often using fast or rapid chargers. This demonstrates that participants were willing to try and make use of local fast chargers where they were available; it is worth noting that use of a large public charging network was free for participants in this trial.

Table 38: Summary characteristics of Local charge event clusters (BEV)

	L1: Slow 'top-up' 37% of charge events	L2: Fast 'top-up' 32% of charge events	L3: Long charge 31% of charge events
Day of the week	76% on weekdays	80% on weekdays	83% on weekdays
Time of day	Predominantly daytime: 48% morning and 31% afternoon	Predominantly daytime: 53% morning and 21% afternoon	Most events were morning (58%) but otherwise spread throughout the day
Charger power	Slow (2-4 kWh)	62% 4-22kWh 29% rapid (22+ kWh)	Slow (2-4 kWh)
Duration of charge	69% less than 2 hours; all less than 4 hours	77% less than 2 hours; all less than 4 hours	All at least 2 hours; 51% >5 hours

Distant events

The types of charge that took place over 50 miles away from home were more complex, varying more strongly on a larger number of charge variables. While the number of distance events were fewer in number than home and local charge events (see Table 40), three clusters were found:

- D1: Short 'top-up' (40%)
- D2: Slow (30%)
- D3: Rapid (30%).

Table 39 summarises the characteristics of the Distant event clusters and shows that all of these events were less likely to occur on weekdays than the local and home charges, suggesting that distant charge events were more likely to be related to weekend leisure trips. Long, slow charge events at a distance from home were more likely to occur in the evening, suggesting that drivers were possibly staying away from home at the weekend, replacing their typical home charge with a charge elsewhere. The convenience

Table 39: Summary characteristics of Distant charge event clusters (BEV)

	D1: Short 'top-ups' 40% of charge events	D2: Slow charges 30% of charge events	D3: Rapid 30% of charge events
Day of the week	63% on weekdays	48% on weekdays	Just over half on weekdays
Time of day	Spread throughout the day and none overnight	Throughout the day but majority occurred in the evening	Majority occurred in the evening and large proportion in the

	D1: Short 'top-ups' 40% of charge events	D2: Slow charges 30% of charge events	D3: Rapid 30% of charge events
			morning and afternoon
Charger power	A range of chargers used from Slow (2-4 kWh) to Rapid	Almost all slow 2-4 kWh	All Rapid
SOC added	Less than 25% SOC	33% <25% 28% 25-49% 27% 50-74% 12% 75+%	Almost half of charges received 50-74% SOC; 37% received 25-49%
Duration of charge	Less than 2 hours	All more than 2 hours; 44% >5 hours	Less than 2 hours

The number of participants that undertook each type of charge is shown in Table 40. All participants charged at home. They also nearly all used each of the three home charge types meaning that participants varied the types of charge they were doing at home. Around half of the participants used the most common type of local charge and only one-quarter used the most common 'away' charge type.

Table 40: Number of events and participants per charge type cluster

Location	Charge cluster	Number of participants	Number of charges
Home	H1 = Mid-duration charge	125	1,582
	H2 = Short 'top-up'	123	1,430
	H3 = Fill-up	126	1,165
Local	L1 = Slow 'top-up'	68	295
	L2 = Fast 'top-up'	41	259
	L3 = Long charge	48	247
Distant	D1 = Short 'top-up'	37	121
	D2 = Slow	38	93
	D3 = Rapid	24	90

Cluster comparison

In general, participants from the different experimental groups were similarly likely to undertake each of the different types of charge. However, there were some differences based on demographics[33]:

- Long home and local charges were more likely to be undertaken by female participants.
- Local charges were more likely to be made by participants in the middle age categories.
- Distant charges were more likely to be made by older people.
- Distant charges were more likely to be made by regular drivers and by drivers with fewer cars in their household.

Predicting charge type based on journey data

The next stage of the analysis used a regression model to explore the extent to which the following journey variables could be used to predict the different types of charge event.

- Day of the week
- Journey start time
- Journey distance (km)
- Energy consumed during journey (kWh)
- SOC at end of journey (%)

The maximum speed reached during a journey was also considered as a potential predictor variable; however, it was found to have a very high correlation (between 0.834 and 0.864) with journey distance and so was excluded. Whilst the predictors listed above can be argued to be related (e.g. journey distance and SOC at end of journey and energy consumed within the journey), they were not found to be highly correlated, possibly since the variables are likely impacted by other journey factors not included here (such as acceleration, SOC at the start of the journey and average speed). As such they were included in the model.

The most common type of charge was a mid-duration home charge (H1). This was used as the reference category for the regression analysis. This means that the analysis compared how well the journey variables predicted each of the other types of charge compared with a mid-duration home charge.

<u>Linking charge events to preceding journeys</u>

To understand the extent to which the journey variables could be used to predict different types of charge event, the charging data was linked to data from the journey which took place immediately before the charge. Using these data, a significant regression model was identified ($\chi^2(40) = 3263.454$, $p < 0.001$) with all variables found to have a significant main effect. The model was able to predict charge events with 56% accuracy. The most accurately predicted clusters were the mid-duration and fill-up events at home (H1 and H3); likely due

[33] All of these were tested using Chi-squared tests and were statistically significant.

to the larger sample size (see Table 41). The model predicts the other types of charge with much lower accuracy, especially D1, D2, and L1 which had very low accuracy.

Although each variable was significant in the overall model, not all variables were significant predictors of each of the charge clusters. The full results are shown in Table 42.

Table 41: Model accuracy for predicting charge clusters using data from previous journeys

Observed cluster	Predicted cluster H1	H2	H3	L1	L2	L3	D1	D2	D3	Percentage Correct
H1	1068	84	161	13	17	5	0	0	1	**79.2%**
H2	385	282	163	6	11	4	0	0	5	**32.9%**
H3	232	0	973	1	20	17	0	0	6	**77.9%**
L1	62	99	36	3	16	4	0	0	1	**1.4%**
L2	57	57	48	2	77	13	0	0	5	**29.7%**
L3	47	22	56	3	49	20	0	0	1	**10.1%**
D1	23	18	28	0	12	1	0	0	11	**0.0%**
D2	25	9	31	0	6	0	1	1	7	**1.3%**
D3	12	0	34	0	12	0	0	0	17	**22.7%**
Overall	**43.6%**	**13.0%**	**34.9%**	**0.6%**	**5.0%**	**1.5%**	**0.0%**	**0.0%**	**1.2%**	**55.7%**

Table 42: Previous journey variables found to be significant predictors of charge clusters

Location	Charge cluster	Significant predictors	Stats
Home	H1 = Mid-duration charge	*Reference*	*N/A*
	H2 = Short 'top-up'	Start time End SOC	$p < 0.001$ $p < 0.001$
	H3 = Long charge	Start time Journey distance End SOC	$p < 0.001$ $p = 0.003$ $p < 0.001$
Local	L1 = Slow 'top-up'	Start time End SOC	$p < 0.001$ $p = 0.003$
	L2 = Fast 'top-up'	Start time Journey distance End SOC	$p < 0.001$ $p < 0.001$ $p < 0.001$
	L3 = Long charge	Start time Journey distance End SOC Weekend/Weekday	$p < 0.001$ $p = 0.009$ $p < 0.001$ $p = 0.001$
Distant	D1 = Fast, short, morning charge	Start time Journey distance Energy consumed End SOC	$p < 0.001$ $p < 0.001$ $p = 0.034$ $p = 0.003$
	D2 = Long, weekend, evening charge	Start time Journey distance End SOC Energy consumed Weekend/Weekday	$p < 0.001$ $p < 0.001$ $p < 0.001$ $p = 0.017$ $p < 0.001$

Location	Charge cluster	Significant predictors	Stats
	D3 = Rapid, weekday, evening charge	Start time Journey distance Energy consumed End SOC Weekend/Weekday	$p < 0.001$ $p < 0.001$ $p = 0.005$ $p < 0.001$ $p = 0.007$

Journey start time and SOC at the end of the journey were found to significantly predict the different charge types. In general, if a journey started later in the day, it was more likely to be a 2-5 hour long home charge (H1) than any of the other charge types. The exception to this was for the home charges that took more than five hours (the H3 cluster) where the direction was the other way around. This is in line with the cluster characteristics which showed that most home charges occur overnight whereas local and distant away from home charges take place during the day suggesting that home charges are generally used after the last journey of the day. This is also in line with result in B.4.1.

The higher the SOC at the end of the previous journey, the more likely the charge was to be a 2-5 hour home charge (H1). This may result from participants needing to stop and charge elsewhere due to low SOC in order to get where they were going in comparison to routinely charging at home based on convenience. The exceptions to this were short home charges (H2) and slow local top-ups (L1) charges which were more likely to have a higher journey end SOC.

The results were as expected for journey distance with longer journeys being more likely to be followed by a local or distant charge.

Linking charge events to subsequent journeys

The charging data was also linked to data from the journey which took place immediately *after* a charge. This analysis was completed to understand if the charging behaviour of participants was a result of their previous journeys or those they were planning to undertake.

Table 43: Model accuracy for predicting charge clusters using data from subsequent journeys

Observed cluster	Predicted cluster									Percent Correct
	H1	H2	H3	L1	L2	L3	D1	D2	D3	
H1	456	118	662	3	38	0	1	0	5	**35.5%**
H2	264	209	202	2	23	0	0	0	5	**29.6%**
H3	368	6	824	0	29	0	0	0	1	**67.1%**
L1	102	72	18	1	5	0	0	0	0	**0.5%**
L2	124	32	35	0	41	0	1	0	10	**16.9%**
L3	85	28	41	0	24	0	0	0	0	**0.0%**
D1	10	30	7	1	5	0	5	0	6	**7.8%**
D2	26	12	22	0	5	0	2	0	5	**0.0%**
D3	13	6	13	0	16	0	1	0	22	**31.0%**
Overall	**35.8%**	**12.7%**	**45.1%**	**0.2%**	**4.6%**	**0.0%**	**0.2%**	**0.0%**	**1.3%**	**38.5%**

Similar to the analysis that looked at the previous journeys, data from the journeys after a charge event were found to significantly predict the charge types ($\chi^2(40) = 1762.233$, $p < 0.001$). All journey variables were found to have a significant main effect. However, this model was only able to predict with 39% accuracy.

Although each variable was significant in the overall model, not all variables were found to be significant predictors of each of the charge clusters. The full results are shown in Table 44.

Table 44: Subsequent journey variables found to be significant predictors of charge clusters

Location	Charge cluster	Sig preds	Stats
Home	H1 = Mid-duration charge	Reference	N/A
	H2 = Short 'top-up'	Weekday	$p = 0.038$
		Start time	$p < 0.001$
		Distance	$p < 0.001$
		End SOC	$p < 0.001$
	H3 = Long charge	Start time	$p < 0.001$
		Distance	$p < 0.001$
		End SOC	$p < 0.001$
Local	L1 = Slow 'top-up'	Start time	$p < 0.001$
		Distance	$p < 0.001$
		End SOC	$p < 0.001$
	L2 = Fast 'top-up'	Weekday	$p = 0.017$
		Start time	$p < 0.001$
		Distance	$p < 0.001$
		Energy consumption	$p = 0.001$
	L3 = Long charge	Weekday	$p = 0.002$
		Start time	$p < 0.001$
Distant	D1 = Fast, short, morning charge	Start time	$p < 0.001$
		End SOC	$p < 0.001$
	D2 = Long, weekend, evening charge	Start time	$p < 0.001$
		End SOC	$p = 0.013$
		Weekend/Weekday	$p < 0.001$
	D3 = Rapid, weekday, evening charge	Start time	$p < 0.001$
		Distance	$p < 0.001$
		Weekend/Weekday	$p = 0.017$

To summarise, the start time of the journeys was able to significantly predict the charge clusters. As the charge clusters for the different location deviated on their time of day, this result is not that surprising. Table 45 shows the averages for the journey predictor variables to illustrate the directions of the results from Table 44.

Table 45: BEV charge cluster model predictor descriptive

Charge cluster	Average start time	Average trip end SOC (%)	Average trip distance	Average energy consumed	% on weekdays
H1	10:10:48	80.48	11.55	103.28	75%
H2	11:33:04	60.84	9.48	93.45	70%
H3	09:07:27	86.97	13.00	111.52	78%
L1	14:15:38	68.81	7.48	94.34	75%
L2	15:04:01	73.75	16.54	95.01	79%
L3	13:35:39	76.20	11.73	102.62	82%
D1	14:33:00	31.90	19.77	86.72	60%
D2	13:12:37	67.04	19.27	112.26	43%
D3	15:36:37	50.19	45.72	118.89	55%

In nearly every case, the earlier the journey start time is, the more likely that the charge was in a 2-4 hour home charge (H1). The exception to this was for the long home charge (H3) cluster; the later the journey is, the more likely it was a mid-duration home charge and not long home charge. These results are likely to be related to the home charges generally happening overnight and being followed by a morning journey whereas local and distant charges occur during the day and are likely to be followed by a later journey home.

The higher the journey end SOC, the more likely the charge was a mid-duration home charge than any of the other clusters; an exception was for the long home charge cluster. This is to be expected as the home charges generally ended on around 100% whereas this was much more varied for charges occurring away from home. The higher the SOC is before the journey, the higher it is likely to be at the end.

The results were as expected for journey distance with shorter (or slower) charges being followed by shorter journeys. This suggests that participants may have been considering their future journeys when planning a charge. However, it may also mean that people who generally had shorter journeys only needed short charges and could accept slower rates of charge.

B.4.2.2 *Comparison of attitudes towards electric vehicles before and after experience*

- → **Attitudes towards purchasing a BEV became more polarised after experience in the trial.**
- → **Mainstream Consumers become more likely to consider purchasing a BEV as a second car and a PHEV as a main car after the trial. After the trial, participants were significantly more likely to agree that a BEV would not be their main car if they owned one.**
- → **Positive changes in attitudes towards BEVs included perceptions of the general pleasantness of the vehicle, running costs, environmental benefits, independence from oil benefits, performance, range and charging capacity, reliability, and safety.**
- → **Participants also generally saw themselves as more like the type of person who would own a BEV after the trial (self-congruity).**
- → **Attitudes in relation to BEV purchase costs became more negative after experience in the trial.**
- → **The responses to all of the PHEV range, charging capability, and safety questions changed significantly in a positive direction over the course of the trial.**
- → **Participants were also generally more likely to consider themselves as similar to the type of person who would own a PHEV and that a PHEV would meet their travel needs.**

The purpose of this supplementary analysis was to determine the extent to which experience in the trial resulted in changes in participants' attitudes. Attitudinal data were collected in the TP1 questionnaire (before the trial experience) and the TP2 questionnaire (after the trial experience), and included information on likelihood to purchase a PiV, and attitudes towards BEVs and PHEVs.

Likelihood to purchase a PiV

Participants were asked to indicate how likely or unlikely they were to consider buying a BEV and PHEV in the next five years as either a main or second car (on a scale from 1 "Very unlikely" to 5 "Very likely"). The Wilcoxon Signed Ranks Test was used to compare responses between the TP1 and TP2 questionnaires to see if likelihood to purchase changed following experience in the trial.

Ratings of likelihood to purchase a BEV before and after the trial are shown in Figure 100. Fewer participants reported they were 'neither likely nor unlikely' to purchase a BEV after experience in the trial, suggesting that attitudes became more polarised. On average, the collective reported likelihood to purchase a BEV as a second car was statistically significantly higher after the trial than before ($Z = 4.695$, $p < 0.001$). No statistically significant differences in likelihood to purchase a BEV as a main car were found, suggesting that the polarising effects were more evenly distributed for BEVs as a main car compared with BEVs as a second car.

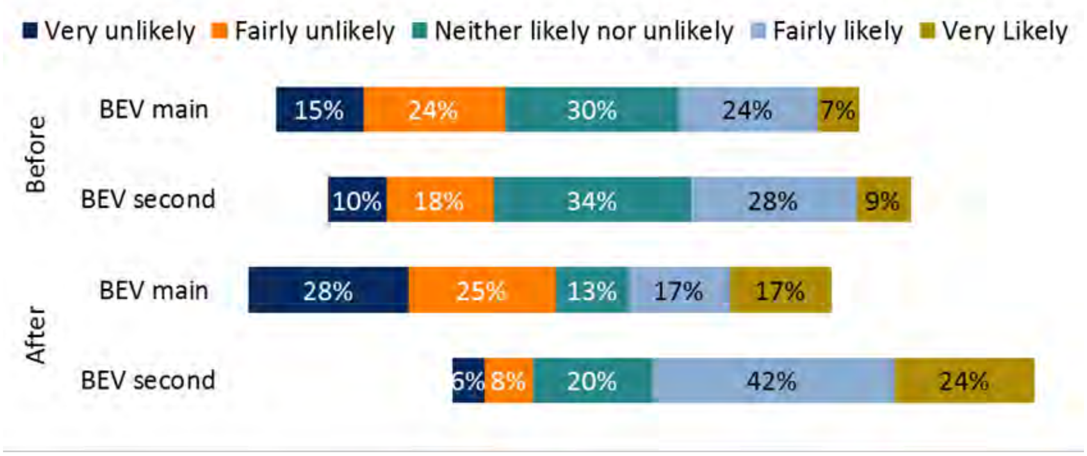


Figure 100: Likelihood to purchase a BEV – results from before and after the trial (N = 121)

Ratings of likelihood to purchase a PHEV before and after the trial are shown in Figure 101.

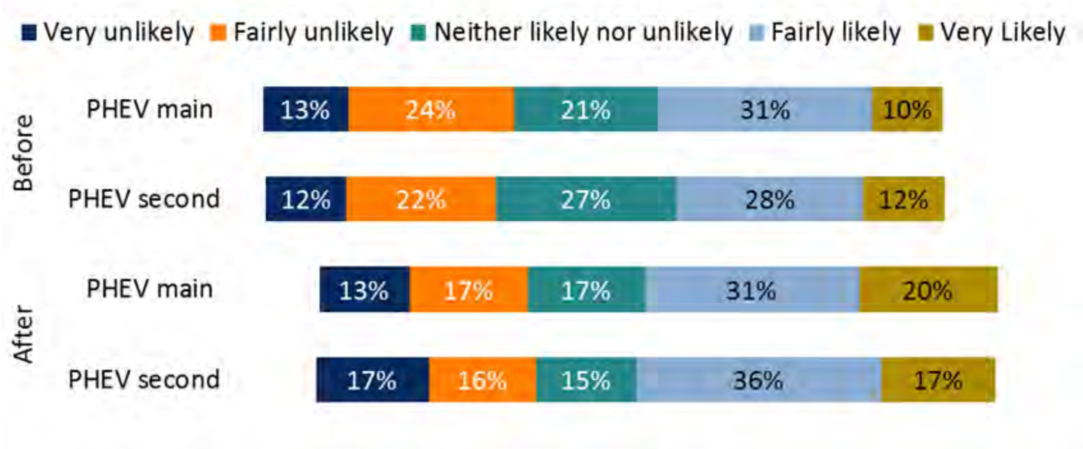


Figure 101: Likelihood to purchase a PHEV – results from before and after the trial (N = 121)

Again, there appeared to be a similar polarisation of opinions after the trial, but to a lesser extent than was observed with likelihood to purchase a BEV. There was a significantly higher likelihood to purchase a PHEV as a main car after the trial compared with before ($Z = -2.178$, $p = 0.029$). No significant differences in likelihood to purchase a PHEV as a second car were found.

Attitudes towards BEVs

Participants were asked a set of questions about their attitudes towards BEVs and PHEVs before and after the trial. These questions covered the following themes:

- Affective attitudes
- Cost
- Environmental benefits
- Independence from oil companies

- Vehicle performance
- Range and charging capabilities
- Reliability
- Safety
- Symbolic attitudes (i.e. the level to which the participant thinks they are similar to someone who would own a BEV or PHEV)
- Travel needs

To examine whether these items could be reduced into a smaller list of related factors, a factor analysis was first conducted. Whilst reliable factors were identified, the factor structure differed between TP1 responses and TP2 responses. As such, comparison of the factors between TP1 and TP2 was not possible. Instead, direct comparisons of responses between TP1 and TP2 were undertaken; the statistically significant results from these comparisons are presented below. The full set of results is shown in Table 46.

Affective

The responses for three out of four questions related to affective attitudes changed significantly over time. All of these attitudes changed in a positive direction (i.e. BEVs were rated more positively after the trial than before). This suggests that in general participants thought BEVs were more pleasant after the trial than they did before.

Cost

Two of the cost-related attitudinal questions showed a significant change over time. Participants' attitudes about the cost of buying a BEV became more negative over time whereas the attitudes around the running costs became more positive.

Environmental benefits

Half of the questions around the environmental benefits of BEVs showed a significant positive change. The attitudes that showed a significant change were related to the impact BEVs have on the environment such as emitting less CO_2. The attitudes that did not show any significant change were related to the individuals' feelings about behaving in a 'green' way. This suggests after the trial the participants recognised the general benefits of a BEV for the environment but their perceptions of the personal benefits to them as individuals didn't change significantly.

Independence from oil companies

Half of the attitudinal items around being independent from oil changed significantly and positively over time. Participants became more likely to agree that being independent from oil and able to charge at home instead of re-fuelling at a petrol station is a good idea after the trial. On the other hand there was no significant change in how much participants agreed that they themselves would like to be more independent from oil and able to charge at home. Taken together, these findings suggest that experiencing a BEV affected participants' attitudes towards the general benefits of BEVs in terms of reducing dependence on oil. However, there did not seem to be a corresponding change in perceived personal benefits of owning a BEV and oil dependence.

Performance

The attitudes towards the performance of BEVs improved across the board with the changes being significant in all but one case (noise when cruising). In general, participants gave higher ratings of BEV performance after the trial than before. This may suggest that the BEV out-performed participants' expectations.

Range and charging capabilities

The BEV sample was selected to include those for whom a BEV was suitable for usual vehicle usage patterns. Nevertheless, the responses to all of the range and charging capability questions changed significantly over the course of the trial; all in a positive direction. This suggests that, in general, participants were less concerned by the range of the BEV and its charging capabilities after they had experienced using it. This is an important result that suggests that long-term experience with a BEV increases confidence that the range and charging characteristics are acceptable.

Reliability

All of the items showed significant changes after experience in the trial and all four showed a positive change, indicating an improvement in perceptions of reliability.

Safety

The questions on attitudes to safety included vehicle occupant safety and the safety of other road users and pedestrians. The responses to these questions changed significantly between the TP1 and TP2 surveys; all in a positive direction. This suggests that in general participants rated BEVs as safer after they had experienced using one.

Symbolic

After the trial, participants rated themselves as being more similar to the type of person who would own a BEV compared with their ratings from before the trial. The majority of questions related to this theme showed a significant positive change.

Travel needs

After the trial, participants were significantly more likely to agree that a BEV would not be their main car if they owned one; this suggests that the experience of using the VW e-Golf (with a real-world range of approximately 125 miles) confirmed for some participants that a BEV was not suitable as their main car. However, they also had a lower level of agreement that BEVs are impractical. The other questions relating to how well travel needs can be met using a BEV also moved in a positive direction (although not significantly).

Table 46: Changes in attitudes towards BEVs over time[34]

Theme	Attitude	Z score	*p*-value	Before (TP1)		After (TP2)		Direction of change[35]
				Mean	SD	Mean	SD	
Affective	BEVs are pleasant to drive	-8.386	< 0.001	3.75	0.71	4.78	0.55	Positive
	I would prefer to drive a conventional car than a BEV	-3.191	0.001	2.63	0.89	2.35	1.06	Positive
	BEVs are a very exciting new technology	-3.387	0.001	4.2	0.77	4.46	0.73	Positive
	BEVs are a current fad which will soon disappear	-1.445	0.148	1.69	0.70	1.6	0.68	Positive
Cost	BEVs are more expensive to run than conventional cars	-5.052	< 0.001	2.09	0.78	1.67	0.74	Positive
	BEVs are more expensive to buy than conventional cars	-3.275	0.001	4.33	0.68	4.54	0.62	Negative
	BEVs are a cheaper option over the longer term	-1.540	0.124	3.35	0.88	3.5	0.93	Positive
	I would be prepared to pay more for a BEV than a conventional car	-0.770	0.441	2.83	0.88	2.92	1.04	Positive
	BEVs will hold its value better than a conventional car	-0.410	0.682	2.95	0.91	2.91	0.92	Negative
	BEVs will lose value more quickly than a conventional car	-0.195	0.845	3.05	0.98	3.02	1.05	Positive
Environmental Benefits	BEVs offer environmental benefits	-2.995	0.003	4.29	0.69	4.46	0.63	Positive
	The environmental benefits of BEVs have been over exaggerated	-2.510	0.012	2.64	0.91	2.44	0.90	Positive
	BEVs emit less carbon dioxide than conventional cars	-2.009	0.044	4.53	0.77	4.69	0.65	Positive
	BEVs are good for the environment	-1.847	0.065	4.2	0.83	4.32	0.80	Positive

[34] Statistically significant results have been shaded.

[35] For this table, a positive change indicates either an increase in a desirable attitude towards PiVs or a reduction in an undesirable attitude, whereas a negative signifies either a reduction in a desirable attitude or an increase in an undesirable attitude.

Theme	Attitude	Z score	*p*-value	Before (TP1) Mean	Before (TP1) SD	After (TP2) Mean	After (TP2) SD	Direction of change[35]
	Driving a BEV would give me a 'feel good factor' because of its green credentials	-1.203	0.229	3.86	0.79	3.94	0.96	Positive
	BEVs are a really good idea	-1.374	0.169	4.33	0.63	4.41	0.68	Positive
Independence from oil	BEVs are a good thing because they make us less dependent on oil	-4.077	< 0.001	4.03	0.78	4.28	0.72	Positive
	Not having to go to a petrol station to refuel would make me more likely to buy a BEV	-3.900	< 0.001	3.25	1.02	3.69	1.09	Positive
	I like the idea of being able to 'refuel' at home rather than have to go to petrol stations	-1.817	0.069	4.23	0.69	4.35	0.79	Positive
	I would like to be less dependent on oil companies for fuelling my car	-0.952	0.341	4.09	0.82	4.14	0.97	Positive
Performance	BEVs perform better than a conventional car	-5.893	< 0.001	3.13	0.76	3.72	0.89	Positive
	BEVs would have better acceleration from 0-30mph compared with a conventional car	-6.571	< 0.001	3.65	1.07	4.43	0.83	Positive
	BEVs would be less responsive when accelerating than a conventional car	-7.146	< 0.001	2.26	1.02	1.30	0.72	Positive
	BEVs would be more powerful than a conventional car	-6.489	< 0.001	2.8	0.83	3.54	0.94	Positive
	BEVs would be noisier when pulling away than a conventional car	-4.227	< 0.001	1.39	0.54	1.16	0.58	Positive
	BEVs would be smoother to drive when accelerating than a conventional car	-7.178	< 0.001	3.91	0.79	4.65	0.59	Positive
	BEVs would be less smooth to drive when cruising	-7.029	< 0.001	2.02	0.80	1.34	0.68	Positive
	BEVs would be less comfortable than a conventional car	-3.959	< 0.001	1.83	0.70	1.50	0.79	Positive

Theme	Attitude	Z score	*p*-value	Before (TP1) Mean	Before (TP1) SD	After (TP2) Mean	After (TP2) SD	Direction of change[35]
	BEVs would have worse acceleration from 30-50mph compared with a conventional car	-6.187	< 0.001	2.57	1.00	1.76	0.92	Positive
	BEVs would be quieter when cruising than a conventional car	-1.674	0.094	4.38	0.68	4.53	0.73	Positive
Range and charging	Adapting to charging a BEV would be difficult for me	-3.523	< 0.001	2.31	0.83	1.94	1.01	Positive
	Having to remember to plug in a BEV would put me off buying one	-2.936	0.003	2.02	0.86	1.76	0.95	Positive
	I would only consider a BEV if I knew I had access to a rapid charging point (i.e. somewhere it would charge to 80% in around 30 minutes)	-3.017	0.003	3.62	1.11	3.26	1.35	Positive
	When driving a BEV, I would always be worried about running out of charge	-2.972	0.003	3.59	1.06	3.24	1.17	Positive
Reliability	The chances of breaking down in a BEV are higher than in a conventional car	-3.661	< 0.001	2.74	0.95	2.35	1.01	Positive
	BEVs are too new to be reliable	-3.535	< 0.001	2.54	0.92	2.23	0.96	Positive
	BEVs are more complicated than a conventional car	-3.333	0.001	2.54	0.99	2.20	1.01	Positive
	BEVs would be more reliable than a conventional car	-2.595	0.009	3.28	0.78	3.44	0.85	Positive
Safety	BEVs are as safe for the driver and passengers as conventional cars	-4.019	< 0.001	4.13	0.81	4.51	0.76	Positive
	BEVs are similar to a conventional car in most respects	-3.257	0.001	3.7	0.84	3.99	0.84	Positive
	BEVs are a danger to people outside the car because of the lack of engine noise	-3.421	0.001	3.16	1.12	2.79	1.17	Positive
Symbolic	I would feel embarrassed to drive a BEV	-5.434	< 0.001	1.57	0.76	1.17	0.39	Positive
	I would feel proud of having a BEV outside my house	-4.706	< 0.001	3.63	0.85	4.03	0.85	Positive

Theme	Attitude	Z score	*p*-value	Before (TP1) Mean	Before (TP1) SD	After (TP2) Mean	After (TP2) SD	Direction of change[35]
	I am the type of person who would drive a BEV	-3.349	0.001	3.84	0.73	4.13	0.89	Positive
	Many people I know would be attracted to owning a BEV	-2.866	0.004	3.21	0.85	3.46	0.79	Positive
	I would only consider a BEV if there were plenty to choose from among the main car manufacturers	-0.030	0.976	3.16	1.06	3.15	1.02	Positive
Travel needs	If I had a BEV, it would be unlikely to be my main or only car	-4.207	< 0.001	3.13	1.22	3.78	1.27	Negative
Travel needs	BEVs are impractical	-2.177	0.03	2.54	0.88	2.31	1.04	Positive
Travel needs	A BEV would suit my daily travel patterns	-0.621	0.535	3.89	0.83	3.95	1.08	Positive
Travel needs	Having a BEV would mean I would have to plan journeys carefully	-0.231	0.818	4.36	0.60	4.34	0.86	Positive
Travel needs	BEVs are suitable for my lifestyle	-0.022	0.983	3.67	0.82	3.70	1.17	Positive

Attitudes towards PHEVs

This section summarises the attitudes towards PHEVs of the participants from the BEV trial. These participants had not experienced a PHEV. The results are shown in Table 47..

Affective

Participants rated the PHEV as being significantly more pleasant to drive after the trial than they did before. This was the only significant difference from the set of questions on affective attitudes.

Independence from oil companies

The responses to one of the items relating to independence from oil changed significantly over time; participants were more likely to agree that they would like to be less oil dependent and that they would like to be able to re-fuel at home after the trial than they did before. On the other hand, these changes did not include the questions on this topic that specifically related to PHEVS:

- Not having to go to a petrol station to refuel would make me more likely to buy a PHEV.
- PHEVs are a good thing because they make us less dependent on oil.

Performance

The attitudes towards the performance of PHEVs improved across the board with the changes being significant in all but one case (which was related to noise levels). In general, participants gave higher ratings of PHEV performance after the trial than before.

Range and charging capabilities

The responses to all of the range and charging capability questions changed significantly over the course of the trial; all in a positive direction. In general participants were less concerned by the range of PHEVs and their charging capabilities after they had experienced a BEV.

Reliability

After the trial, participants were significantly less likely to agree with the statement "PHEVs are too new to be reliable". This was the only significant change in attitudes related to reliability.

Safety

The responses to all of the safety-related questions changed significantly between the TP1 and TP2 questionnaires in a positive direction. This suggests that in general participants rated PHEVs as safer after they had experienced using a BEV, possibly implying that participants attributed the characteristics to PiVs in general.

Symbolic

After the trial, participants tended to rate themselves as being more similar to the type of person who would own a PHEV than they did before the trial. The majority of these results were significant.

Travel needs

After the trial, participants more strongly agreed that a PHEV would suit their travel needs and lifestyle. In general these changes were significant.

Looking at these results collectively, it appears that participants attributed some characteristics such as safety and charging capabilities to PiVs in general instead of only to BEVs, which participants experienced in the trial. This suggests that experience of a BEV may have impacted certain Mainstream Consumer attitudes to PHEVs.

Table 47: Changes in attitudes towards PHEVs over time[36]

Theme	Attitude	Z score	*p*-value	Before (TP1)		After (TP2)		Direction of change[37]
				Mean	SD	Mean	SD	
Affective	I would prefer to drive a conventional car than a PHEV	-1.592	0.111	2.36	0.91	2.21	0.97	Positive
	PHEVs are a current fad which will soon disappear	-1.325	0.185	2.26	1.02	2.14	0.98	Positive
	PHEVs are a very exciting new technology	-0.473	0.636	3.76	0.88	3.8	0.97	Positive
	PHEVs are pleasant to drive	-3.326	0.001	3.61	0.69	3.87	0.72	Positive
Cost	I would be prepared to pay more for a PHEV than a conventional car	-1.051	0.293	3.06	0.93	2.98	0.98	Negative
	PHEVs are a cheaper option over the long term	-1.553	0.120	3.24	0.76	3.35	0.84	Positive
	PHEVs are more expensive to buy than conventional cars	-0.412	0.680	4.13	0.68	4.17	0.60	Negative
	PHEVs are more expensive to run than conventional cars	-1.156	0.248	2.36	0.74	2.28	0.80	Positive
	PHEVs will hold its value better than a conventional car	-1.584	0.113	3.12	0.78	3.01	0.84	Negative
	PHEVs will lose value more quickly than a conventional car	-0.576	0.564	2.86	0.84	2.82	0.86	Positive
Environmental Benefits	Driving a PHEV would give me a 'feel good factor' because of its green credentials	-1.781	0.075	3.67	0.86	3.54	0.95	Negative
	PHEVs are good for the environment	-0.52	0.603	3.87	0.79	3.83	0.82	Negative
	PHEVs emit less carbon dioxide than conventional cars	-0.523	0.601	4.09	0.73	4.13	0.64	Positive

[36] Statistically significant results have been shaded.

[37] For this table, a positive change indicates either an increase in a desirable attitude towards EVs or a reduction in an undesirable attitude whereas a negative signifies either a reduction in a desirable attitude or an increase in an undesirable attitude.

Theme	Attitude	Z score	*p*-value	Before (TP1) Mean	Before (TP1) SD	After (TP2) Mean	After (TP2) SD	Direction of change[37]
	PHEVs offer environmental benefits	-0.615	0.539	3.97	0.71	4.01	0.68	Positive
	The environmental benefits of PHEVs have been over exaggerated	-0.604	0.546	2.75	0.85	2.69	1.04	Positive
	PHEVs are a really good idea	-0.307	0.759	4.00	0.75	4.02	0.82	Positive
Independence from oil	I like the idea of being able to 'refuel' at home rather than have to go to petrol stations	-3.219	0.001	4.08	0.65	4.28	0.76	Positive
	I would like to be less dependent on oil companies for refuelling my car	-2.441	0.015	4.06	0.73	4.22	0.74	Positive
	Not having to go to a petrol station to refuel would make me more likely to buy a PHEV	-1.177	0.239	3.66	0.93	3.76	1.05	Positive
	PHEVs are a good thing because they make us less dependent on oil	-0.623	0.533	3.95	0.75	3.91	0.82	Negative
Performance	PHEVs perform better than a conventional car	-1.555	0.12	3.17	0.69	3.30	0.74	Positive
	PHEVs would be less comfortable than a conventional car	-4.205	< 0.001	2.01	0.68	1.69	0.65	Positive
	PHEVs would be less responsive when accelerating than a conventional car	-4.067	< 0.001	2.55	0.84	2.16	0.72	Positive
	PHEVs would be less smooth to drive when cruising	-3.857	< 0.001	2.24	0.74	1.91	0.69	Positive
	PHEVs would be more powerful than a conventional car	-3.539	< 0.001	2.76	0.72	3.07	0.79	Positive
	PHEVs would be noisier when pulling away than a conventional car	-1.363	0.173	1.93	0.62	1.83	0.69	Positive
	PHEVs would be quieter when cruising than a conventional car	-0.256	0.798	3.44	0.97	3.46	0.92	Positive

Theme	Attitude	Z score	*p*-value	Before (TP1) Mean	Before (TP1) SD	After (TP2) Mean	After (TP2) SD	Direction of change[37]
	PHEVs would be smoother to drive when accelerating than a conventional car	-2.209	0.027	3.43	0.76	3.65	0.81	Positive
	PHEVs would have better acceleration from 0-30mph compared with a conventional car	-4.705	< 0.001	3.24	0.80	3.69	0.77	Positive
	PHEVs would have worse acceleration from 30-50mph compared with a conventional car	-4.248	< 0.001	2.67	0.71	2.28	0.82	Positive
Range and charging	Adapting to charging a PHEV would be difficult for me	-4.201	< 0.001	1.92	0.70	1.56	0.80	Positive
	Having to remember to plug in a PHEV would out be off buying one	-3.748	< 0.001	1.95	0.78	1.65	0.75	Positive
	I would only consider a PHEV if I knew I had access to a rapid charging point (i.e. somewhere it would charge to 80% in around 30 mins)	-2.053	0.040	2.90	1.18	2.64	1.15	Positive
	When driving a PHEV, I would always be worried about running out of charge	-3.48	0.001	2.00	0.86	1.72	0.77	Positive
Reliability	PHEVs are more complicated than a conventional car	-0.309	0.757	3.46	0.97	3.44	1.07	Positive
	PHEVs are too new to be reliable	-2.252	0.024	2.47	0.82	2.29	0.75	Positive
	PHEVs would be more reliable than a conventional car	-1.236	0.217	2.74	0.65	2.82	0.66	Positive
	The chances of breaking down in a PHEV are higher than in a conventional car	-1.11	0.267	2.66	0.81	2.57	0.91	Positive
Safety	PHEVs are a danger to people outside the car because of the lack of engine noise	-2.965	0.003	2.78	1.03	2.46	0.97	Positive
	PHEVs are as safe for the driver and passengers as conventional cars	-2.274	0.023	4.13	0.68	4.30	0.68	Positive
	PHEVs are similar to conventional cars in most respects	-2.023	0.043	3.80	0.81	3.96	0.80	Positive

Theme	Attitude	Z score	*p*-value	Before (TP1) Mean	Before (TP1) SD	After (TP2) Mean	After (TP2) SD	Direction of change[37]
Symbolic	I am the type of person who would drive a PHEV	-1.969	0.049	3.8	0.77	3.94	0.91	Positive
	I would feel embarrassed to drive a PHEV	-1.439	0.150	1.61	0.66	1.54	0.81	Positive
	I would feel proud of having a PHEV outside my house	-3.212	0.001	3.54	0.84	3.77	0.88	Positive
	I would only consider a PHEV if there were plenty to choose from among the main car manufacturers	-0.416	0.678	3.2	1.03	3.23	1.00	Negative
	Many people I know would be attracted to owning a PHEV	-2.443	0.015	3.43	0.83	3.65	0.92	Positive
Travel needs	A PHEV would suit my daily travel patterns	-2.539	0.011	4.05	0.71	4.22	0.72	Positive
	Having a PHEV would mean I would have to plan journeys carefully	-2.331	0.020	2.47	0.97	2.24	0.98	Positive
	If I had a PHEV, it would be unlikely to be my main or only car	-0.5	0.617	2.31	1.04	2.28	1.21	Positive
	PHEVs are impractical	-2.622	0.009	2.06	0.70	1.89	0.72	Positive
	PHEVs are suitable for my lifestyle	-1.45	0.147	4	0.71	4.11	0.75	Positive

B.5 PHEV Charging Trial results

B.5.1 *Core analyses*

B.5.1.1 *What is the charging behaviour of mainstream consumers when not participating in a managed charging scheme?*

- → **On weekdays, PHEV home charges frequently started in the evenings (3pm-8pm) whereas charges away from home frequently started in the morning (6am-10am).**
- → **Weekend charges at home followed a similar pattern to home weekday charges, with most charges starting in the evening (3pm-10pm).**
- → **The most common locations when charging away from home were "a place of work or education" and "a shopping mall".**

The focus of this analysis was to understand the charging behaviours of PHEV participants in the control group. The analysis used data from vehicle telematics and the CPMS, supplemented by questionnaire data where relevant.

Charging at home

In the PHEV Charging Trial there were 5,026 home charge events, accounting for about 86% of all charge events recorded during the trial. All PHEV participants charged at home during the trial. Around 58% of PHEV participants also charged away from home.

Figure 102 shows the proportion of home charge events by charge start time (in one-hour time intervals) for weekday and weekend charge events for the control group.

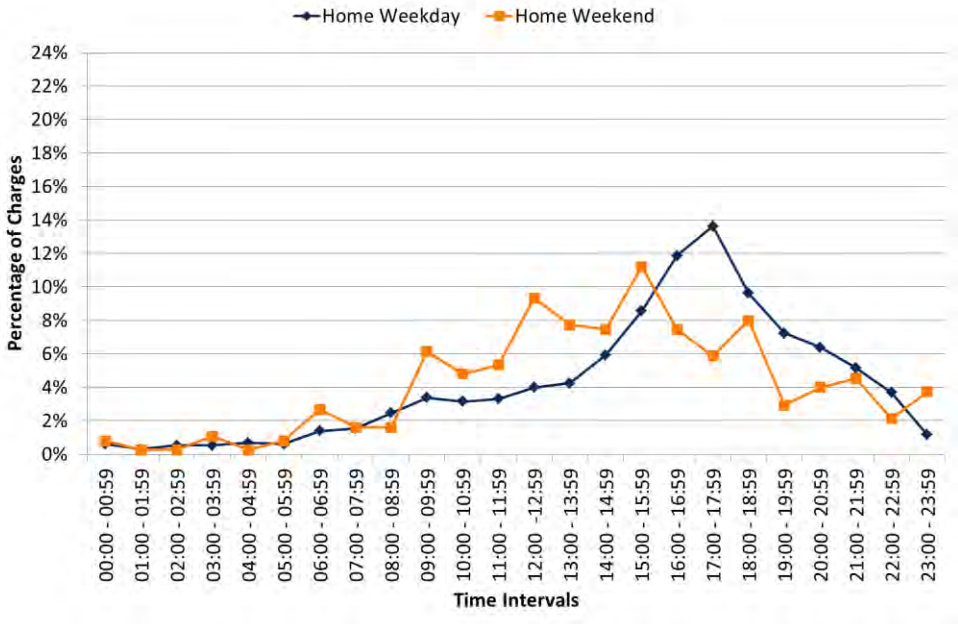


Figure 102: Proportion of weekday and weekend home charge events home by charge start time for PHEV Control group (N = 1299 for weekdays, N = 375 for weekends)

Statistical analysis showed that there was a significant difference in the distribution of start times between weekday and weekend charge events ($\chi^2 = 54.29$, $p < 0.001$). The majority of weekday home PHEV charges started in the evening; a clear peak is visible from 15:00 to 19:00; whereas weekend charges were more spread out..

Figure 49 shows the average energy delivered per control group participant[38]. The peak energy usage for weekdays was between 17:00 – 19:00 whereas for weekends it was earlier in the evening at around 16:00-17:00. The overall energy profile for the weekends was much flatter than for weekdays were energy usage was concentrated in the early evening.

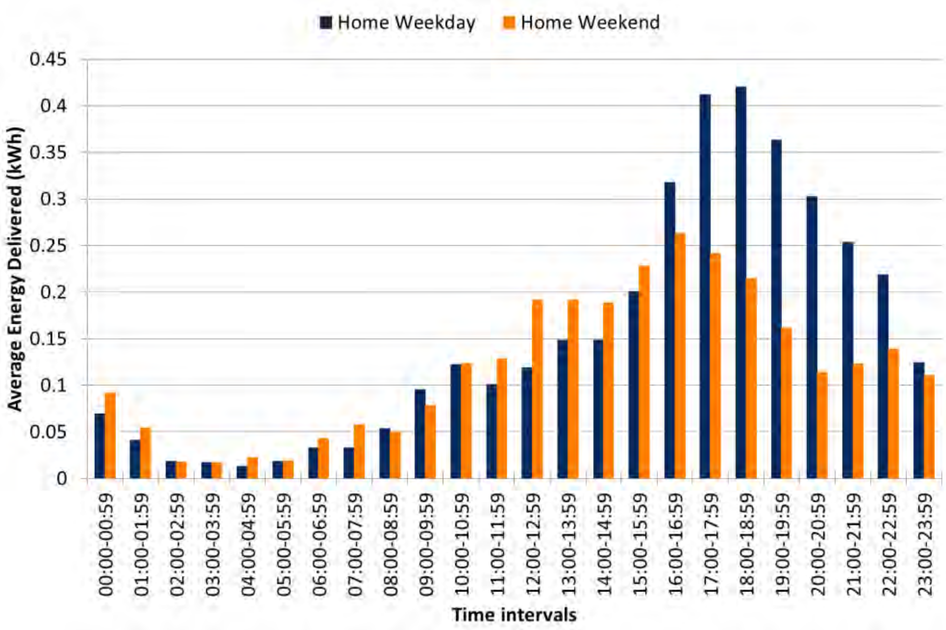


Figure 103: Average energy delivered per participant per day for home charge events in the BEV control group.

Charging away from home

A total of 780 charge events away from home were recorded in the PHEV Charging Trial. In the control group, there were 168 weekday charges and 27 weekend charges away from home. The total amount of energy delivered to control group vehicles across home and away charge events amounted to 8842kWh, with away charging accounting for 599kWh of this (approx. 7%).

Figure 104 shows the distribution of charge start times at home and away from home on weekdays. The pattern of charges away from home for Control group participants shows an upward trend in the early morning between 06:00 and 10:00.

[38] As described in section B.4.1.1, this calculation assumed a consistent charging rate over the duration of each charge event.

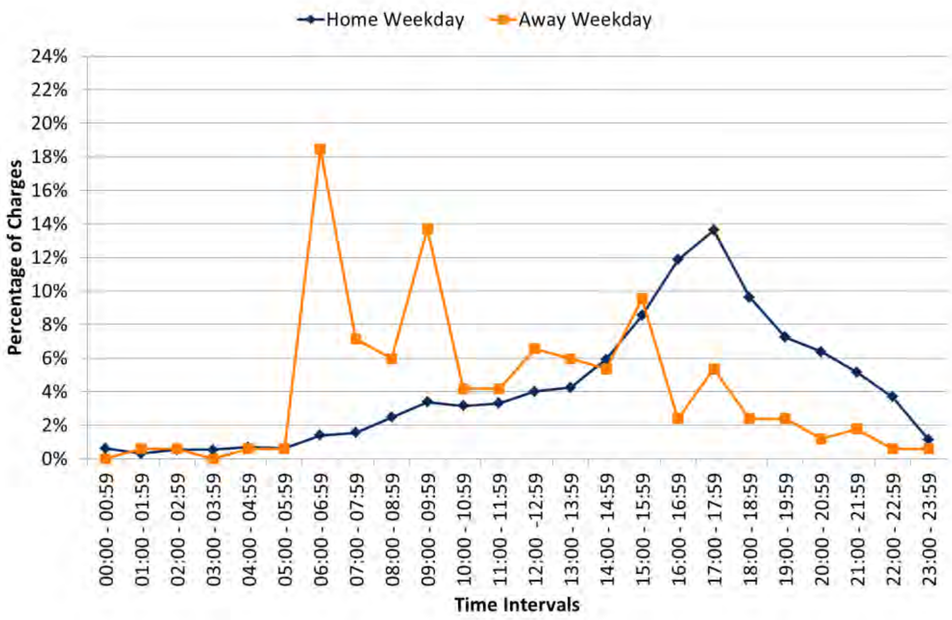


Figure 104: Proportion of weekday charge events at home and away from home by charge start time for Control group PHEV participants (N = 1,299 for home, N = 168 for away)

Figure 105 shows the distribution of charge start times at home and away from home on weekends. Most of the charges away from home happened around midday – although these patterns should be interpreted with caution since the number of away from home charges on weekends was small.

The greater variability in charging profiles on weekends compared with weekdays is consistent with activity patterns at the weekend differing from those on a typical weekday.

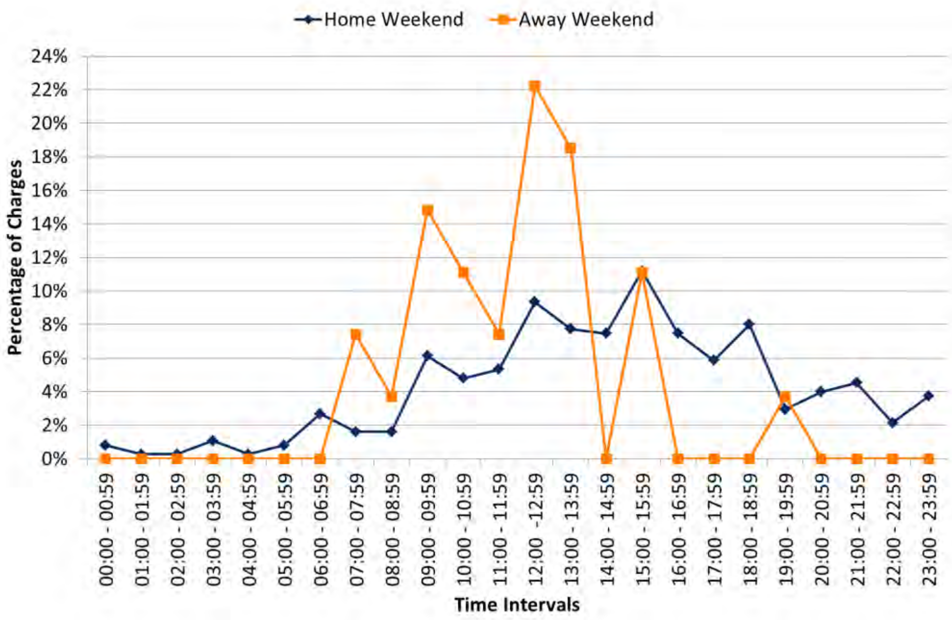


Figure 105: Proportion of weekend charge events at home and away from home by charge start time for Control group PHEV participants (N = 371 for home, N = 27 for away)

Figure 106 shows the percentage of participants who reported (in the TP2 questionnaire) that they had access to a chargepoint at various locations away from home. The most commonly reported place where a chargepoint was available was at motorway service areas, followed by supermarkets and fee-charging car parks. Around a third of the PHEV participants reported that they had access to a chargepoint at work.

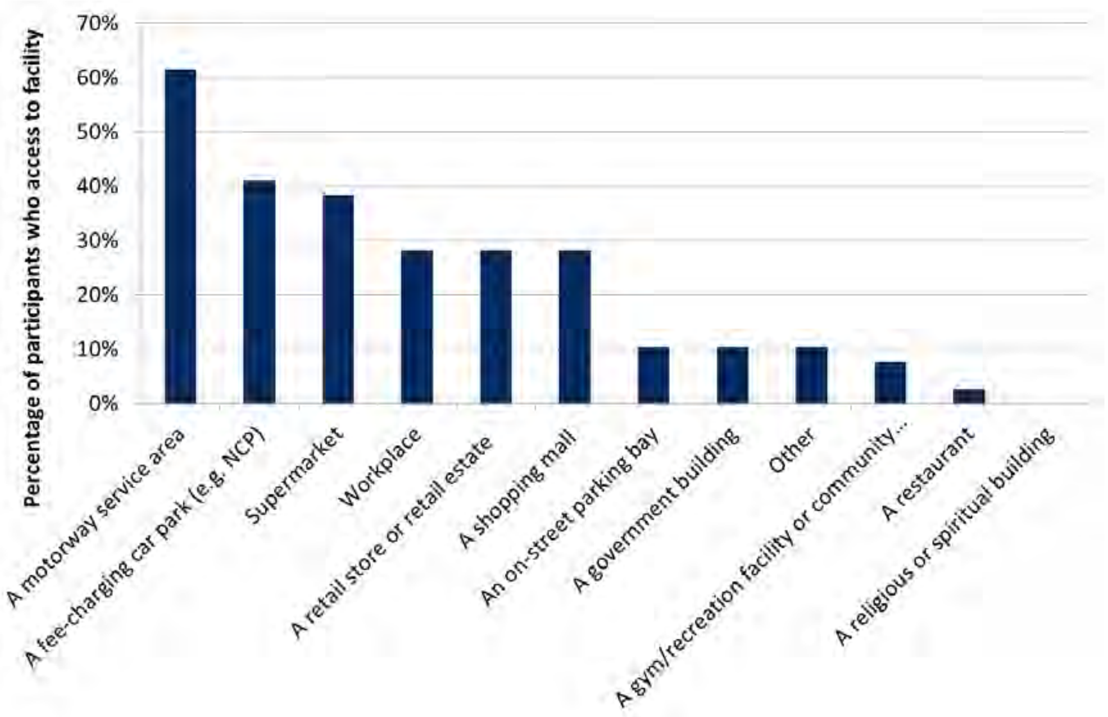


Figure 106: Proportion of control group PHEV participants who reported they had access to public chargepoints (N = 121)

Figure 107 shows the self-reported frequency at which PHEV participants charged at various locations away from home. Despite the highest share of participants stating they had access to public charging at motorway service areas, no participants reported undertaking a charge at this location. Instead, the most common place where participants reported actually using public chargepoints was at their place of work or education, followed by supermarkets and shopping malls.

Figure 107: Regularity of Control group participants charging away from home (N = 121)

B.5.1.2 *How does the charging behaviour of mainstream consumers when participating in an unmanaged charging scheme compare with when participating in a Supplier-Managed or User-Managed Charging scheme?*

→ **Home plug-in times were not strongly influenced by participation in managed charging schemes; there was a slight shift to later in the evening for MC groups.**

→ **Home charge start times were substantially influenced by participation in a managed charging scheme.**

→ **The UMC scheme shifted home charge start times to later in the evening relative to the Control group (6pm-11pm); this shift was in line with the Low tariff period.**

→ **The SMC scheme shifted home charge start times into the overnight period (1am-6am); charging started later than the BEV SMC charges, since the smaller batteries in the PHEVs required less charging time to reach 100% SOC.**

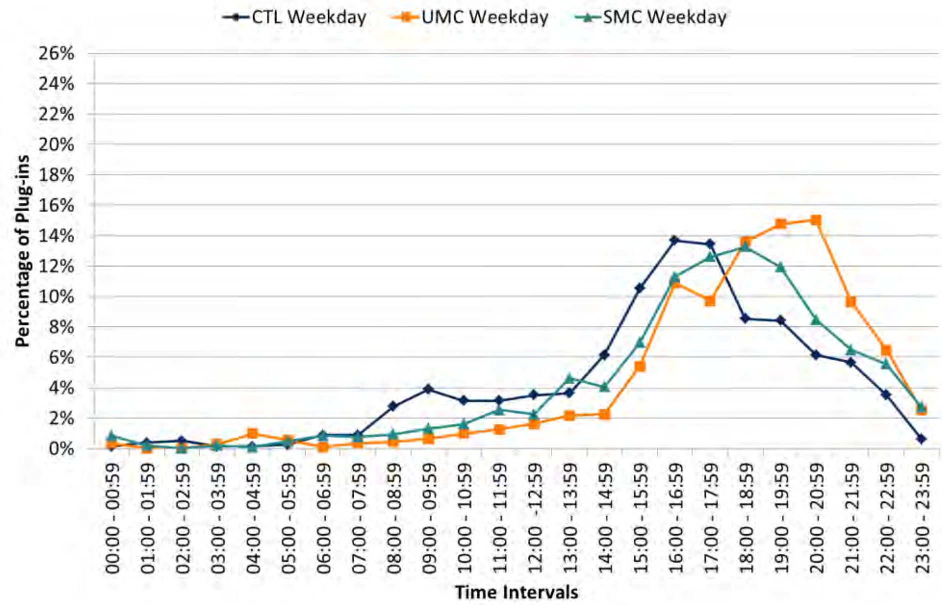
This section combines together the results to the following two research questions:

- How does the charging behaviour of mainstream consumers when participating in a managed charging scheme compare with their behaviour when they are not?
- How does the charging behaviour of mainstream consumers when participating in a Supplier-Managed Charging scheme compare with their behaviour when participating in a User-Managed Charging scheme?

The focus of this analysis was to understand the charging behaviours of PHEV participants in the Control group compared with those in the UMC and SMC groups. The analysis used data from vehicle telematics and the CPMS.

Charging at home

Figure 108 shows the plug-in times of weekday and weekend home charge events for Control, SMC and UMC participants.



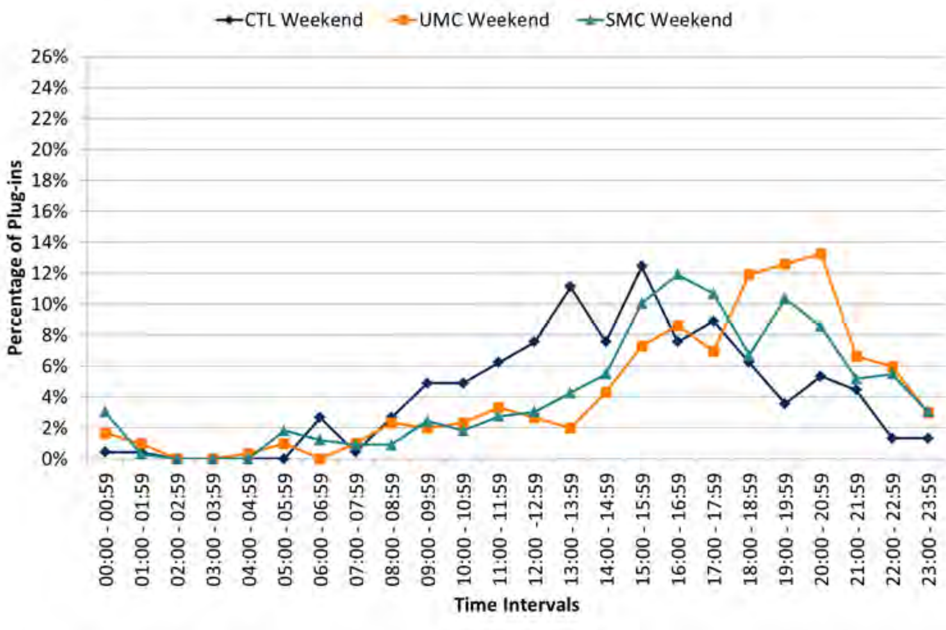


Figure 108: Proportion of home charge events by plug-in time for Control, UMC and SMC PHEV participants (N = 3,826) (Top – Weekday, Bottom – Weekend)

There was a significant difference in the distribution of weekday plug-in times between the SMC and UMC groups ($\chi^2 = 39.81$, $p < 0.001$), between the SMC and Control groups ($\chi^2 = 42.65$, $p < 0.001$) and between the UMC and Control groups ($\chi^2 = 147.30$, $p < 0.001$). In the SMC group, there were fewer plug-ins during the evening period (64%), compared with the UMC group (74%), and more plug-ins during the morning and afternoon (8% and 18% compared with 4% and 11% respectively).

Figure 109 shows the charge start times of weekday and weekend home charge events for Control, SMC and UMC participants.

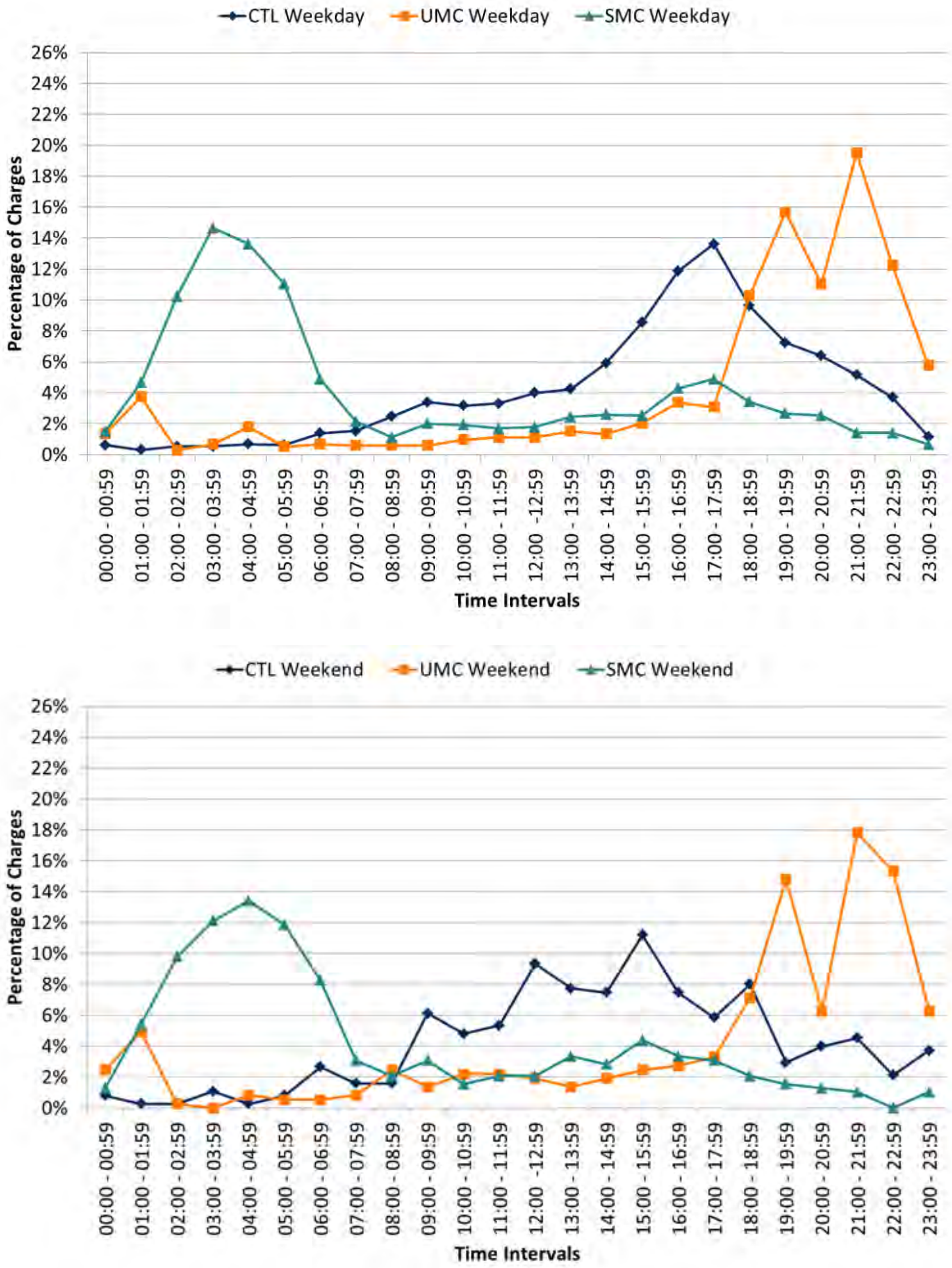


Figure 109: Proportion of home charge events by charge start time for Control, UMC and SMC PHEV participants (N = 5,110) (Top – Weekday, Bottom – Weekend)

There was a significant difference in the distribution of weekday charge start times between SMC and UMC groups (χ^2 = 541.62, p < 0.001), between the SMC and Control groups (Weekdays: χ^2 = 783.02, p < 0.001), and between the UMC and Control groups (Weekdays: χ^2 =340.06, p < 0.001). There were also significant differences between the groups for weekend charge events (SMC vs. UMC: χ^2 = 137.63, p < 0.001; SMC vs Control: χ^2 = 200.13, p < 0.001; UMC vs. Control: χ^2 = 143.45, p < 0.001).

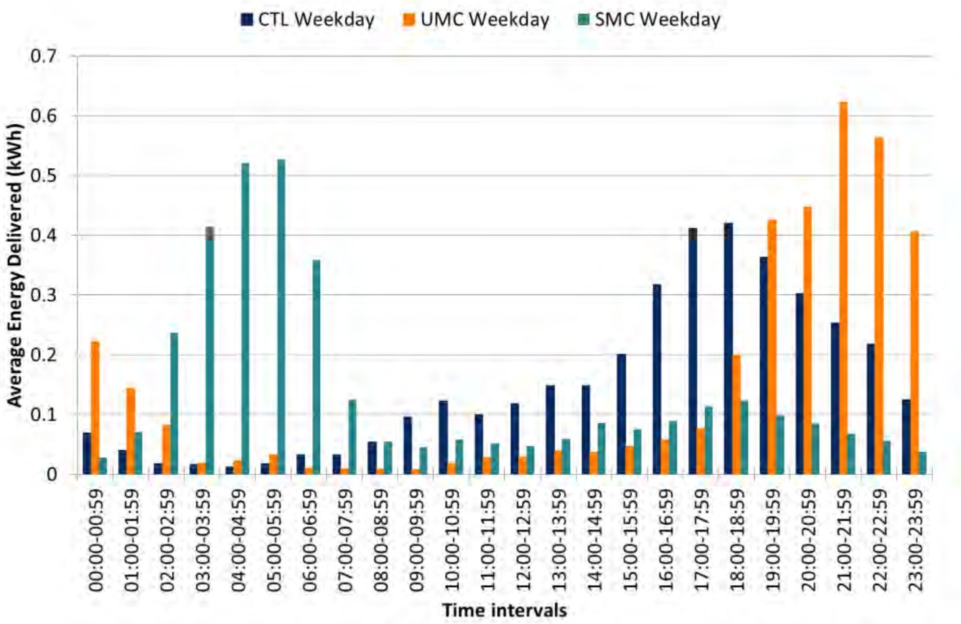
In the Control group, there was a peak in weekday charge events starting between 5pm and 6pm. In comparison, the majority of charge events in the UMC group were shifted to later in the evening, with a peak between 7pm and 8pm and against between 9pm and 10pm. For the SMC group, most of the charging events occurred in the overnight period, starting between 2am and 7am.

In addition, analysis showed significant differences in charging profiles between weekday and weekend charge events for both the UMC ($\chi^2 = 21.51$, $p < 0.001$) and SMC ($\chi^2 = 19.56$, $p < 0.001$) groups. In both cases, weekday charge events were less likely to start in the morning or afternoon and more likely to start in the evening, compared with weekend charge events.

As explained in section A.9, the charge start times in the SMC group were governed by the way the SMC system was configured for the purposes of the trial. There was a similar reduction in PHEV SMC charges starting during the late afternoon and early evening periods as was observed in the BEV Charging Trial (see section B.4.1.2). However, the peak in PHEV charges is more distinct in the overnight period (1am-6am) than was observed with BEVs. The PHEV could be fully charged at home in about 2-2.5 hours compared with about 10.5 hours for the BEV; this was due to the smaller battery capacity (8.7kWh vs. 35.8kWh of nominal capacity). Therefore, if participants, for example, set a Desired SOC of 100%, and a Departure Time in the early morning around 7am-8am (as is typical for commuters) then the system will have started the charge around three to four hours before that. The charging profiles in a real-world SMC scheme may be more spread out then those observed in this trial (see section B.4.1.2); even so, the data from this trial shows that SMC can be an effective means of shifting charging demand into the overnight period.

Figure 110 shows the average energy delivered per hour of the day per participant for each experimental group.

These data support the patterns seen in the profile of charge start times, with the two managed charging schemes shifting peak energy demand to later in the evening (in the UMC group) and into the overnight/early morning period (in the SMC group). It should be noted, as described above, that this calculation assumed a consistent charging rate over the duration of each charge event. Peaks can be seen for both the UMC and SMC cases, however, the SMC peak can be flattened in the real-world with a more sophisticated algorithm than the one used in the trial (as discussed above).



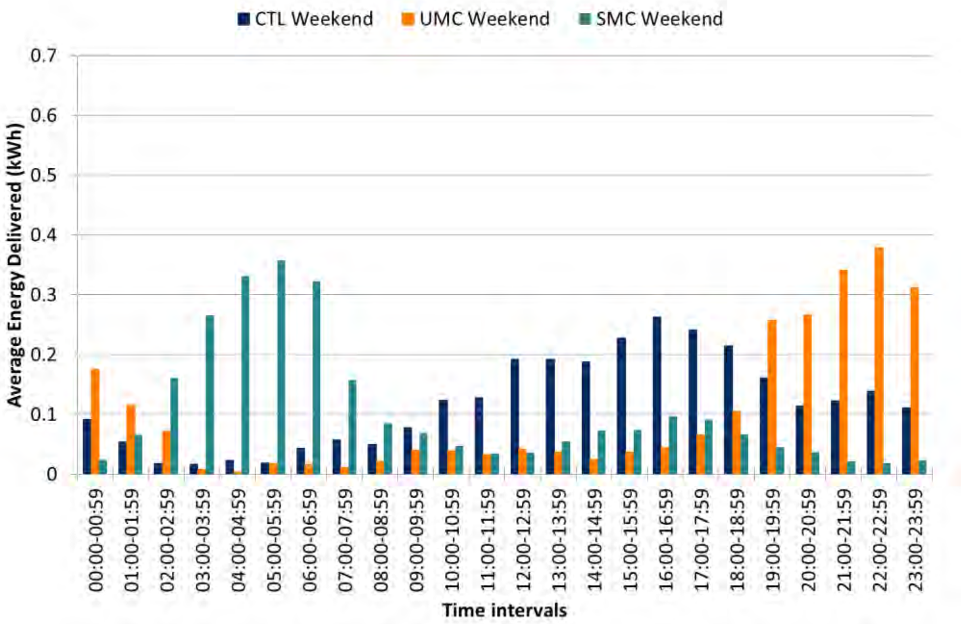


Figure 110: Average energy delivered per participant per hour of the day for Control, UMC and SMC PHEV participants (N = 3,822) (Top – Weekday, Bottom – Weekend)

Charging away from home

The managed charging schemes experienced by participants in the trial only applied to charge events at home; however, it may be hypothesised that experience with managed charging at home could also impact behaviours when charging away from home. As such, this section compares the charging behaviours away from home between participants in the Control group and participants in the managed charging groups. When considering the results of this analysis it is important to note that the sample of away from home charge events (N = 780) was considerably smaller than that for home charge events (N = 5,026).

Figure 111 shows the proportion of away from home charge events by charge start times for the Control group and the SMC and UMC groups. A high proportion of events across all three groups occurred in the morning period (6am-10am).

There was a significant difference in the distribution of weekday charging profiles away from home between SMC and UMC ($\chi^2 = 28.55$, $p < 0.001$) and between SMC and Control ($\chi^2 = 8.04$, $p = 0.045$). There was also a significant difference between SMC and Control charge events on weekends ($\chi^2 = 14.17$, $p = 0.003$). SMC events were more likely to start during the evening or overnight (31% compared with 13% of UMC charge events) and less likely to start during the morning or afternoon.

In addition, there was also a significant difference in charging profiles between weekday and weekend charge events in the SMC group ($\chi^2 = 10.59$, $p = 0.014$). Weekday charge events were more likely to start during the morning, and less likely to start during other periods of the day, compared with weekend charges. There was some evidence of a similar difference in charging profiles between events in the UMC group, but this was not significant at the 5% level ($\chi^2 = 7.71$, $p = 0.052$).

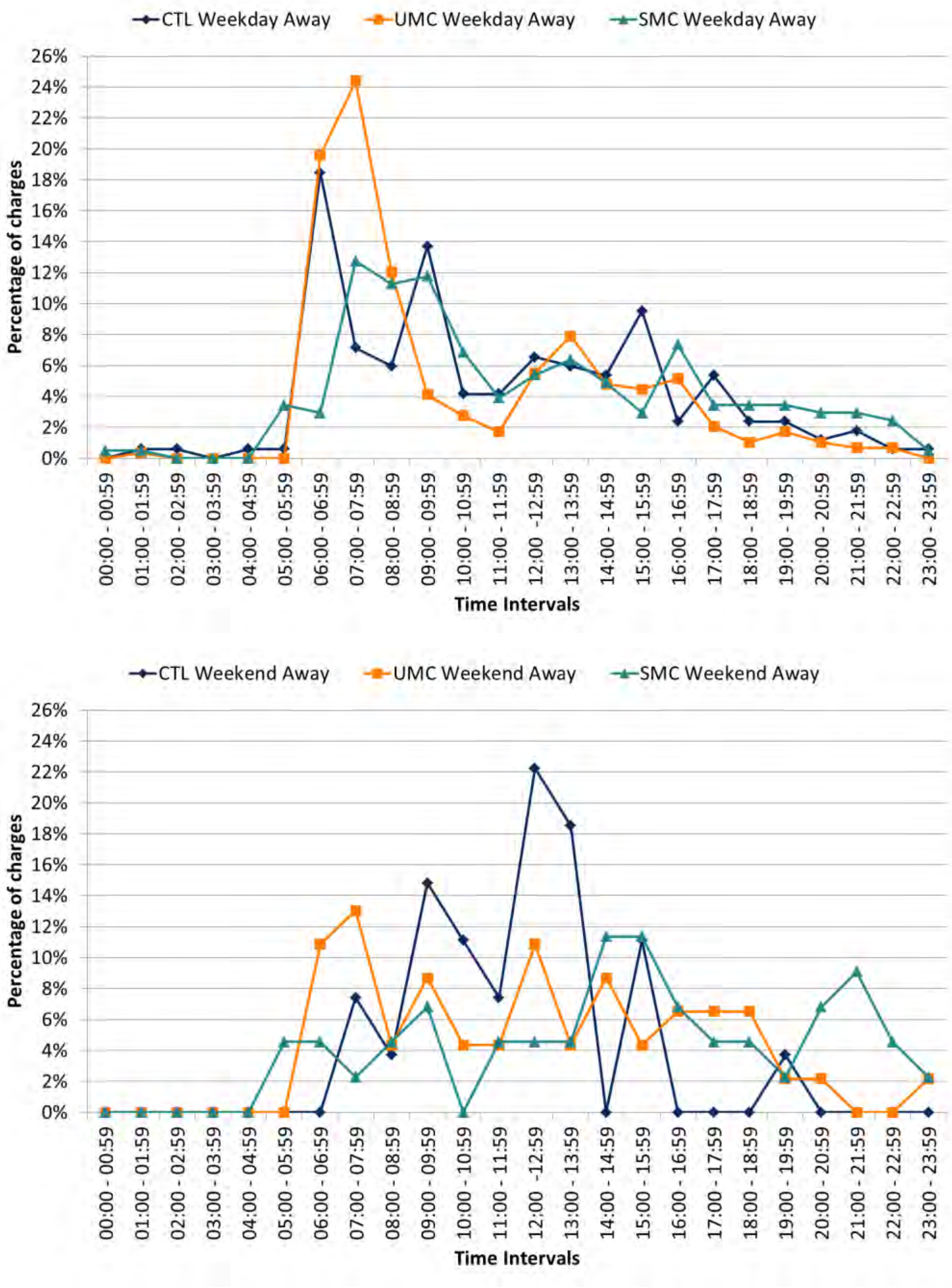


Figure 111: Proportion of away from home charge events by charge start time for Control, UMC and SMC PHEV participants (N = 780)

B.5.1.3 *What are the diurnal, weekly and seasonal time profiles of charging when participating (or not) in a given managed charging scheme?*

- → **Home plug-in times on weekdays were slightly delayed for SMC-Winter as compared to SMC-Summer. Despite this, the charge start times for both groups occurred early in the morning.**
- → **Home plug-in times on weekdays for UMC-Summer and UMC-Winter participants followed similar patterns with majority of plug-ins occurring between 4pm-11pm. UMC-Summer charge start times are more spread out across the Low tariff period, while UMC-Winter participants see spikes between 7pm-8pm and 9pm-10pm.**
- → **Over three quarters of all UMC charging events started in the Low tariff band.**

The focus of this analysis was to understand how the charging behaviours of PHEV participants varied between the Summer and Winter sub-groups of UMC and SMC, and between the real-world seasons experienced by participants in the trial (approximately winter, spring and summer). Analysis of the diurnal and weekly variation in PHEV charging profiles is provided in sections B.5.1.2 and B.5.1.5, respectively. The analysis used data from vehicle telematics and the CPMS.

Comparisons between Summer and Winter sub-groups

This analysis compares the charging behaviours of participants assigned to the SMC-Summer, SMC-Winter, UMC-Summer, UMC-Winter and Control charging groups. Home and away from home charges have been analysed separately.

UMC-Summer and UMC-Winter

The proportion of UMC charge events starting in each of the tariff bands is shown for weekend and weekday events in Table 48. There was a significant difference between charge start times in different bands on weekdays ($\chi^2 = 40.328$, $p < 0.001$) and on weekends ($\chi^2 = 16.049$, $p = 0.001$). UMC-Winter participants charged more frequently in the Low tariff band on both weekdays and weekends, compared with UMC-Summer participants.

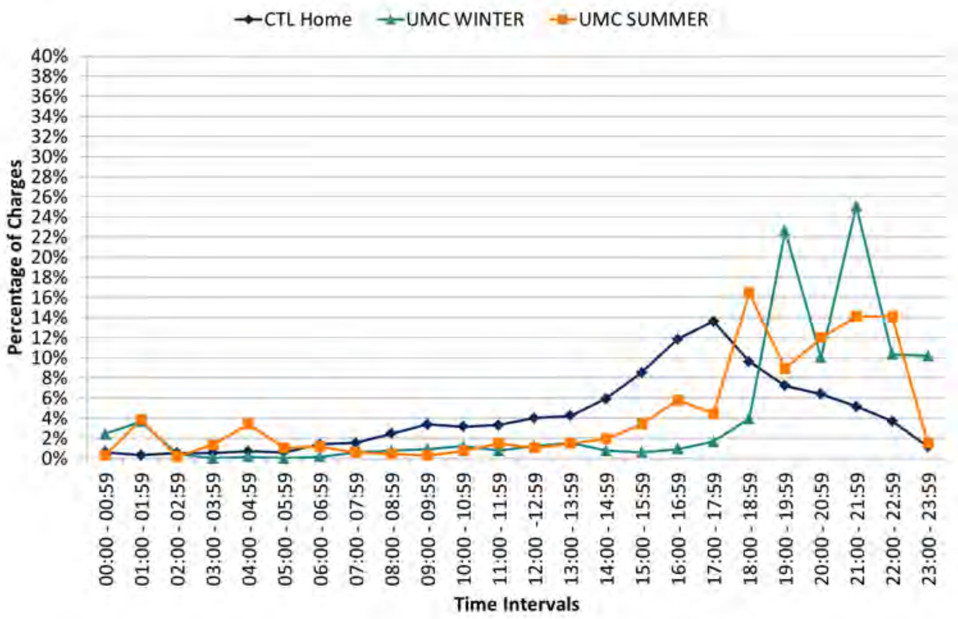
Table 48: PHEV charge start times for home charges on weekdays by tariff band

	Weekdays		Weekends	
Tariff Band	**UMC-SUMMER**	**UMC-WINTER**	**UMC-SUMMER**	**UMC-WINTER**
Low	72.70%	84.95%	59.09%	81.15%
Standard	6.68%	2.43%	9.09%	4.19%
Medium	5.04%	5.47%	12.63%	9.95%
High	15.58%	7.14%	19.19%	4.71%

In all cases the majority of charge events started in the Low tariff band; showing a good level of engagement with the managed charging scheme. The proportion of UMC-Summer events starting in the Low tariff period was greater than the proportion for UMC-Winter participants.

This difference is larger still at weekends. There were also more charge events starting in the High tariff band for UMC-Summer participants compared with UMC-Winter participants.

Figure 112 shows the proportion of home charge events by charge start time for Control, UMC-Summer and UMC-Winter groups.



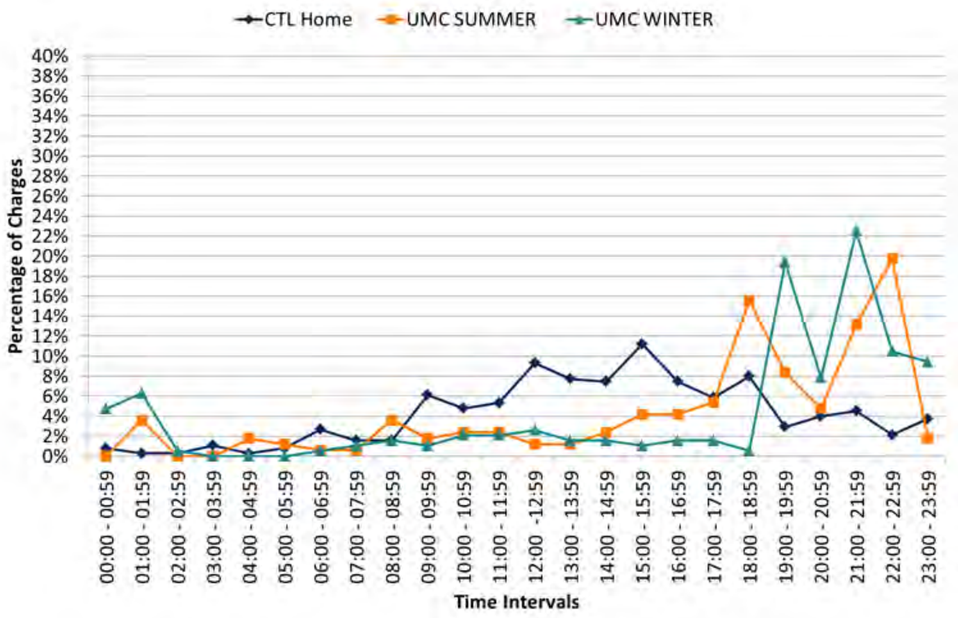


Figure 112: Proportion of home charge events by charge start time for Control, UMC-Summer and UMC-Winter PHEV participants (N = 3,364) (Top – Weekday, Bottom – Weekend)

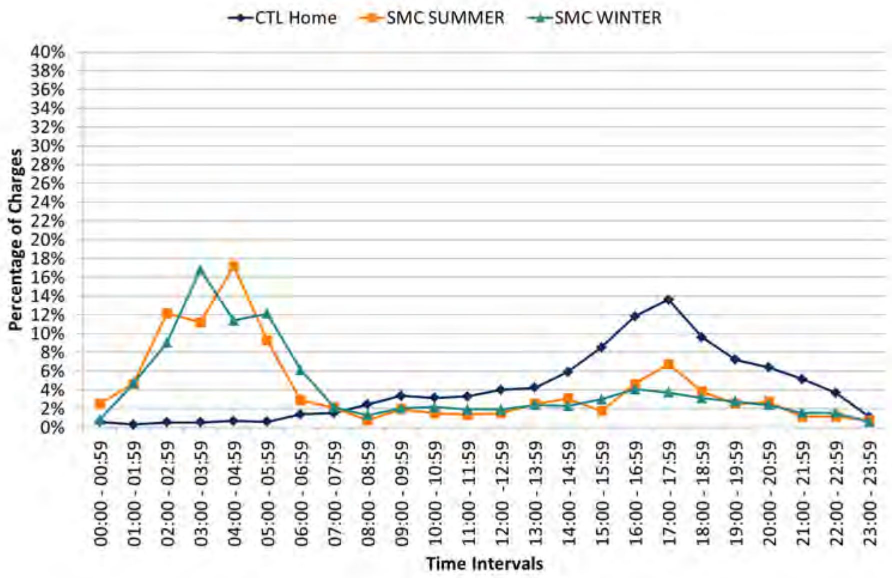
Both on weekdays and weekends, it can be seen that the peaks in charge start times are broadly in line with the start of the Low tariff band; 7pm for UMC-Winter participants and 6pm for UMC-Summer participants. There was a significant difference in charge start times between the UMC-Summer and UMC-Winter groups on weekdays (χ^2 = 8.57, p = 0.036) and on weekends (χ^2 = 9.55, p = 0.023).

SMC-Summer and SMC-Winter

There was a significant difference in plug-in times between the SMC-Summer and SMC-Winter groups on weekdays ($\chi^2 = 24.61$, $p < 0.001$) and weekends ($\chi^2 = 9.45$, $p = 0.024$). For SMC-Summer charge events, participants were less likely to plug in their vehicle overnight (10pm-6am – 5% compared with 15% of SMC-Winter charge events), and more likely to plug in during the daytime. One possible explanation may be increased use of the vehicle during the day and early evening in summer compared with winter; this is supported by the journey data. Most of the time, participants in all groups tended to plug in their vehicles in the evening, but charges usually start early in the morning, in order to follow the settings set by the participants and to maximise Savings Points.

Figure 113 shows the distribution of the charge start times between SMC-Summer, SMC-Winter and Control participants.

SMC charges occurred mostly in the overnight period. Statistical analysis revealed that there was a significant difference in the distribution of SMC-Summer and SMC-Winter charge start times on weekdays ($\chi^2 = 9.06$, $p = 0.029$). SMC-Summer charge events were more likely to start during the evening or overnight (81% compared with 75% of SMC-Winter events), and less likely to start during the morning or afternoon.



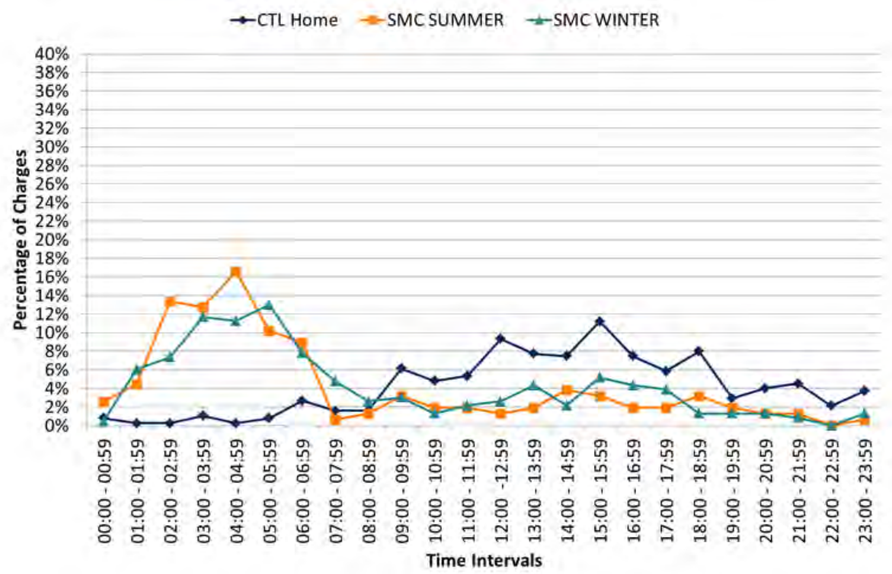


Figure 113: Proportion of home charge events by charge start time for Control, SMC-Summer and SMC-Winter PHEV participants (N = 3,413) (Top – Weekday, Bottom – Weekend)

Comparisons between real-world seasons experienced in the trial

In order to gain a deeper understanding of PHEV charging patterns, participants' behaviours through the seasons was also analysed. All charge events from November through to February have been classified as winter events, events in March, April and May have been classified as spring events and events occurring from June through till the end of the trial (mid-September) have been classified as summer.

Figure 114 shows the average number of charging events per participant by season. From this graph, we can see that participants tended to charge slightly more often in Spring than the other seasons.

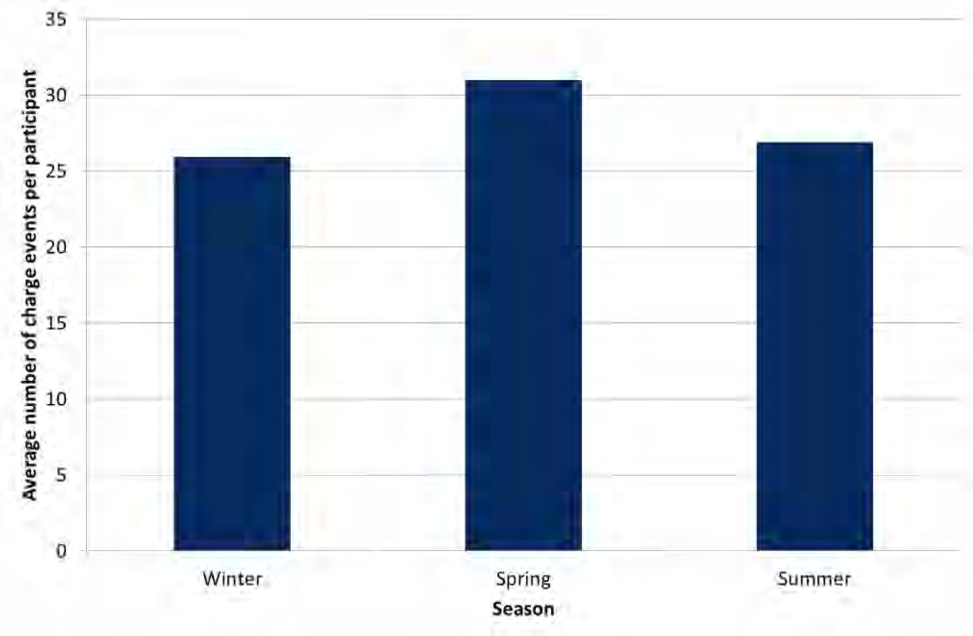


Figure 114: Average number of charging events per participant by season

B.5.1.4 *What are the between-participant variabilities in mainstream consumer charging behaviour when participating (or not) in a given managed charging scheme?*

- → **Participants in the UMC and SMC groups consistently plugged in their vehicle at home during the early-mid evening part of the day. There was slightly more variability between participants in the Control group than the managed charging groups.**
- → **There was little difference in PHEV charge start time variability between the three trial groups.**
- → **PHEV SOC at plug-in was most commonly between 10-25%; variability was greater in the UMC group.**
- → **The vast majority of PHEV charges at home resulted in the vehicle being fully charged.**
- → **Plug-out times of home charges were most consistent between participants in the UMC-Winter and SMC-Summer groups. Across the UMC and SMC groups, participants consistently unplugged their vehicle during mid-late morning.**

The focus of this analysis was to understand how the level of between-participant charging behaviours within each experimental group. The analysis used data from vehicle telematics and the CPMS.

For the purposes of this analysis, per-participant median values were calculated for the following charging metrics: plug-in time, charge start time, SOC at plug-in and plug-out, charge stop time and plug-out time. For example, the median plug-in time for each participant was calculated, averaging across all charge events undertaken by a given participant, and thus removing any within-participant variability from the metrics. In the case of charge and plug-in/out times, medians were calculated for each one-day period from midday-midday, as the vast majority of home charges started in the evening or overnight.

To understand *between*-participant variability, these per-participant values have been presented using boxplots. The boxplots are shown for each experimental group to illustrate the distribution of charging data across the participant sample. Within each boxplot, the solid line in the middle of the box represents the median value, and the upper and lower edges of the box represent the upper and lower quartiles, respectively.

Plug-in and charge start times

Figure 115 presents the distribution of median home plug-in times for each group. All of the experimental groups had similar inter-quartile ranges; this suggests that differences in charging profiles observed between the groups were due to a shift in charging behaviour, rather than an increase in variability in charging.

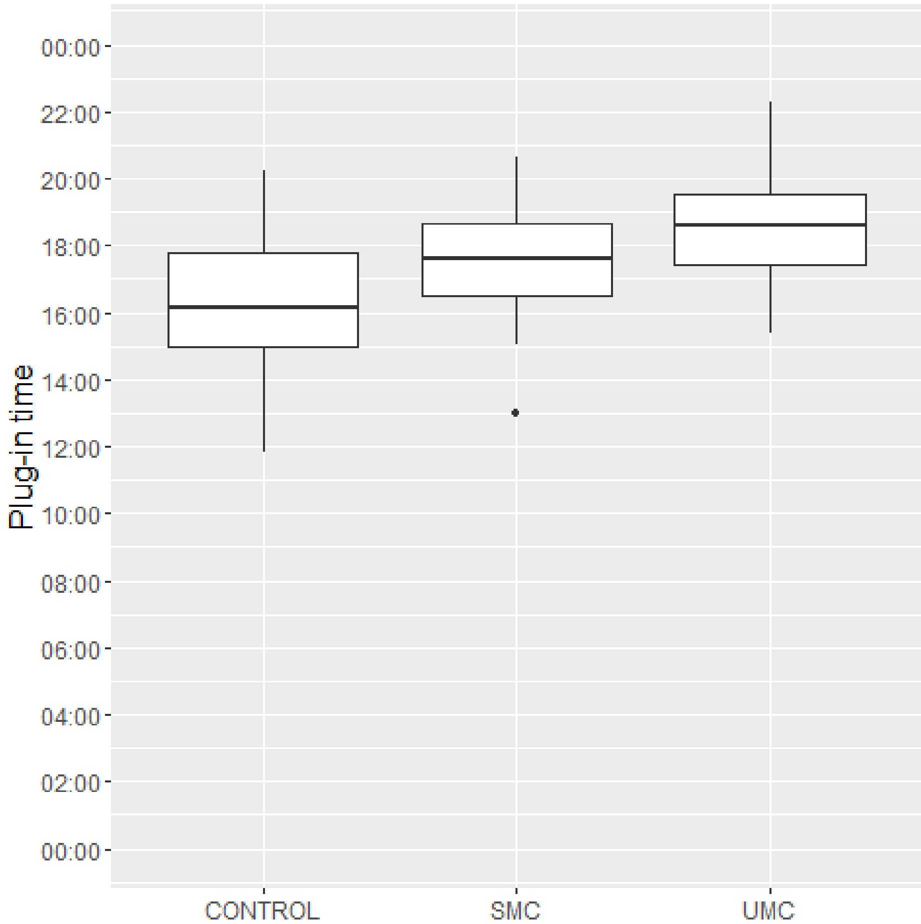


Figure 115: Boxplot showing median and IQR home plug-in times among PHEV participants in each trial group (N = 121)

Figure 116 presents the distribution of median charge start times for home charges in each trial group. Whilst the median charge start times vary between groups, the results show a similar level of variability among participants in the three different groups.

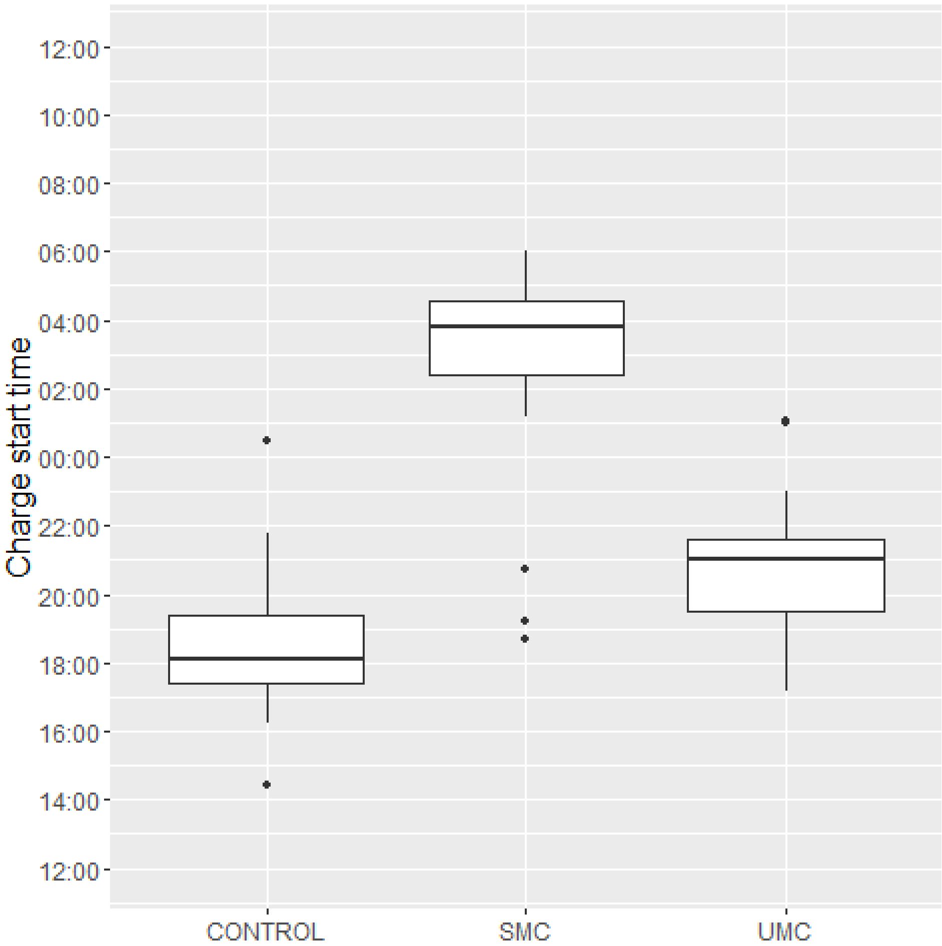


Figure 116: Boxplot showing median and IQR home charge start times among PHEV participants in each trial group (N = 121)

SOC at plug-in and plug-out

Figure 117 presents the distribution of median SOC at plug-in for each trial group. The results show that there was a greater level of variability between participants in the UMC trial group compared with those in the SMC and Control groups; reasons for this are unclear. Participants in all groups generally plugged in their vehicle with an SOC between 10% and 25%. This is in contrast to the BEV Charging Trial where almost no charge events began with an SOC less than 20% (see section B.4.1.4). This suggests that PHEV drivers were more likely to run their battery down than BEV drivers; possibly due to a combination of the smaller battery capacity and the ability to fall back on petrol power if SOC reached 0%.

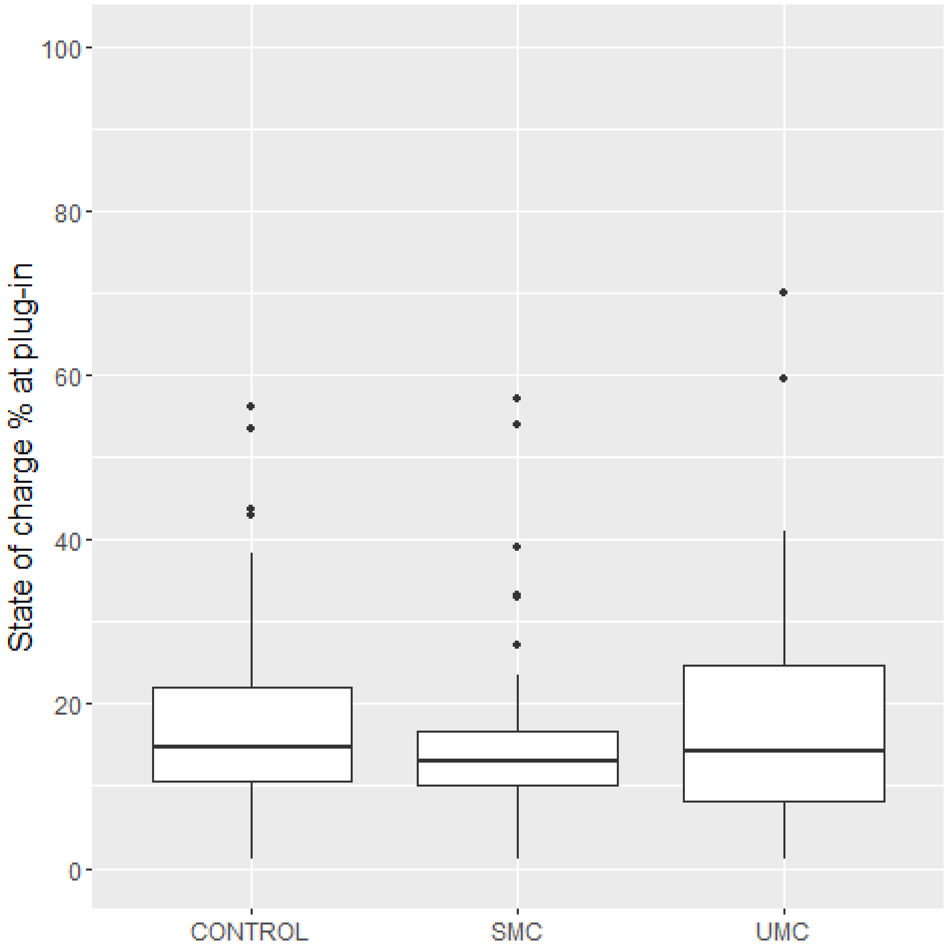


Figure 117: Boxplot showing median and IQR SOC at plug-in time of home charges among PHEV participants in each trial group (N = 121)

Figure 118 presents the distribution of median SOC at plug-out for each trial group. The results show that, for all groups, the median state of charge (99%) was equal to both the upper and lower quartiles; hence the boxplots do not contain a box. These results show that almost all participants routinely charged to 100% SOC, irrespective of the group they were in.

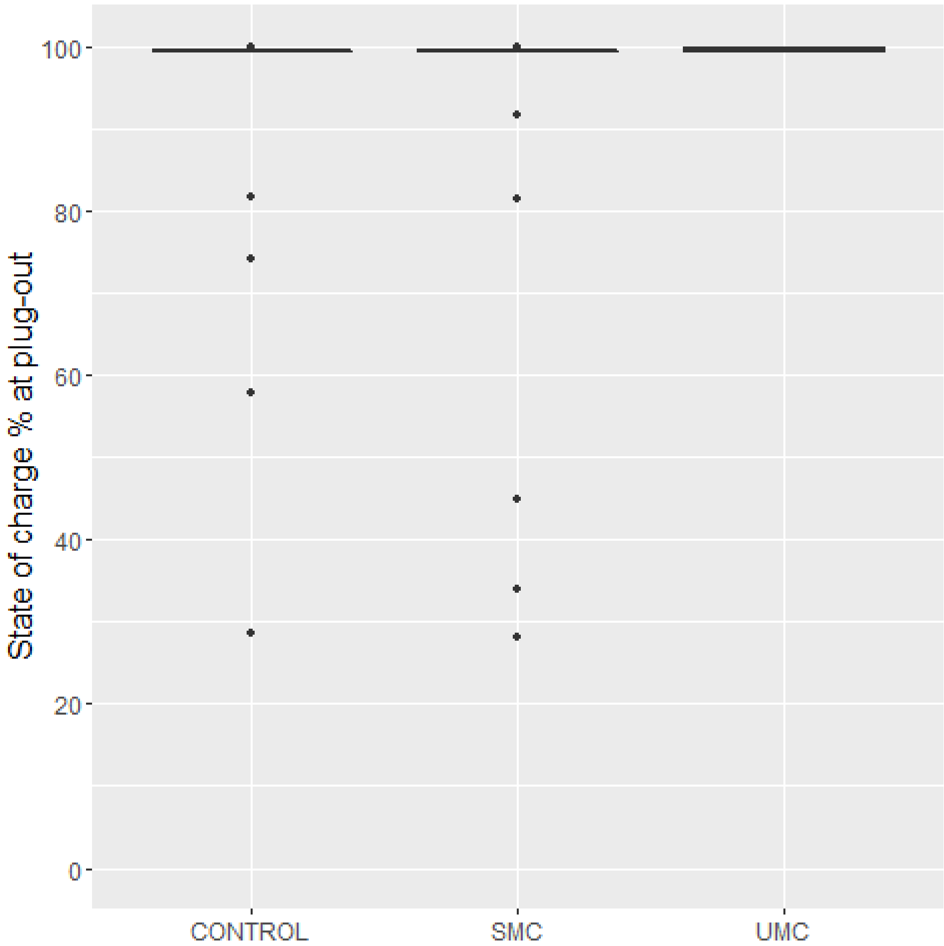


Figure 118: Boxplot showing median and IQR SOC at plug-out time of home charges among PHEV participants in each trial group (N = 121)

Figure 119 presents the distribution of median SOC at plug-in for each trial group for charges that occurred away from home. It can be seen that there was a greater level of variability for the SMC and UMC groups. Most charges started when the SOC was below 20%, indicating that PHEV drivers had used most of their charge at the point of plugging in, as was observed for home charges; this appeared to be broadly consistent between control, UMC and SMC groups.

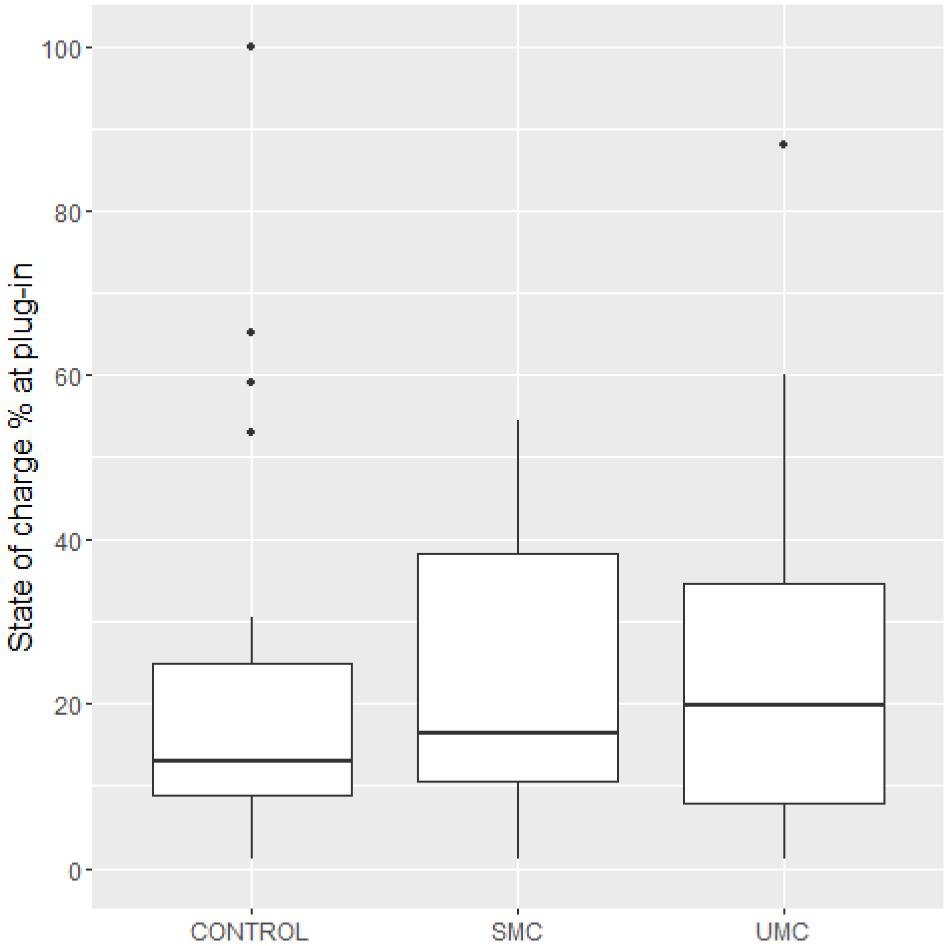


Figure 119: Boxplot showing median and IQR SOC at charge start for away charges among PHEV participants in each trial group (N = 70)

Figure 120 shows the distribution of median SOC added for each trial group for charges that occurred away from home. There was a high level of variability here; managed charging participants typically added over 50% SOC during away charges, compared with 30% in the control group. This can be correlated with Figure 121 which shows the distribution of median energy delivered during charging for away charge events across all participants. The VW Golf GTE had a 8.7 kWh nominal capacity; the median kWh added to the battery during away from home charges was about 3 kWh in the control group, 6 kWh in the SMC group, and 5 kWh in the UMC group. The size of the sample is small, so these results should be treated as indicative only.

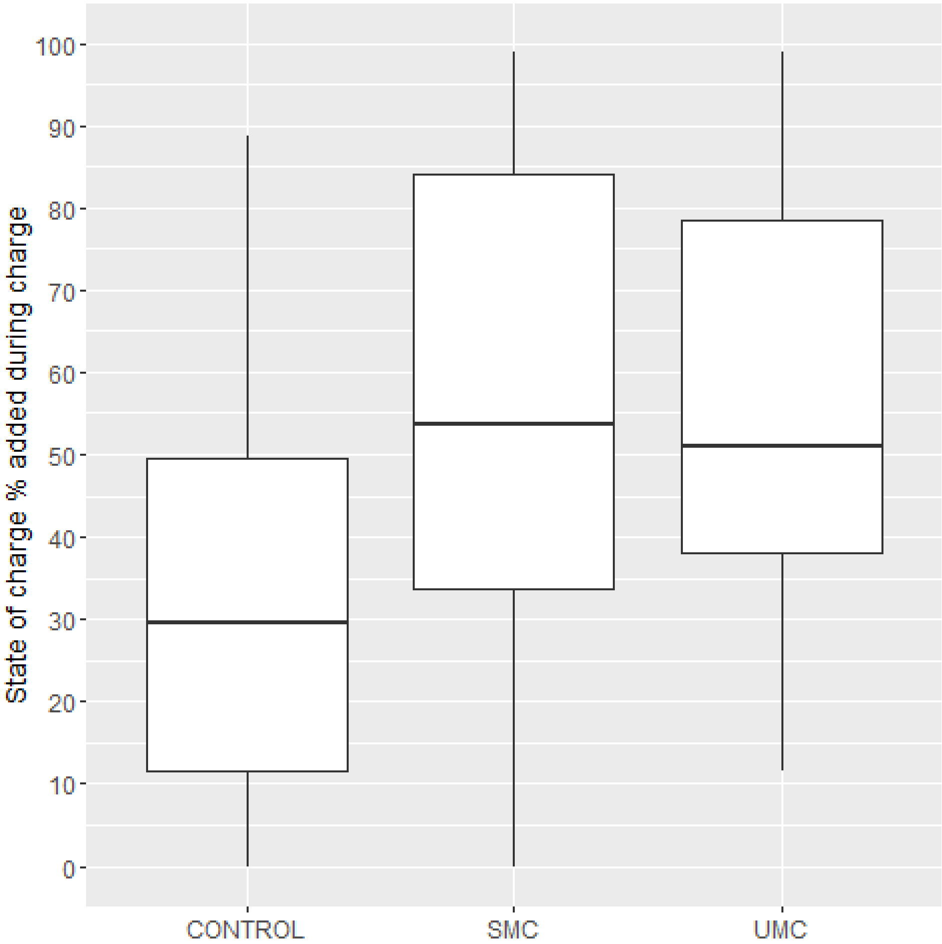


Figure 120: Boxplot showing median and IQR SOC added for away charges among PHEV participants in each trial group (N = 70)

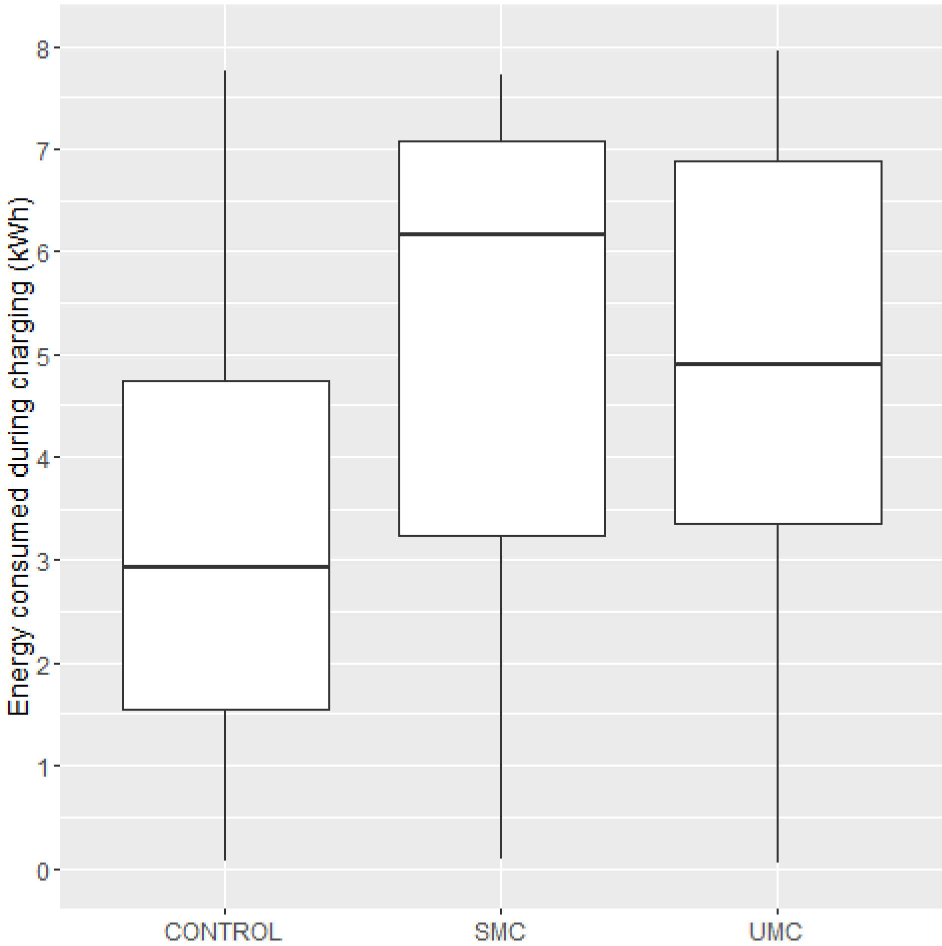


Figure 121: Boxplot showing median and IQR energy delivered during charging for away charges among PHEV participants in each trial group (N = 70)

Plug-out and charge stop times

Figure 122 presents the distribution of median charge stop times for each trial group. The results show a slightly greater level of variability among participants in the UMC trial group, compared with those in the other groups. In SMC, the charge stop times were likely less variable because of the configuration of the SMC scheme; charge stop times would have been set for one hour before the Departure Time (for scheduled charges). The majority of Departure Times requested by participants were between 5am and 9am; confirming this explanation of the more narrow distribution in charge stop times compared to UMC.

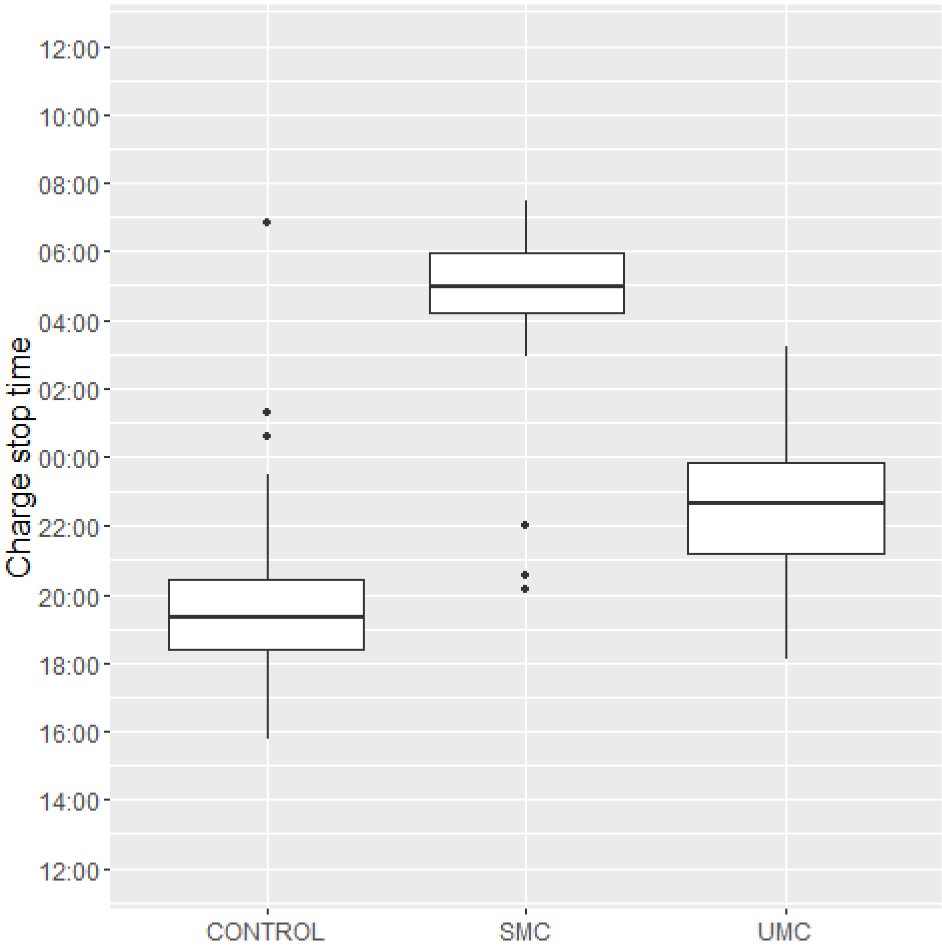


Figure 122: Boxplot showing median and IQR home end charge time among PHEV participants in each trial group (N = 121)

Figure 123 presents the distribution of median plug-out times for each trial group. The control group has vastly more within group variability than both of the managed charging scheme groups. Both of the UMC and SMC groups had very similar levels of variability.

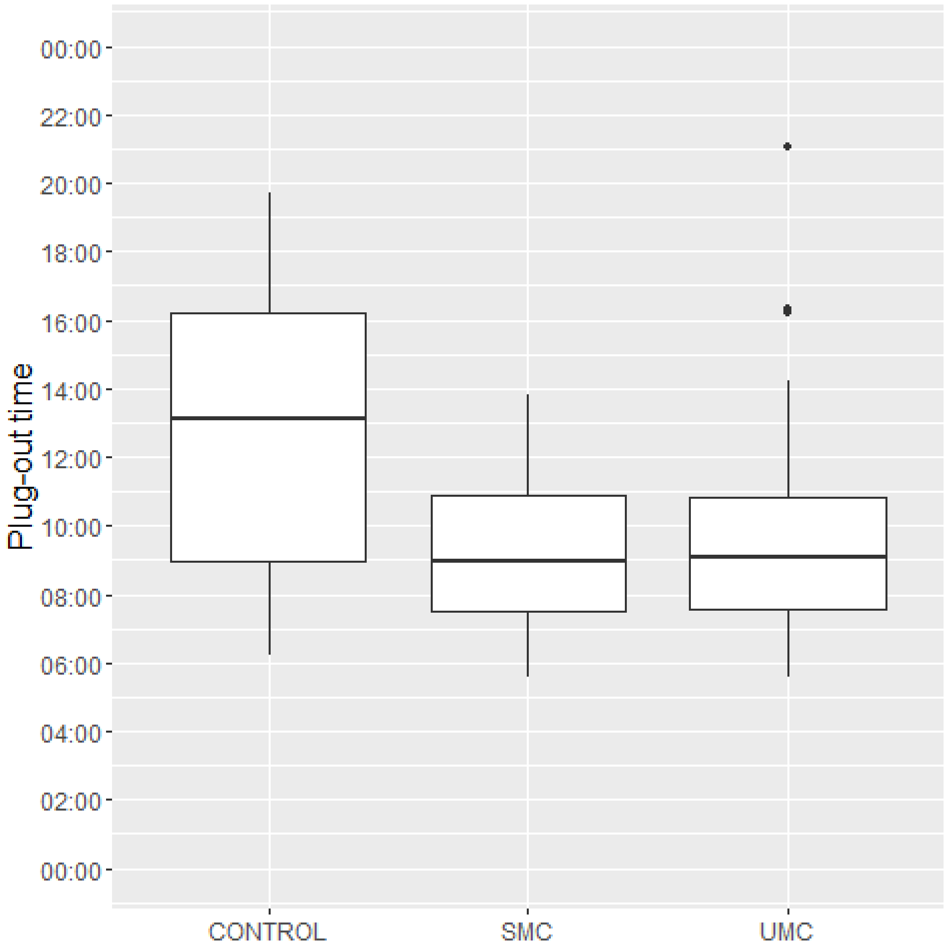


Figure 123: Boxplot showing median and IQR home plug-out times among PHEV participants in each trial group (N = 121)

B.5.1.5 *How does charging behaviour vary with time over the first eight weeks of using and charging a PiV, whether participating in a managed charging scheme or not?*

→ **There were no statistically significant differences in the average number of charges per participant per week across the 8 weeks of the trial period.**

Using data from vehicle telematics and the CPMS, this analysis investigated the extent to which charging behaviour varied between different weeks of the trial.

Figure 124 shows the average number of home charge events per participant for each week of the trial. The data shows that the frequency of charging was relatively stable across the eight weeks. However, there were also large standard deviations in the number of charges per participant per week; as such there were no statistically significant differences in the mean number of charges.

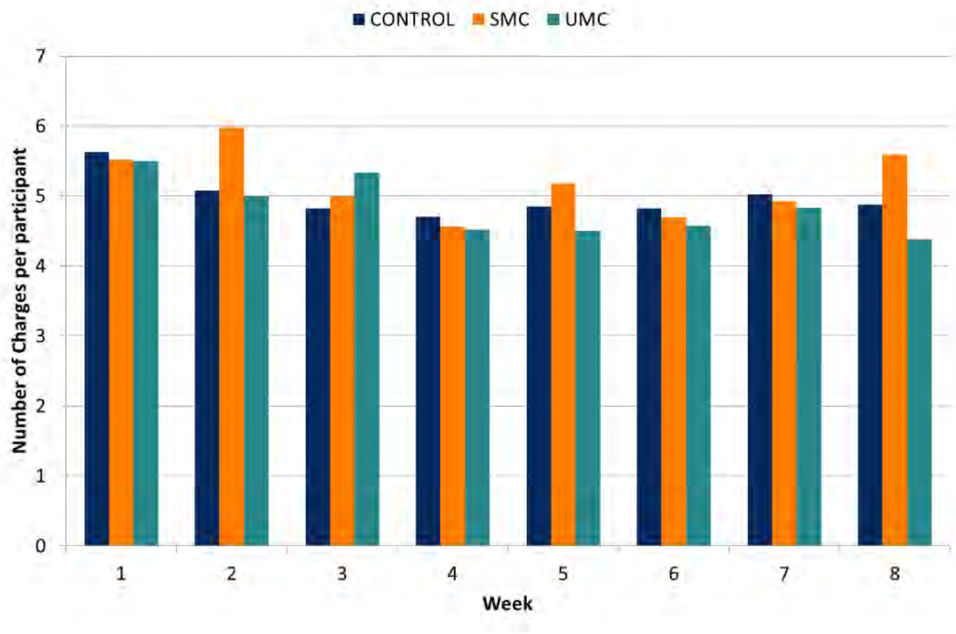


Figure 124: Average number of PHEV home charges per week per participant across all groups

Figure 125 shows the proportion of home charges by UMC/SMC driver input method, split across the 8 weeks of the trial. These data show a similar general trend to that seen in the BEV Charging Trial, with decreasing use of 'Charge Now' and setting a new schedules, and increasing use of the default settings. A similar trend is seen in the UMC and SMC groups. This suggests that PHEV drivers settled into their charging patterns as the trial progressed, making greater use of their default charge preferences and reducing the level of input needed on the app.

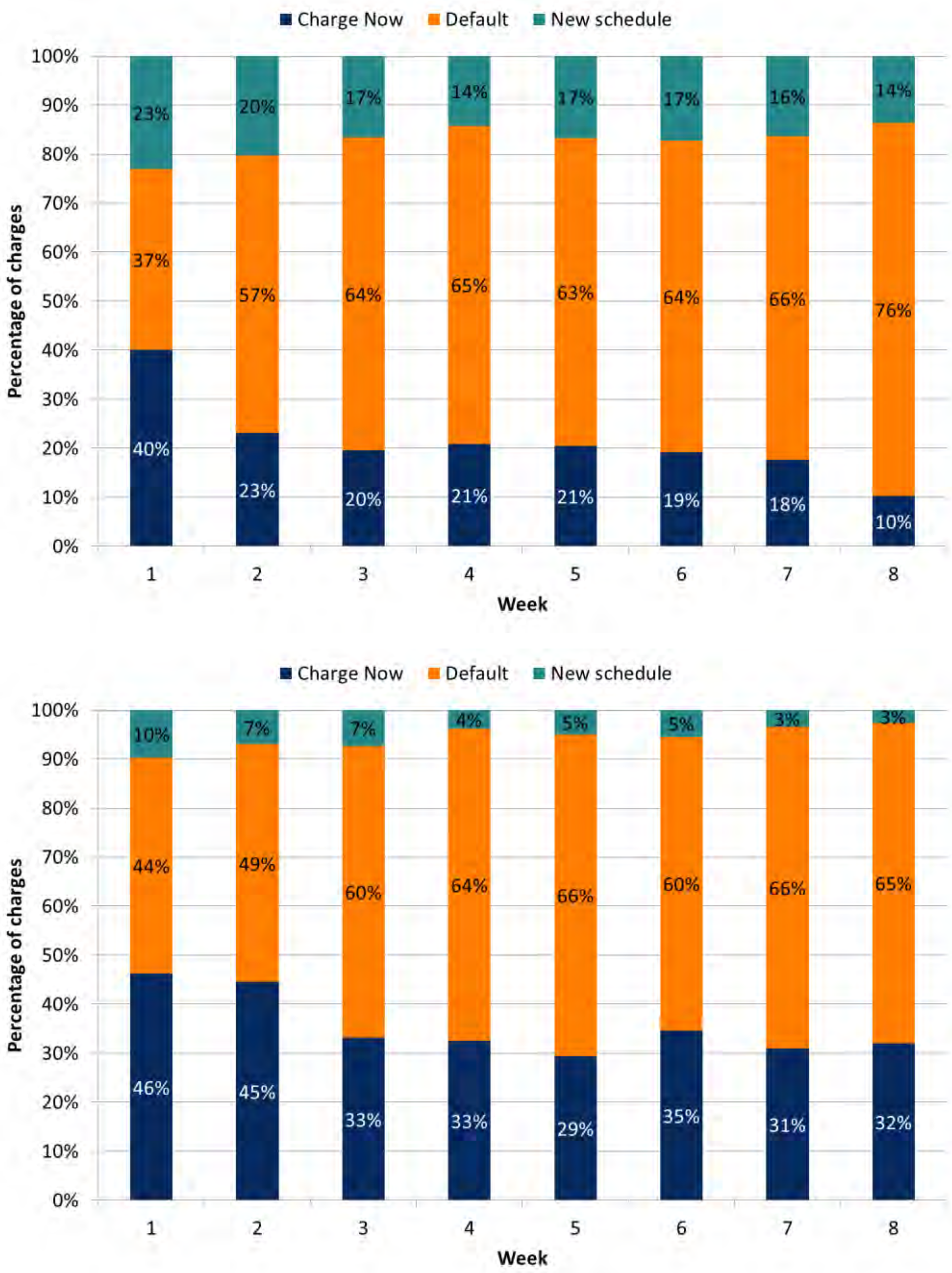


Figure 125: Proportion of charges by driver input method for each week in the trial (Top – SMC; Bottom – UMC)

In addition to the measures explored above, weekly differences in the SOC at plug-in and plug-out, and the amount of SOC added per charge, were also explored. However, no notable trends were established, suggesting that these metrics did not change over the course of the trial.

B.5.1.6 *How do mainstream consumers interact with specific features of User- and Supplier-Managed Charging?*

- **The average number of home charges per participant over the eight weeks was 32 in both groups.;**
- **There were significant differences between the SMC and UMC groups in how they interacted with the app:**
  - **Participants in the SMC group set a new charge schedule more frequently (17% of home charges) than the UMC group (6% of home charges).**
  - **For both groups, just less than two thirds of charges were initiated using the default settings.**
  - **For UMC, 36% of charges were initiated using 'Charge Now', compared with 22% in SMC.**
- **The Control group reported interacting with the app relatively infrequently compared with the UMC and SMC groups.**
- **As drivers familiarised themselves with the vehicles and charging, there was less engagement with the app: the proportion of charges where the participant selected the default settings increased over the eight weeks.**

Using data from vehicle telematics and the CPMS, this analysis investigated whether there were differences in the way SMC and UMC participants engaged with the managed charging schemes.

On average, participants charged 32 times at home in the two groups. For each charge event the driver could either 'Charge Now', use the 'Default' settings in the app, or apply a 'New schedule' where they selected new settings for that specific charge session. Figure 126 presents the proportion of charges of each of these types.

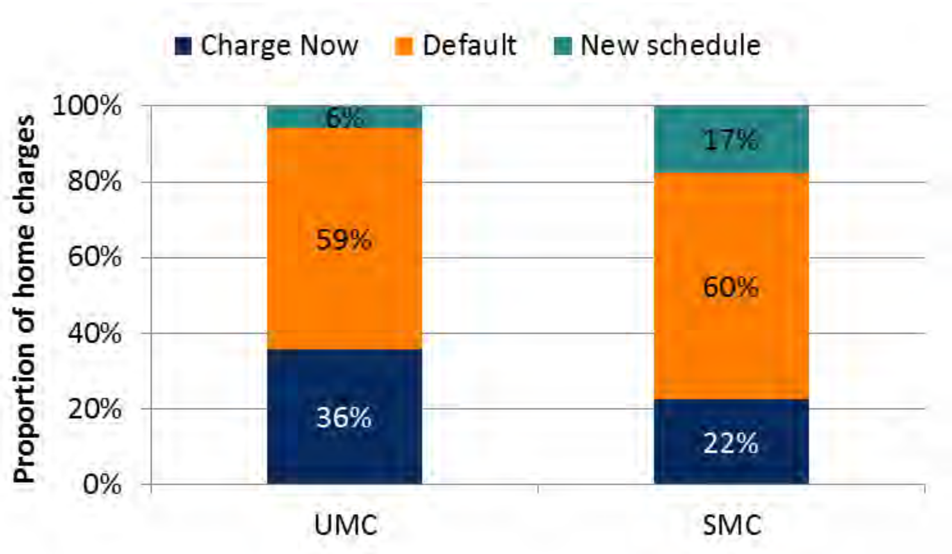


Figure 126: Proportion of home charges for each group by driver input selected (N = 2,597)

The SMC group set a new schedule more frequently (17% of charge events) compared with the UMC group (6% in the UMC group). In contrast, for the UMC group, 36% of charges were initiated using 'Charge Now' compared with 22% in SMC. Chi-squared tests showed the differences between groups were statistically significant ($p < 0.001$). Examination of use of the various driver input methods across the 8 week trial period showed a tendency for the use of defaults to increase between week 1 and week 8.

Similar to the BEV Charging Trial findings, UMC and SMC PHEV charge events initiated by the default settings, or by a new schedule setting, were found to have significantly longer plug-in durations than 'Charge Now' events and control group charges. PHEV participants who were engaged in the Managed Charging schemes tended to plug-in for longer than if they chose to 'opt out' of managed charging by using the 'Charge Now' function. Similar to the BEV trial this supports the conclusion that engagement with Managed Charging is successful in shifting charging behaviour and increasing the opportunity for flexibility, except where users occasionally decide to override. It is likely that such override decisions were influenced by drivers needing to use the car again sooner than they would normally (when opting in to Managed Charging).

Participants were also asked about how frequently they interacted with the smartphone app during the trial; responses for each of the three groups are shown in Figure 127.

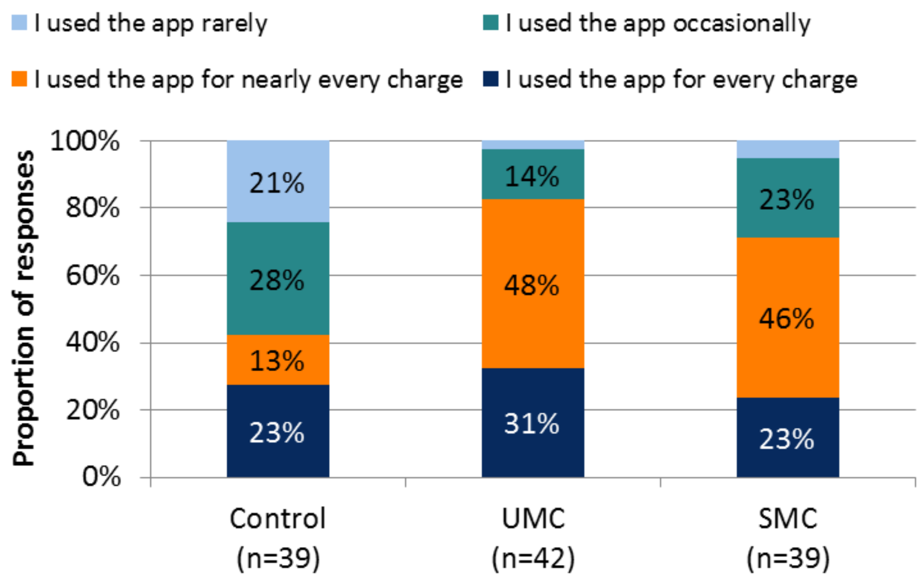


Figure 127: Proportion of responses to TP2 questionnaire "How often did you make use of the features on the smartphone app when charging the vehicle during the trial?" by trial group

The results show that the Control group interacted with the app relatively infrequently (for this group the app provided information only, e.g. SOC and charging status) compared with the UMC and SMC groups (who used the app to set when the vehicle should charge, or the level of charge required and by when respectively). An independent samples Kruskall-Wallis test showed there was a significant difference between the three groups ($p = 0.004$) and pairwise Mann-Whitney tests showed that this difference was between the UMC and Control group ($p = 0.002$) and the SMC and Control groups ($p = 0.012$).

Participants' ratings of satisfaction with the smartphone app – reported on a scale of 'very satisfied' to 'very unsatisfied' – are shown in Figure 128.

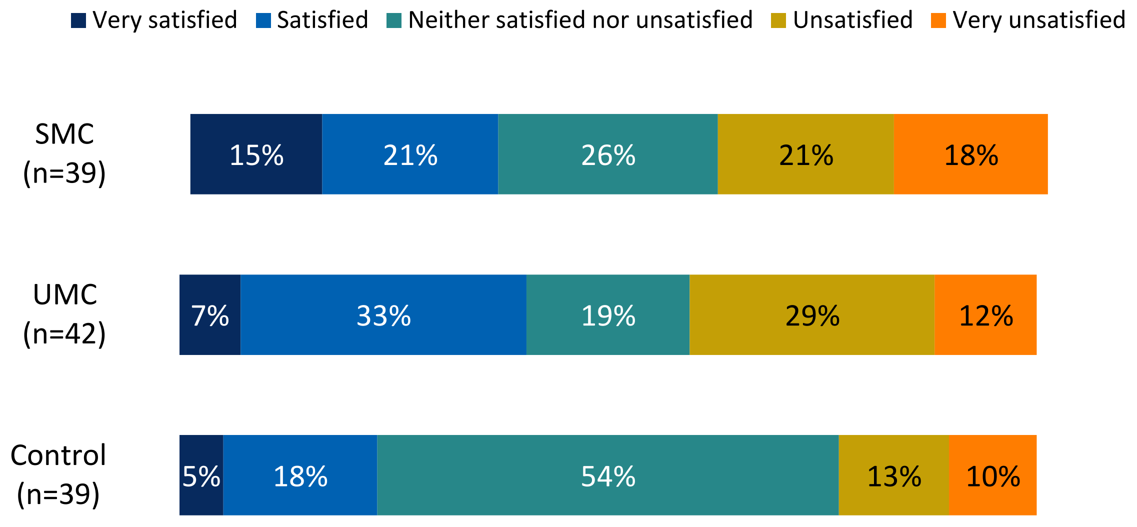


Figure 128: Proportion of responses to TP2 questionnaire "How would you rate your level of satisfaction with the charging tariff smartphone application?" by trial group

A higher proportion of the SMC (38%) and UMC (40%) groups were unsatisfied or very unsatisfied with the smartphone app compared with the Control group (23%); however, an independent samples Kruskall-Wallis test showed that this difference was not significant between the three groups (p = 0.997).

B.5.1.7 *What preferences do mainstream consumers have between Supplier-Managed Charging, User-Managed Charging, and no managed charging?*

- → **There were no differences between groups in the self-reported satisfaction with the charging schemes; the majority of participants reported being very satisfied, satisfied, or neither satisfied nor unsatisfied.**
- → **There were no differences in the reported likelihood to choose the scheme they experienced in the trial if they owned a BEV or PHEV in future.**
- → **When given a choice between the three types of charging scheme, UMC was the preferred option for most participants in all three groups. However, a greater share (around 30%) of the SMC group said they would choose a SMC scheme if they had a PHEV in future, compared with 10% of the Control group and 17% of the UMC group.**

This analysis examined data from the TP2 questionnaires to understand participants' preferences for the three types of charging scheme.

Participants were first asked to indicate their level of satisfaction with the charging scheme they experienced in the trial. Figure 129 presents the distribution of these responses for each experimental group.

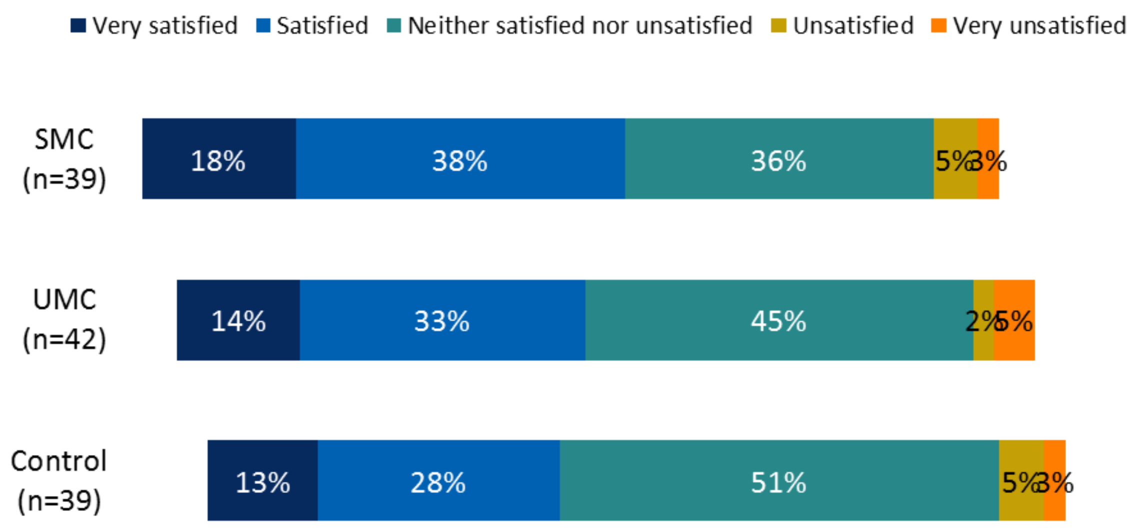


Figure 129: Proportion of participants who reported they were satisfied or unsatisfied with the charging scheme they experienced in the trial (N = 120)

The vast majority of participants reported being very satisfied, satisfied, or neither satisfied nor unsatisfied with the tariff they were on. Independent samples Kruskall-Wallis tests showed that these results did not differ significantly across groups (*p* = 0.498).

Figure 130 shows how likely or unlikely the participants were to choose the charging scheme experienced if they owned a BEV or PHEV. There were no significant differences in likelihood of participants to choose the scheme they experienced across the groups (BEV owned: *p* = 0.374; PHEV owned: *p* = 0.051).

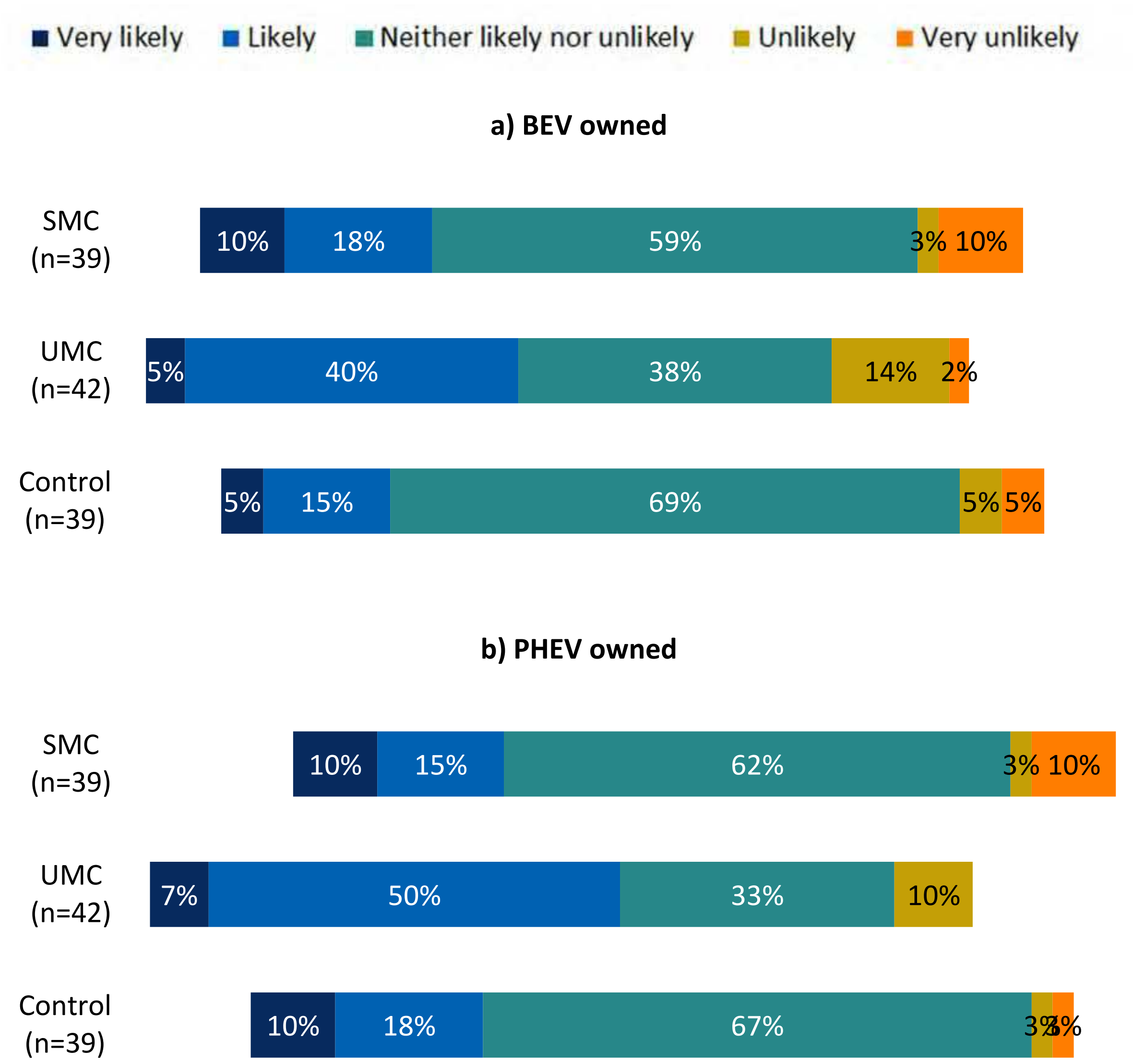


Figure 130: Proportion of participants likely or unlikely to choose the charging scheme they experienced in the trial if they owned a BEV (a) or PHEV (b) (N = 120)

Participants were then given a description of the three different types of charging scheme and asked which type they would choose if they owned a BEV or PHEV (Figure 131). For both vehicle types, user-managed charging was the preferred option for all three groups. Chi-squared tests show there was a no significant difference in the responses for the three groups if a BEV was owned (p = 0.117), but there was a significant difference for the PHEV (p = 0.006).

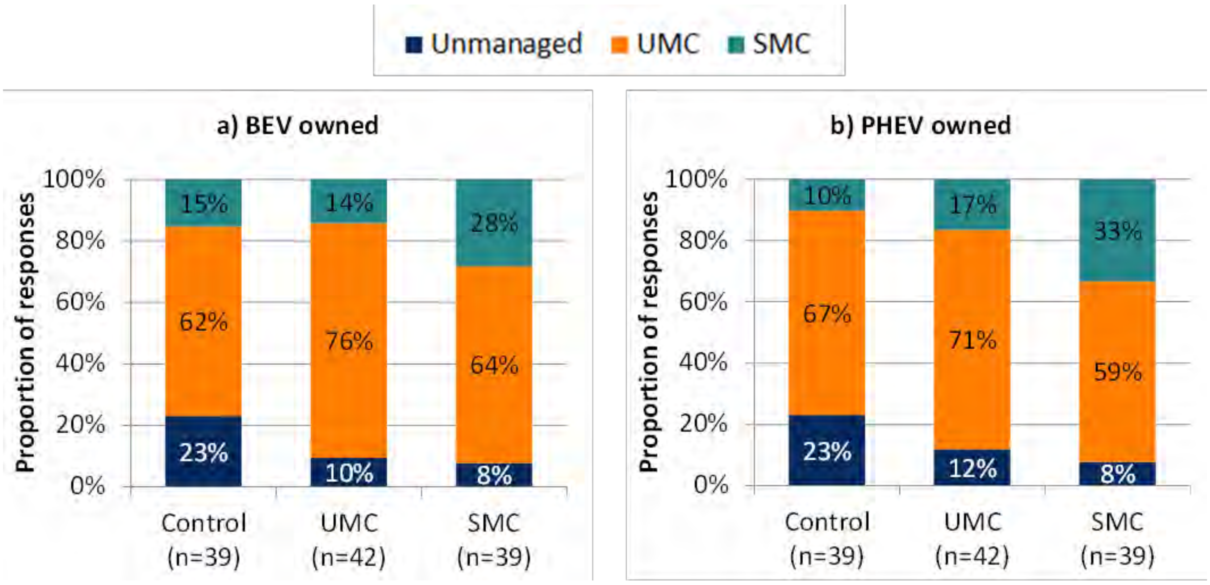


Figure 131: Proportion of participants likely or unlikely to choose unmanaged, UMC or SMC schemes by experimental group if they owned a BEV (a) or PHEV (b) (N = 120)

B.5.1.8 *What factors influence preferences between Supplier-Managed Charging, User-Managed Charging, and no managed charging?*

- → **Participants' choice of charging scheme was dependent on expected annual savings.**
- → **Managed charging was less attractive if peak electricity costs were high, even if the expected annual savings remained the same. This may be due to a perceived risk of needing to charge during peak times which would erode annual savings. A larger effect was observed for SMC users, possibly because they felt they had less control and ability to avoid peak rates.**
- → **Provision of an override function increased the share of participants predicted to choose SMC. This was even true of an override function where the user bears all the financial penalty of changing settings in a particular charging session.**
- → **Participants showed greater willingness to pay for managed charging, particularly SMC, if there was nearby 7kW public charging within five minutes of their home.**
- → **Participants' underlying attitudes towards UMC and SMC were positive.**
- → **Participants' perceptions of the importance of having control over when the vehicle charges impacted the choice of charging scheme; participants who rated control as more important were more likely to choose a UMC or unmanaged scheme.**

Choice experiment analysis

Table 49 presents the choice coefficients derived for the PHEV trial participants, according to the utility equation shown in Table 19.

As demonstrated in section B.4.1.8 for the BEV trial participants, these choice coefficients provide quantification of how PHEV trial participants traded-off different aspects of managed charging against one another when choosing between schemes. This section provides an analogous analysis for the PHEV trial participants, with each coefficient discussed in terms of

WTP. This shows the expected annual savings that participants are willing to forgo in order to choose a tariff with that particular attribute.

Table 49: Choice coefficients from the choice experiment for PHEV trial participants

Attribute	Choice Coefficient	Standard Error	*p*-value[39]
Estimate of annual savings (£/yr)	0.006739	0.000742	0
Additional cost of SMC charging during peak hours (£/kWh)	0.595246	0.098235	0
Additional cost of UMC charging during peak hours (£/kWh)	-1.25315	0.218943	0
5 minutes to nearest rapid chargepoint (SMC)	0.595246	0.098235	0
5 minutes to nearest rapid chargepoint (UMC)	0.245626	0.098904	0.013
Override available, but changing configuration results in loss of all financial reward for that charge event	0.22693	0.101714	0.0257
Override available, complete flexibility to change configuration	0.489903	0.100446	0
Alternative Specific Constant (SMC)	0.438774	0.120773	0.0003
Alternative Specific Constant (UMC)	0.903115	0.105894	0

Additional cost of charging during peak hours

Figure 132 presents the linear relationship derived between WTP and peak cost of UMC and SMC relative to unmanaged charging. As for BEVs, WTP for higher peak costs is more negative for SMC than UMC (-£2.71/yr per p/kWh, vs. -£1.86/yr per p/kWh), although the relative difference is smaller than for BEVs. It was proposed for the BEV participants that the more negative WTP under SMC was due to the perception of less control in avoiding peak costs. For PHEVs, charge times are shorter and so participants are less likely to have to charge at peak times, and consequently there may be lower perceived risk in charging under SMC, compared with BEVs.

[39] As reported by N-Logit.

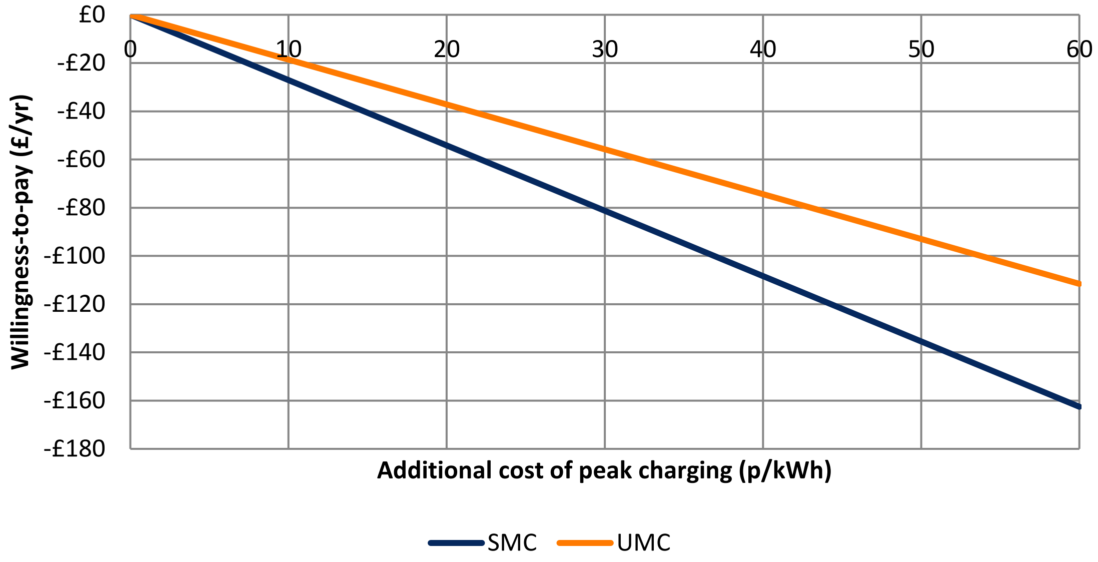


Figure 132: PHEV trial participants' willingness to pay for additional cost of peak charging compared with unmanaged charging

However, in general, WTP for peak charging cost is more negative for PHEVs than BEVs, which suggests that the PHEV participants are more averse to increasing peak costs. This is surprising given the expectation that PHEV drivers are less likely to have to charge during peak times, although this may be due to the higher charging frequency of the PHEV sample compared with the BEV sample. On average there were 48 PHEV charges per participant compared with 38 BEV charges. This difference could in part be due to the higher annual mileages of the PHEV sample; for example, the PHEV trial had a greater share of participants (16%) who reported high annual mileages (more than 15,000 miles) compared with the BEV Trial (9%). However, on average PHEV participants plugged in to charge on 98% of days where a trip was made (compared with 74% for BEV participants). This high charging frequency indicates that the PHEV participants recognised the benefits of driving a high share of their mileage under electric power. Plugging in to charge requires effort on the part of the driver and so if there was little interest in driving under electric power, it might be expected that PHEV participants would charge less often than BEV participants, preferring instead to refuel as they would a conventional petrol or diesel car. Due to the smaller battery, PHEV participants had to charge more often than BEV drivers to ensure their share of mileage driven under electric power was adequate, but displayed a willingness to do so. As a consequence, the PHEV participants may feel more at risk of needing to charge during peak hours and so in general have lower appetite to accept it.

<u>Override Function</u>

Figure 133 shows PHEV trial participants' WTP for an override function in the SMC scheme. Similar to BEV participants, two different levels of override were tested:

1. User can change settings once set, but this results in loss of all savings from that charging event.
2. User has full flexibility to change settings and savings for that event are still passed through.

The second level was worth approximately double the first level, where users incur a financial penalty for changing settings. However, in both cases, WTP was about 70% what it was for BEVs. This is to be expected since PHEV drivers have the option of driving under ICE power if the car is needed earlier than specified at the plug-in time. Consequently, they have less of a need to override their original charging settings. However, the fact that the WTP is non-zero and positive, suggests that PHEV participants show a desire to run their cars on electric power over fuel.

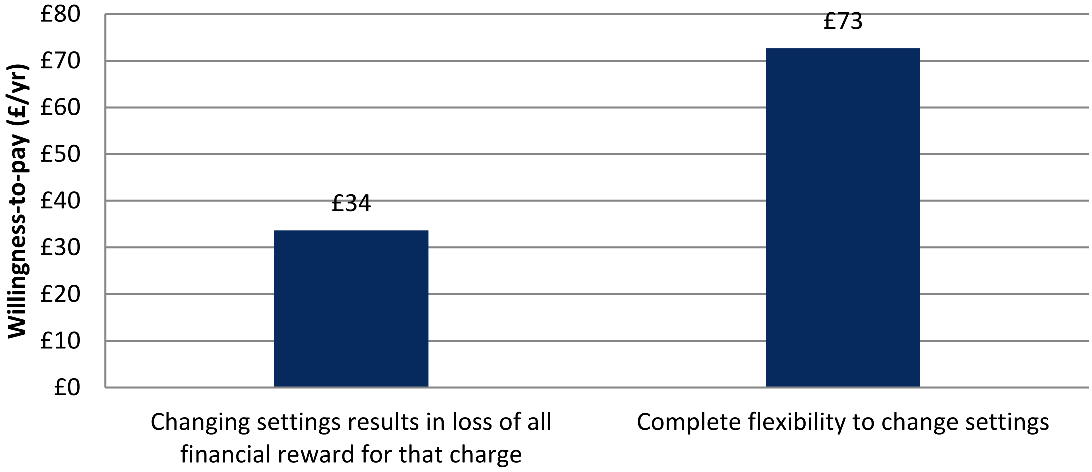


Figure 133: PHEV trial participants' willingness to pay for override function in SMC tariffs.

<u>Proximity of 7kW Public Charging</u>

Similar to the BEV trial participants, the choice experiment investigated the value of nearby public charging for PHEV participants when choosing between charging schemes. A nearby public chargepoint may provide a back-up option in case managed charging results in the car's SOC being too low, for example because the car is needed earlier than expected or must be charged during peak times. However, whilst BEV participants can utilise rapid charging, the PHEV model used in the trial could not and so the value of nearby 7kW public charging was tested instead (see Section A.12.2.1). The PHEV participants' resulting additional WTP for SMC and UMC tariffs when public charging is nearby is shown in Figure 133.

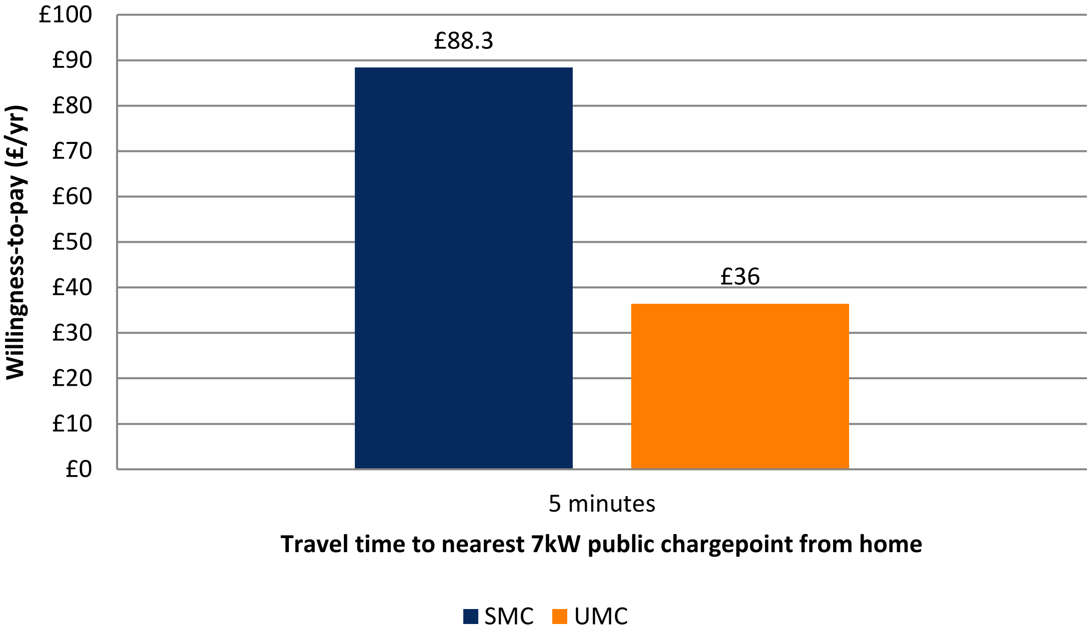


Figure 134: PHEV trial participants' willingness to pay for SMC and UMC tariffs when nearest 7kW public chargepoint is five minutes away from home

The choice experiment tested WTP at proximities of five minutes, 15 minutes and 30 minutes travel time to the nearest 7kW public chargepoints. At the five minute level, the additional WTP was larger for the SMC tariff, as was observed for the BEV participants. It is assumed that the need for a back-up charging option is larger with SMC where the participant perceives less control. At the 15 minute and 30 minute proximity levels, statistically significant coefficients could not be derived. It was therefore concluded that PHEV participants placed no value, with respect to their charging scheme choice, when the nearest chargepoint was 15 minutes away or more.

This is in contrast with the BEV participants who were found to continue to place value in rapid chargepoints that were 30 minutes away when considering an SMC scheme. Furthermore, in general, the additional WTP for both SMC and UMC with nearby 7kW public charging was less than for the BEV participants and rapid chargepoints at an equivalent level of proximity. Both findings are unsurprising since the convenience provided by a 7kW charge is less than a 50kW rapid chargepoint, owing to its lower charge rate, while the risk that the public chargepoint is mitigating is less for PHEV drivers who can run on liquid fuel if necessary. The suggestion, therefore, is that PHEV drivers who use a managed charging tariff use only rely on a public charging point as a back-up if it's very nearby (i.e. less than 15 minutes) but if any further they will simply run on fuel instead.

In future, it is possible that rapid charging capability will become the norm for PHEVs, and thus availability of nearby rapid public charging would be expected to add more utility to managed charging than 7kW public charging. However, this is considered unlikely because at present there is only one PHEV model, the Mitsubishi Outlander, compatible with 50kW DC charge points. Due to its small battery it charges at a considerably lower rate than the 50kW available and consequently charge point operators actively discourage these vehicles from using their charge points as they block BEVs which can utilise more of the available capacity.

PHEVs also have less need for en-route rapid charging, since they can continue to drive under fuel power when their battery is depleted.

Anticipatory Charging and Accuracy of Annual Savings Estimate

Similar to the BEV participants, no statistically significant coefficients could be derived for the accuracy of the estimate of annual savings and the availability of anticipatory charging. Anticipatory charging is likely to have been considered even less valuable for the PHEV sample, compared with the BEV sample, as they showed even less appetite to set a reduced desired state of charge (see Figure 135).

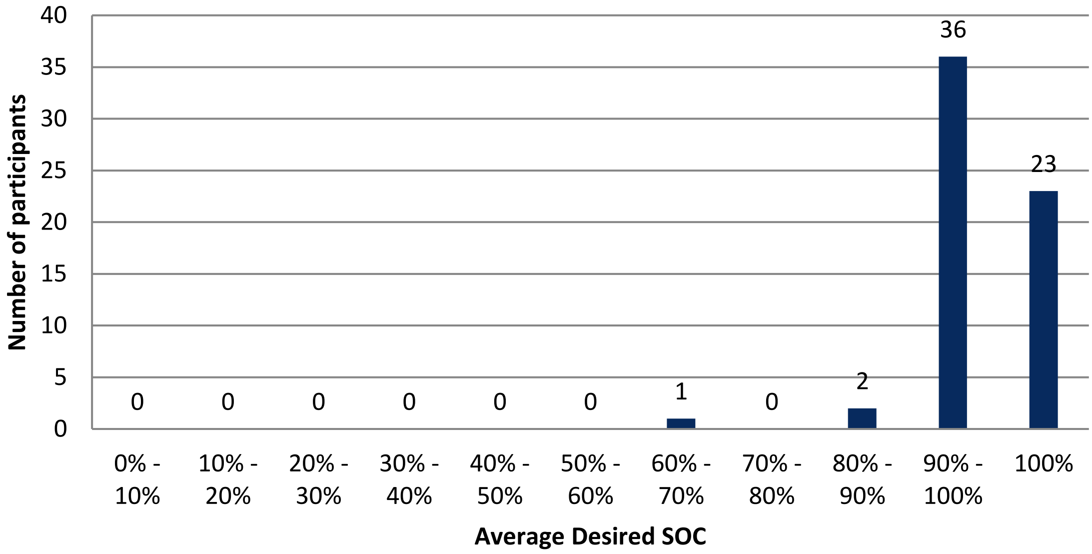


Figure 135: Number of PHEV participants in SMC group by average Desired State of Charge

Indeed, 23 out of 39 participants always set their desired SOC to 100%, and only one participant set the majority of their charge events with a desired SOC of less than 90%. This is unsurprising given the smaller battery in a PHEV, which also means the desired state of charge must be set lower than for a BEV in order to gain significant value from anticipatory charging.

As for BEVs, it was assumed that these attributes did not influence tariff choice and so they were excluded from the final utility equations shown in Table 19.However, whilst BEV drivers may begin to place value in anticipatory charging in future as battery ranges increase, PHEV batteries may remain too small for an analogous development to be observed amongst PHEV drivers.

Net attitudes towards UMC and SMC

Using an identical method to that presented in section B.4.1.8 for the BEV participants, the choice experiment results can be used to derive the PHEV participants' WTP for the unobserved factors of the SMC and UMC tariffs. These are the factors not directly tested in the choice experiment through attributes, but still contribute to the participants' choice, and are indicative of the underlying attitudes towards managed charging.

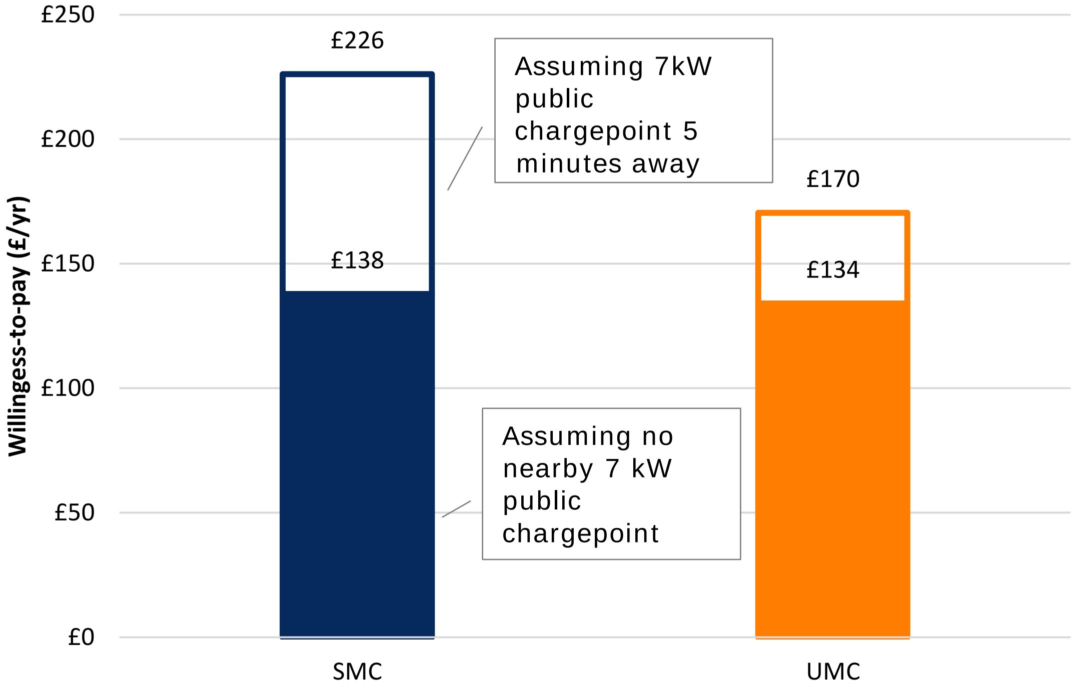


Figure 136: $ASC_{SMC,unobserved}$ and $ASC_{UMC,unobserved}$ derived for PHEV trial participants, assuming tariffs are equivalent to unmanaged charging with no nearby 7kW public chargepoint as well as nearest 7kW public chargepoint is five minutes away

Figure 136 shows the portion of the Alternative Specific Constants (ASC) that account for the unobserved factors of SMC and UMC, expressed in terms of WTP. It is unclear whether SMC and UMC can be considered equivalent to unmanaged charging when there either is or is not nearby public charging. However, as for the BEV participants, regardless of public charging proximity, the WTP values are strongly positive for both UMC and SMC. This suggests that PHEV participants show no overall net bias against managed charging. The values shown in Figure 136 suggest a preference for SMC compared with UMC; however, ultimately choice between these two schemes will also depend on the other attribute values, such as expected annual savings and peak charging cost.

As for the BEV sample, an attempt was made to derive choice coefficients for each of the charging groups (UMC, SMC and Control group) within the PHEV sample. However, a statistically significant set of choice coefficients could only be derived for the SMC group. A comparison between groups was therefore not possible.

Questionnaire analysis

To supplement the data from the choice experiment, analysis of the TP2 questionnaire data was also undertaken to explore the factors which influenced mainstream consumer preferences for managed charging. Two regression models were built; one to explore the impact of a series of factors on likelihood to choose managed charging if consumers owned a BEV, and another for if they owned a PHEV. These models used data from the TP2 questionnaire which asked participants to rate how important or unimportant the following factors would be if they owned a BEV and were choosing a charging scheme:

- Cost of charging

- Convenience
- Simplicity
- Predictability of energy bill
- Compatibility with vehicle use and charging needs
- Ability to make savings
- Control over when your vehicle will charge
- Predictability of having a full charge when car is needed
- Control of charging via an app or website

The importance of each of these features was measured on a five-point scale from (1) 'Not at all important' to (5) 'Extremely important'. There were no significant differences in the responses to these questions between the experimental groups. This suggests that the ratings of importance were not greatly influenced by the type of charging schemes experienced by BEV participants in the trial. The regression analyses described in the following sections were therefore undertaken to assess whether the importance of these factors depended on the type of charging scheme that participants would chose in *future*.

BEV model

A factor analysis was performed on the set of items to examine whether the list could be reduced into a smaller set of factors. However, as found for the BEV trial, the factor structure identified from this analysis was not found to be reliable, and so the individual item responses were examined instead.

Kruskall-Wallis tests were performed on each individual questionnaire item to examine if there were significant differences in responses between participants who indicated they would chose unmanaged charging, UMC or SMC. Only one item showed significant differences; "Control over when your vehicle will charge" ($\chi^2 = 8.916$, $p = 0.012$). As shown in Figure 137, participants who chose the UMC scheme were the most likely to report that having control over when the vehicle charges was 'extremely important'. The participants who chose the SMC scheme were the most likely to rate this feature as only 'slightly important'.

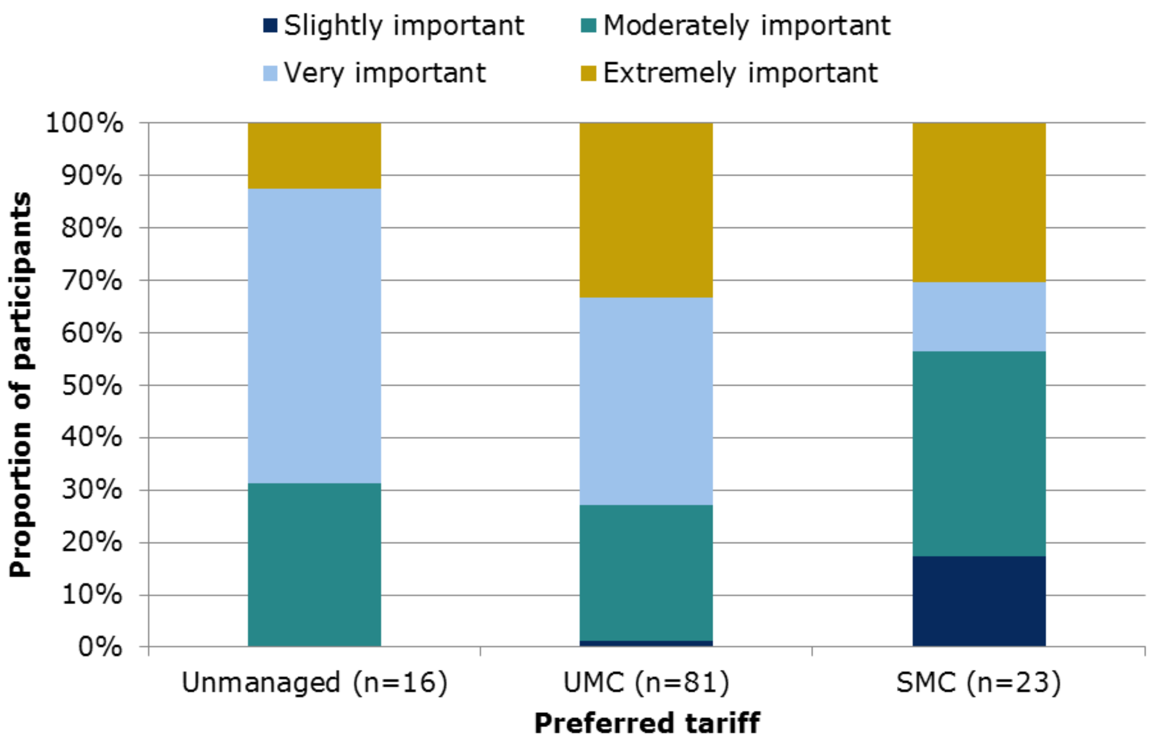


Figure 137: Proportion of participants who rated control over when the vehicle charges as important or unimportant by chosen charging scheme (if they owned a BEV)

PHEV model

The TP2 questionnaire also asked participants to rate how important or unimportant the factors would be if they owned a PHEV. Again the factor analysis created scores that proved to be poor predictors. Kruskall-Wallis tests were run on each item to see if there were significant differences in responses between participants who indicated they would chose unmanaged charging, UMC or SMC.

Ratings of the importance of being able to control when the vehicle charged was the only item found to significantly vary (χ^2 = 8.293, p = 0.016). As shown in Figure 138, the results were similar for the participants who chose unmanaged charging and UMC. However, a larger proportion of participants who chose SMC (46%) rated having control over the charge as ‘slightly’ or ‘moderately’ important compared to the groups who chose the unmanaged (24%) and UMC schemes (19%).

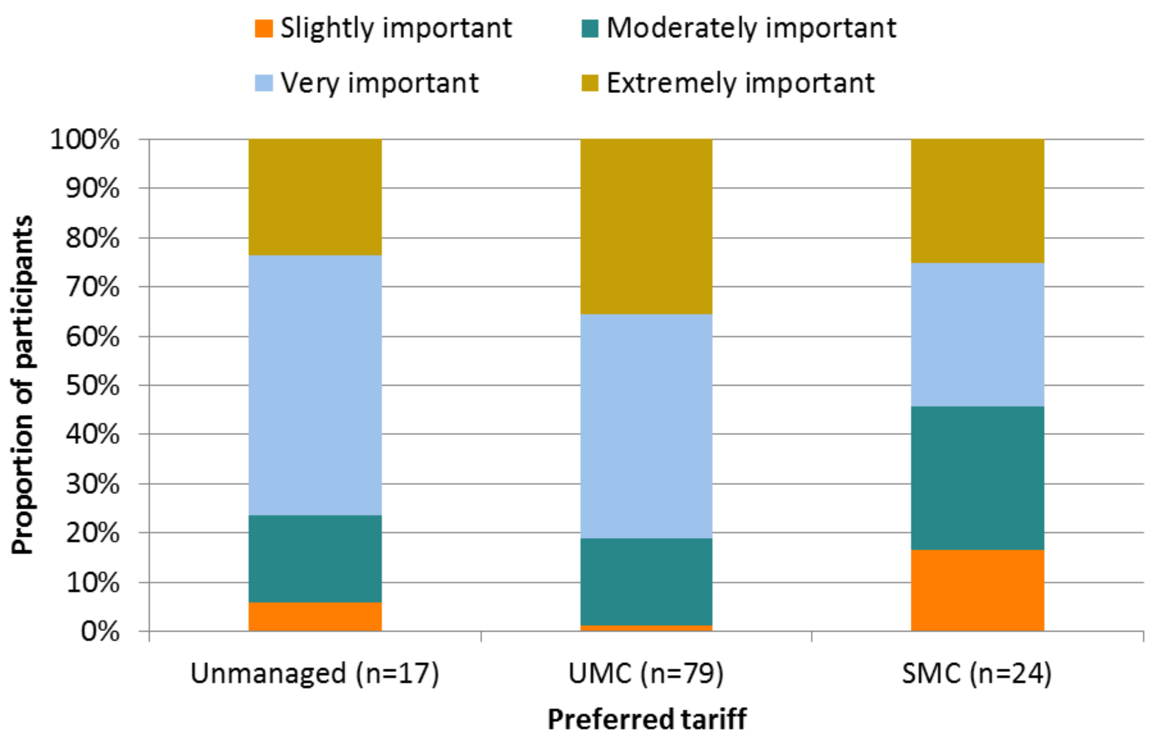


Figure 138: Proportion of participants who rated control over when the vehicle charges as important or unimportant by chosen charging scheme (if they owned a PHEV)

B.5.1.9 *What are the impacts of different User-Managed Charging tariffs and Supplier-Managed Charging schemes on a consumer's likelihood to participate in these arrangements?*

- → **Annual cost savings have a very strong influence on the decision to choose a managed charging scheme, although PHEV participants are less sensitive than BEV participants.**
- → **Managed charging becomes less attractive with higher peak electricity costs, even if the expected annual savings remain the same. SMC is more sensitive than UMC to peak electricity cost, although the difference is smaller than for the BEV participants.**
- → **PHEV participants place value in features that reduce the risk of managed charging; for example, an override function and nearby public charging. However, in general, they place less value in these features compared with the BEV participants.**

Using the simple choice model outlined in Appendix A.15.5.1, the relative influence of each managed charging attribute on the PHEV participants' choice of charging tariff can be illustrated. In each case, the value of the attribute of interest is varied, with all others held at their reference values, and the share of participants choosing each tariff is estimated in the choice model.

Expected annual charging cost savings

Figure 139 and Figure 140 illustrate how expected charging costs savings influence the share of participants predicted to choose SMC or UMC. Whilst it is a significant factor in a participant's decision, the PHEV trial participants appear slightly less sensitive to expected savings than the BEV sample (see Figure 90 and Figure 91). The reason for this is that the associated choice coefficient for expected annual savings is smaller for PHEVs (0.00674 vs. 0.00995 for BEVs), and so this attribute contributes a smaller amount to the overall utility of each scheme. For both vehicle samples, a £1 saving is worth the same and so they might be expected to have very similar choice coefficients for expected savings. But this suggests that electricity costs are less of a concern for PHEV drivers, which may be because they contribute a smaller amount to overall running costs for PHEVs compared with BEVs.

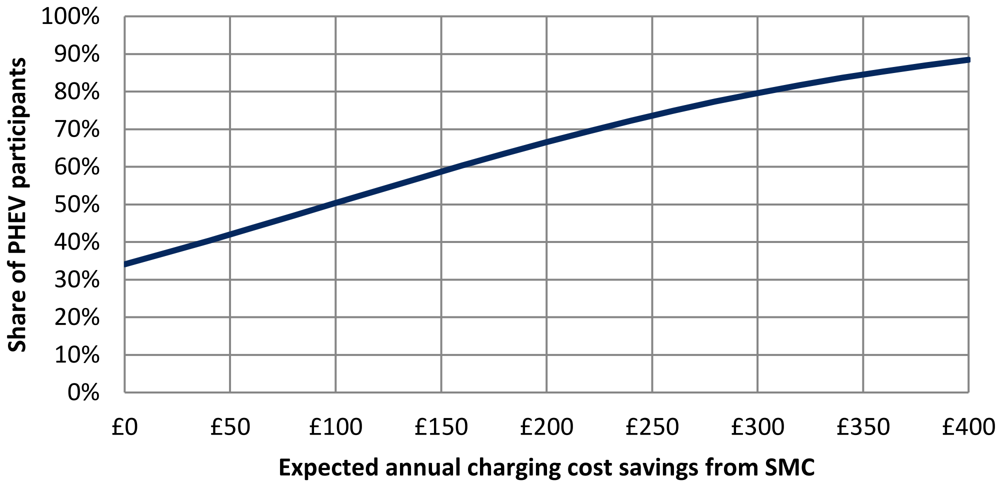


Figure 139: Share of PHEV trial participants predicted to choose SMC, at different levels of expected annual charging cost savings (all other attribute values are held constant at their reference values)

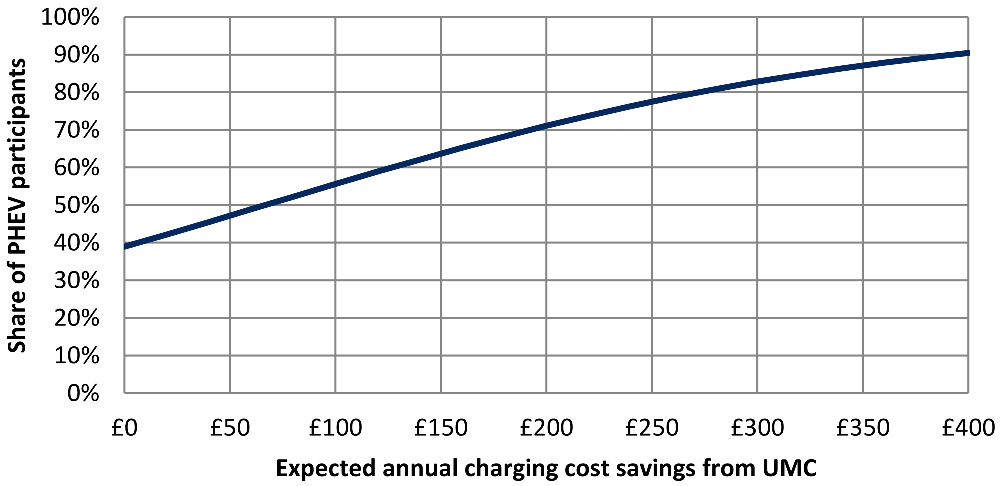


Figure 140: Share of PHEV trial participants predicted to choose UMC, at different levels of expected annual charging cost savings (all other attribute values are held constant at their reference values)

Additional cost of charging during peak hours

As revealed in Figure 132, PHEV participants show a greater WTP for a lower SMC peak charging cost than UMC. The consequence is that participant choice is more sensitive to SMC peak cost (Figure 141) than UMC peak cost (Figure 142).

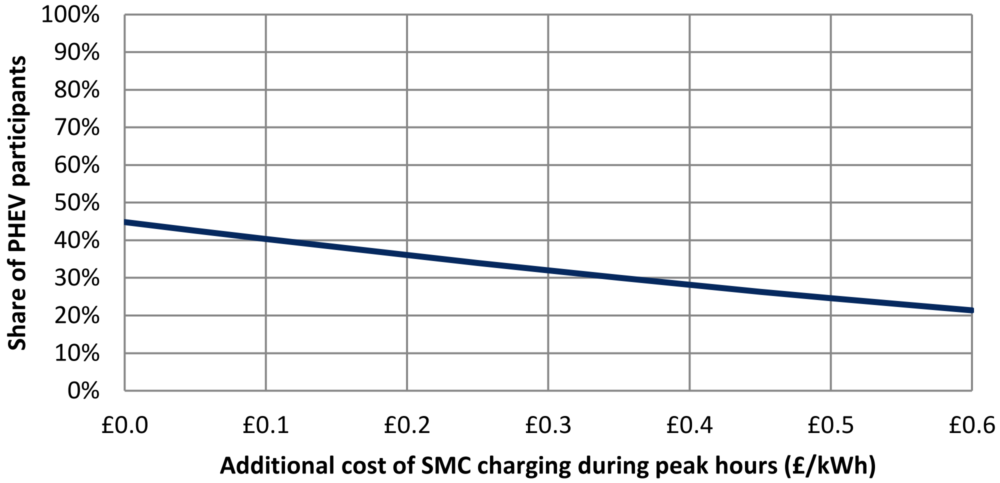


Figure 141: Share of PHEV trial participants predicted to choose SMC, at different levels of peak charging cost relative to unmanaged charging (all other attribute values are held constant at their reference values)

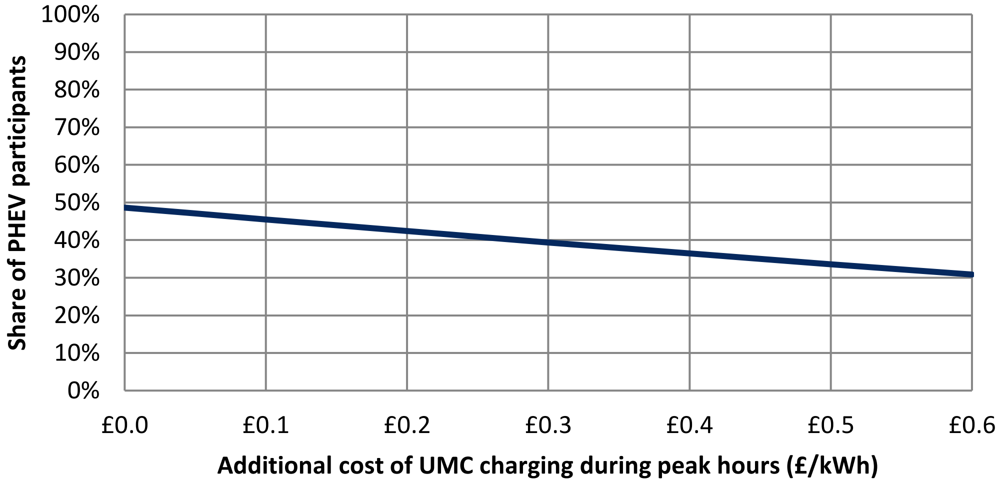


Figure 142: Share of PHEV trial participants predicted to choose UMC, at different levels of peak charging cost relative to unmanaged charging (all other attribute values are held constant at their reference values)

Proximity of 7kW Public Chargepoints

As for BEV trial participants, the influence of public chargepoint proximity on consumer choice cannot be tested independently for SMC and UMC. The share of PHEV trial participants predicted to choose each of the schemes under a range of proximities is shown in Figure 143. Since additional WTP is assumed to be zero when the nearest chargepoint is 15 minutes away or more, beyond this point there is no change in predicted share. As proximity decreases below 15 minutes, the overall share of managed charging increases; however, because the utility of SMC grows faster than UMC, the UMC share decreases.

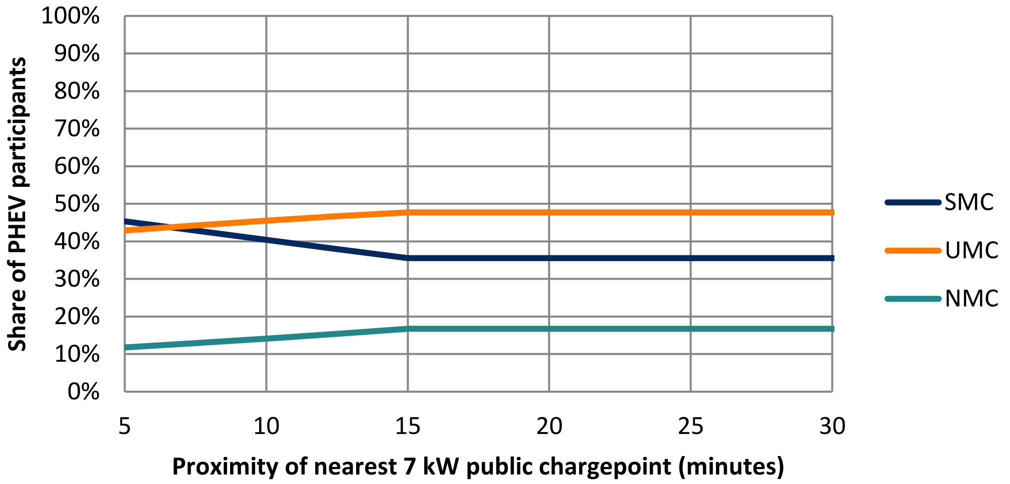


Figure 143: Share of PHEV trial participants predicted to choose SMC and UMC, with different proximities of the nearest 7 kW public chargepoint (all other attribute values are held constant at their reference values)

Override Function

Figure 144 illustrates how the predicted share of PHEV participants choosing SMC is affected by the provision of different levels of override function. WTP for an override function was in general lower for PHEV participants compared with the BEV sample, and this is reflected in the smaller change in participant choice as additional override flexibility is added.

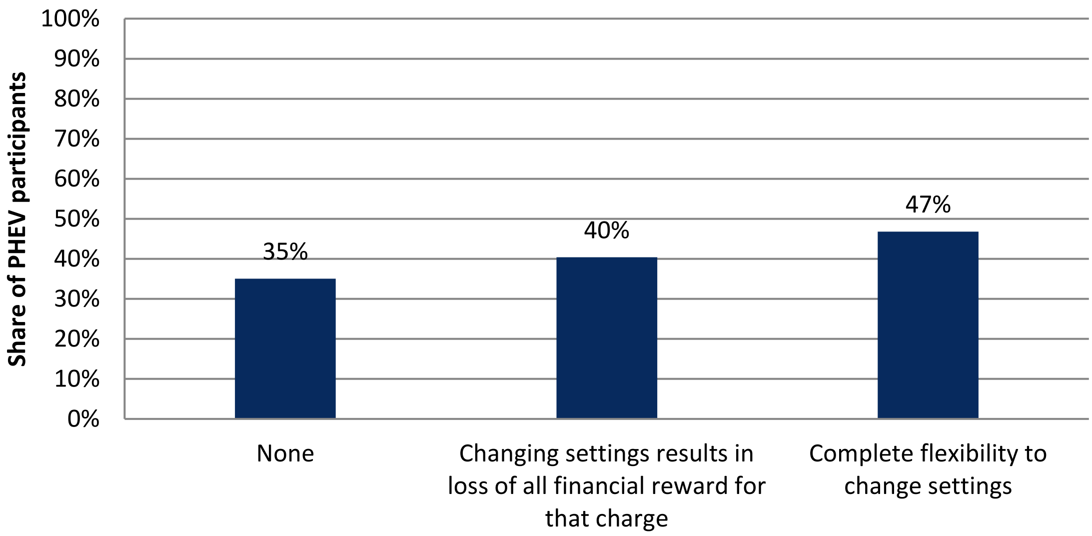


Figure 144: Share of PHEV trial participants predicted to choose SMC, with different levels of override function

B.5.1.10 *What are the impacts of different User-Managed Charging tariffs and Supplier-Managed Charging schemes on the likelihood of car buyers choosing a PHEV/BEV over other powertrains?*

→ **Participants in all groups were more likely to purchase a BEV as a second car (50% at least fairly likely) in the next five years compared to as a main car (32% at least fairly likely).**

→ **There was relatively little difference in the proportion of participants at least fairly likely to purchase a PHEV as a main and second car; there were no significant differences between groups.**

→ **There were no significant differences between the three groups in terms of the influence of availability of managed charging on likelihood to purchase a BEV or PHEV in the future.**

→ **When responses were combined across the three groups, availability of a SMC scheme was more likely to be rated 'not at all' likely to influence the decision to purchase a BEV or PHEV than the availability of a UMC scheme.**

The focus of this analysis was to understand how the availability of UMC or SMC schemes may impact on likelihood to purchase an electric vehicle in the future. The analysis used data from the TP2 questionnaires.

Participants were first asked to rate how likely it was that they would choose to purchase a BEV or PHEV as a main or second car in the next five years. They were then asked whether availability of a UMC or SMC scheme would make this purchase more or less likely.

Figure 145 presents the overall reported likelihood of purchase of a BEV or PHEV as a main or second car in the next five years; these results were compared across the three groups. The responses show that participants in all groups were much more likely to report that they would purchase a BEV as a second car in the next five years compared to as a main car (32% reported being at least fairly likely to purchase a BEV as a main car compared with 50% who reported the same for a BEV as a second car). For the PHEV, there was relatively little difference in the proportion who reported being at least fairly likely to purchase one of these vehicles between the main and second car (53% compared with 57% for the three groups combined).

Statistical tests (independent samples Kruskall-Wallis tests) showed that there was no significant difference in the distribution of responses across the three groups for any of these questions (BEV main car: $p = 0.857$; BEV second car: $p = 0.249$; PHEV main car: $p = 0.650$; PHEV second car: $p = 0.930$).

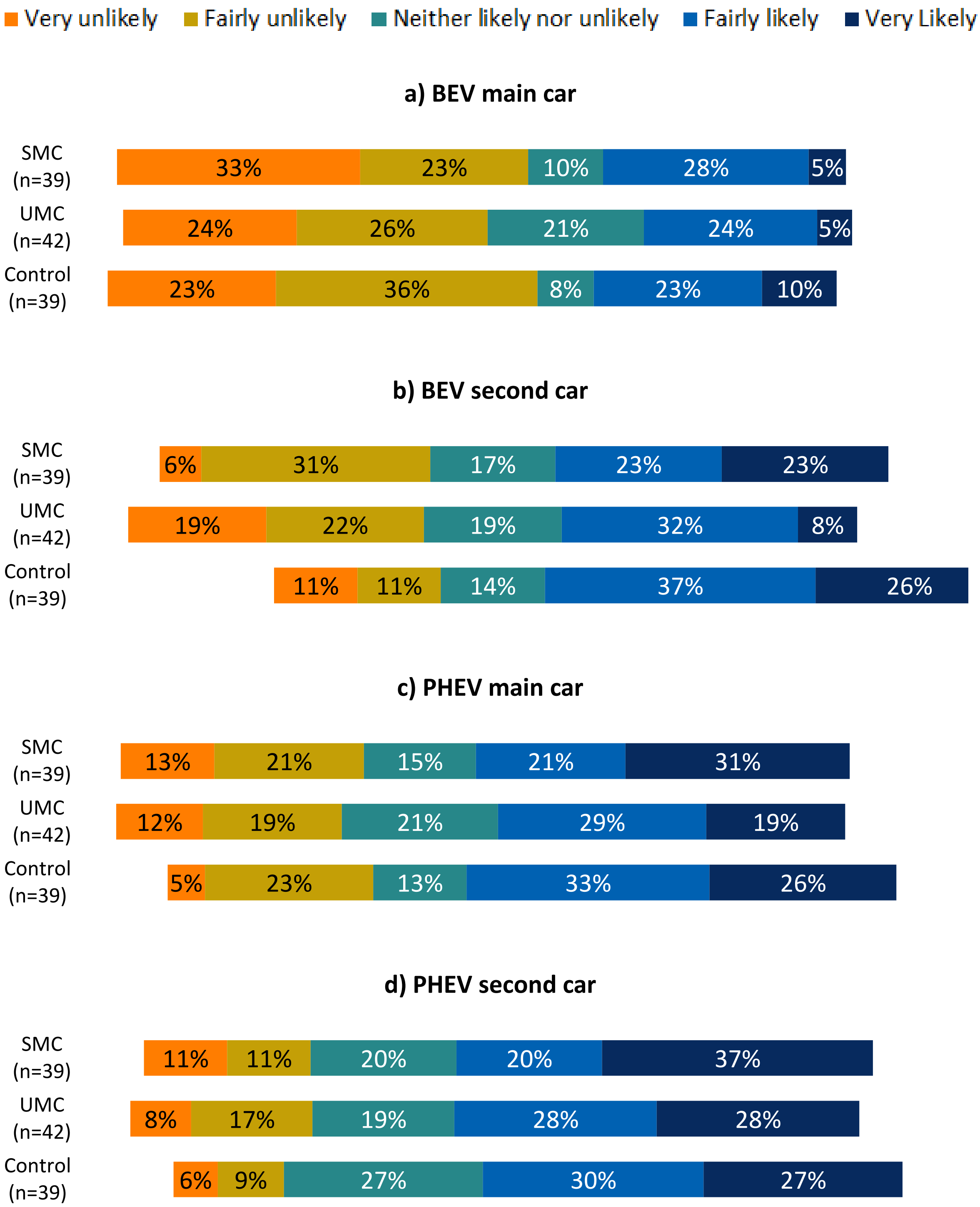


Figure 145: Proportion of responses to TP2 questionnaire "Please indicate how likely or unlikely it is that in the next 5 years, I would choose to have (a) a BEV as a main car, (b) a BEV as a second car, (c) a PHEV as a main car, (d) a PHEV as a second car"[40]

[40] N/A responses are removed from participants who do not have a second car in the household.

Figure 146 shows the distribution of each group's response to the question "If a User-Managed Charging tariff were available, would this make you more likely to have (a) a BEV as a main car, (b) a BEV as a second car, (c) a PHEV as a main car, (d) a PHEV as a second car?".

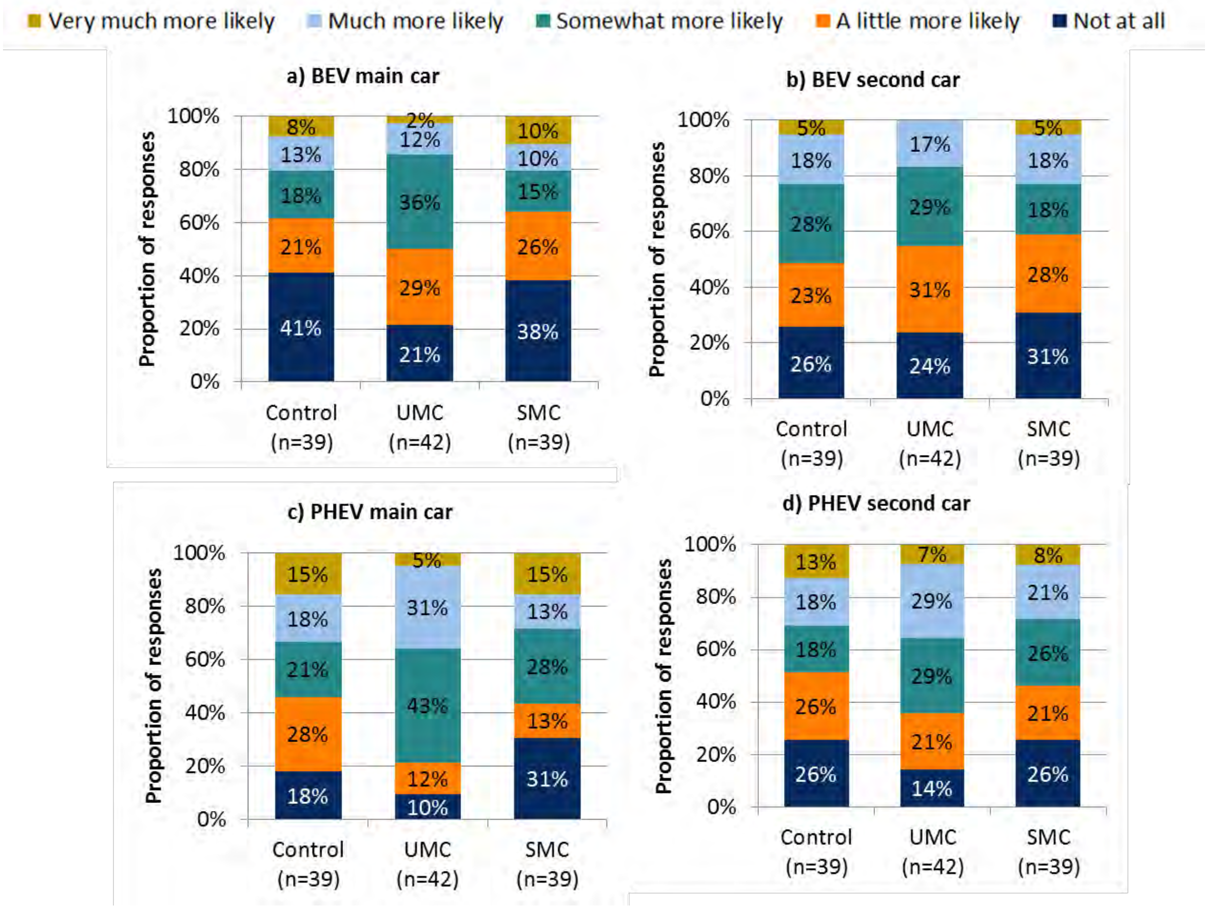


Figure 146: Proportion of responses to TP2 questionnaire "If a User-Managed Charging tariff were available, would this make you more likely to have (a) a BEV as a main car, (b) a BEV as a second car, (c) a PHEV as a main car, (d) a PHEV as a second car?"

There were no significant differences in responses between groups, suggesting that, in general, the charging scheme each participant experienced in the trial did not influence whether the availability of a UMC scheme would increase the likelihood of purchasing a BEV or PHEV in the future.

Figure 147 shows the distribution of each group's response to the question "If a Supplier-Managed Charging tariff were available, would this make you more likely to have (a) a BEV as a main car, (b) a BEV as a second car, (c) a PHEV as a main car, (d) a PHEV as a second car?".

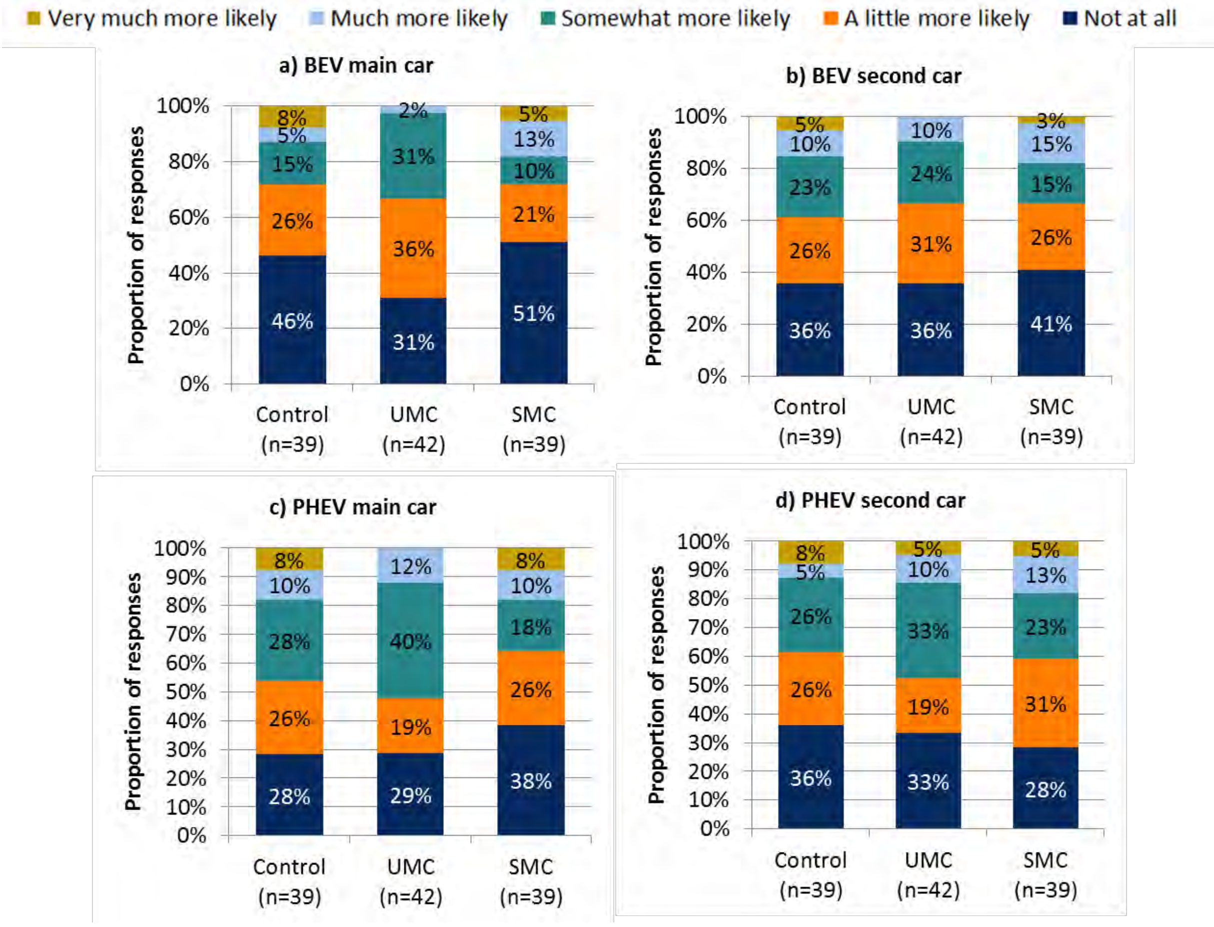


Figure 147: Proportion of responses to TP2 questionnaire “If a Supplier-Managed Charging tariff were available, would this make you more likely to have (a) a BEV as a main car, (b) a BEV as a second car, (c) a PHEV as a main car, (d) a PHEV as a second car?”

There were no significant differences in responses between groups, suggesting that, in general, the group each participant was assigned to in the trial did not influence whether the availability of a user-managed charging tariff would increase the chance of the participant purchasing a BEV or PHEV in the future.

Figure 148 combines the responses across the three groups. The results show that availability of a SMC scheme was more likely to be rated ‘not at all’ likely to influence the decision to purchase a BEV or PHEV than the availability of a UMC scheme (BEV main car: $p = 0.001$; BEV second car: $p = 0.001$; PHEV main car: $p < 0.001$; PHEV second car: $p < 0.001$).

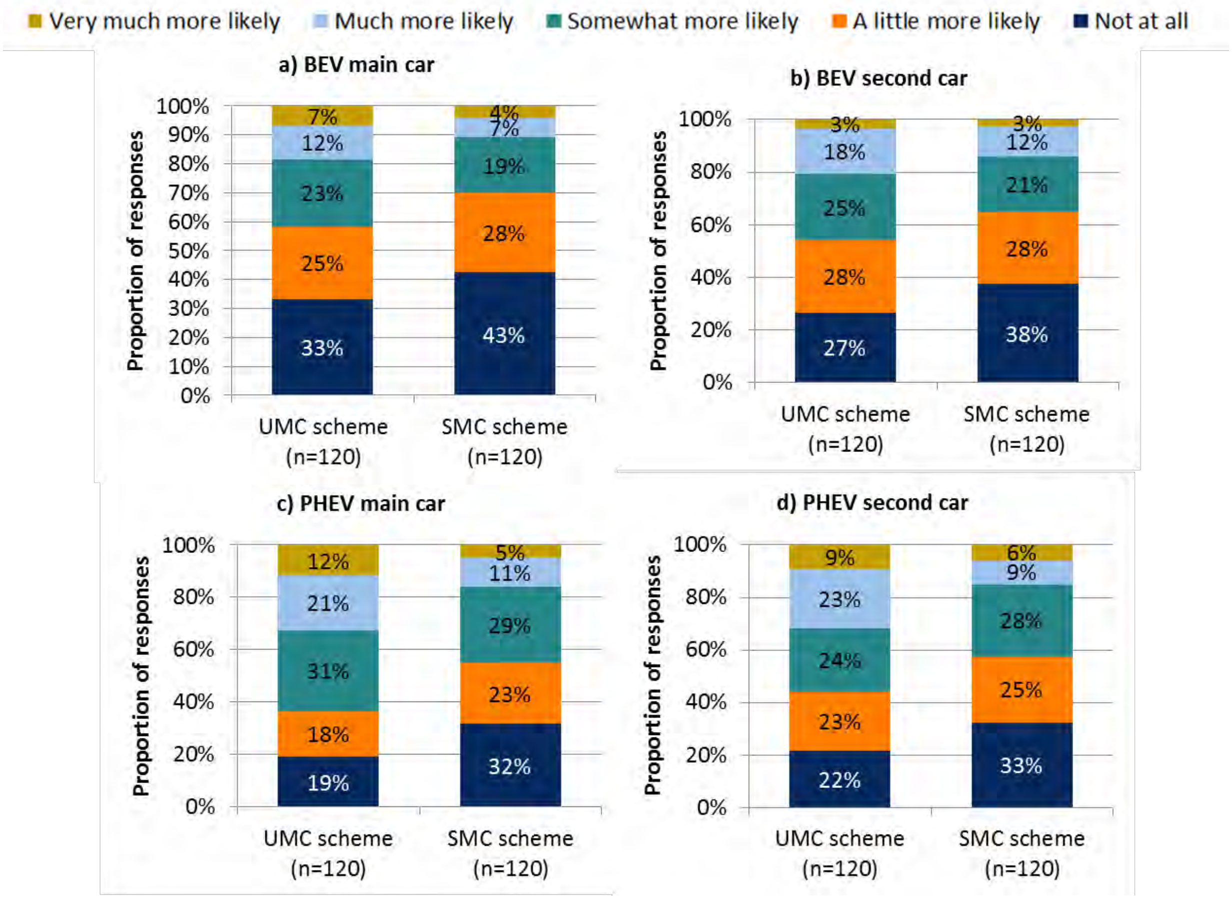


Figure 148: Proportion of responses to TP2 questionnaire "If a User- or Supplier-Managed Charging tariff were available, would this make you more likely to have (a) a BEV as a main car, (b) a BEV as a second car, (c) a PHEV as a main car, (d) a PHEV as a second car?"

B.5.2 *Supplementary analysis*

B.5.2.1 *Identification of factors influencing charging behaviour*

- → **Eight types of charge event were identified from the cluster analysis; two at home, four within the local area, and two over 50 miles away from participants' homes.**
- → **Home charges and charges more than 50 miles from home were generally defined by the amount of SOC added; home charges typically provided more than 75% charge and charges 50 miles away typically provided less than 75% charge.**
- → **Local charges were categorised in terms of time of day and charge duration; they were also more likely to be dependent on the availability of public or work chargepoints.**
- → **Data from the previous journey was better at predicting the type of charge than the subsequent journey.**

The purpose of this supplementary analysis was to identify what factors, if any, from the vehicle telematics data could be used to predict PHEV charging behaviour. The analysis was split into two component parts. First, a cluster analysis was undertaken on the charging data to identify distinct categories of charge events. Second, regression analysis was used to examine the extent to which journey variables could be used to predict the different categories of charge event.

Identifying types of charging

Cluster analysis was used to group PHEV charge events into distinct categories on the basis of the following charging variables in Table 50:

Table 50: Variables and levels used for cluster analysis

Variable	Levels
Distance from home	• Home • Local: less than 50 miles from home • Distant: more than 50 miles away from home
Day of the week	• Weekday charges • Weekend charges
Time of day	• Morning (6am-12pm) • Afternoon (12pm-4pm) • Evening (4pm-10pm) • Overnight (10pm-6am)
Charger power	• <2 kW • 2-4 kW • 4-22 kW • 22+ kW
Duration of charge	• <2 hours • 2-5 hours • 5+ hours
Amount of SOC added	• <25% • 25-49% • 50-74% • 75% +

The outcome of this analysis was two clusters with duration being the key driver. In order to be consistent with the BEV analysis and to allow for the differences between home charges and public or workplace charges to be explored, the cluster analysis was re-run separately on the three distance-from-home categories. In other words, the ‘Distance from home’ categories were prescribed boundaries between the clusters. The other variables listed above were fed into a clustering algorithm and used to elicit naturally occurring groupings in the charge events.

Home events

Two clusters were found to describe the home charging events:

- H1: 75%+ SOC added (56%)
- H2: <75% SOC added (44%)

The separation of these two clusters was driven by the amount of charge added. As most charge events finished on close to 100% SOC, home events are mostly defined by the amount of charge required to reach a full battery. Each of these events was predominantly overnight and on a weekday.

Local events

Local events were divided based on duration, and consequently the amount of SOC added. However, time of day was also important. Four clusters were identified:

- L1: Mid-length morning fill-up (29%)
- L2: Mid-length afternoon fill-up (26%)
- L3: Long charge (18%)
- L4: Short ‘top-up’ (27%)

After the trial, participants reported that the majority of charges away from home took place at work. This suggests that one of the key differences in the types of local charge event may be charger availability at work. Most charge events started in the morning (supporting the influence of work charging) although short charges typically occurred at the weekend rather than during the week as with the other charge types. This suggests that participants were using charging away from home to top up when using the vehicle for leisure activities (for example shopping). This was completed even though the charge added was small suggesting some level of convenience motivated the decision to charge.

Table 51: Summary characteristics of Local charge event clusters (PHEV)

	L1: Mid-length morning fill-up 29% of charge events	L2: Mid-length afternoon fill-up 26% of charge events	L3: Long charge 18% of charge events	L4: Short charge 27% of charge events
Day of the week	All on weekdays	66% on weekdays	77% on weekdays	88% at weekends
Time of day	All morning charges	Most events were morning (55%) but otherwise spread	Predominantly morning (77%)	Predominantly morning (43%) although 36% started in the afternoon

	L1: Mid-length morning fill-up 29% of charge events	L2: Mid-length afternoon fill-up 26% of charge events	L3: Long charge 18% of charge events	L4: Short charge 27% of charge events
		throughout the day		
SOC added	38% added over 75% SOC 35% added 50-74% SOC 27% added 25-49% SOC	41% added over 75% SOC 35% added 50-74% SOC 24% added 25-49% SOC	All events delivered at least 75% SOC	All less than 50% SOC; two-thirds less than 25% SOC
Duration of charge	All 1-3 hours	Almost all 1-3 hours	All >3 hours	All <1 hour

•

Distant events

Out of all of the charges that took place more than 50 miles from home, two clusters were identified. Similar to the home charges, charge duration was the key defining factor. However, there was more deviation over time of day.

The types of charge were:

- D1: Fill-up (62%)
- D2: Top-up (38%)

The Fill-up (D1) charges can be described as follows:

- Two-thirds lasted one to three hours and the rest lasted over three.
- Over half (52%) delivered over 75% SOC, 30% delivered 50-74% and 18% delivered 25-49%.
- Just over a third started in the evening at between 19% and 26% started in the other time of day categories.

The Top-up (D2) charges can be described as follows:

- All lasted less than an hour and 79% delivered less than 25% SOC.
- Close to a third of these events started in the morning, afternoon or evening with very few starting overnight.

In both cases just over 70% took place on weekdays reflecting the overall results breakdown by day of the week.

Cluster comparison

The number of participants that used each type of charge is shown in Table 52. Nearly all participants used each of the two home charge types, whereas around a third used the most common type of local charge and only a small proportion used the most common 'away' charge type.

Table 52: Number of events and participants per charge type cluster

Location	Charge cluster	Number of participants	Number of charges
Home	H1 = 75% + SOC added	119	3,262
	H2 = <75% SOC added	120	2,607
Local	L1 = Mid-length morning fill-ups	28	216
	L2 = Mid-length afternoon fill-ups	43	199
	L3 = Long morning charges	15	236
	L4 = Short morning top-ups	48	204
Distant	D1 = Fill-ups	16	89
	D2 = 'Top-ups'	15	55

In general, participants from the different trial groups were similarly likely to use each of the charge types above. However there were some differences based on demographics[41]:

- People living in rural areas or on town fringes were more likely than those in more urban areas to undertake 'away' charges. This may be related to the average trip length for these two groups of participants. On average, trips made by participants living in rural areas were 1.5 miles longer than those living in urban areas ($p < 0.001$).
- Local long morning charges (L3) were more likely to be used by people living in urban city or town centres.
- Local long morning charges (L3) were more likely to be people in the middle age categories (specifically 25-29 and 55-59 years).
- Participants aged 60-65 and 19-24 were the most likely to charge over 50 miles away from home.
- Male participants were more likely than females to charge over 50 miles away from home.
- Local charges were more likely to be used by "every-day" drivers.

Predicting charge types with journey data

This part of the analysis looks at how data from the journey before a charge completed can be used to predict the type of charge that took place. In order to do this, the charge data was linked to the journey that happened immediately before it.

The most common type of charge was a home charge that added 75% or more charge to the battery (H1). This was used as the reference category for the regression analysis. This means

[41] All of these were tested using Chi-square and were statistically significant using the 0.05 significance value.

that the results compare how well the journey variable predicts each of the other types of charge occurs over a mid-duration home charge. For example, the results may say that the longer a journey is, the more likely the following charge was further than 50 miles away from home to fill up the battery instead of a home fill-up charge.

The journey variables used were[42]:

- Day of the week
- Start time
- Distance
- EV fraction
- MPG
- End SOC

Data from previous journeys

Using the data from the previous journey to predict the charge type created a significant model ($\chi^2(49) = 4313.514$, $p < 0.001$) with all variables have a significant main effect. This model predicted cluster membership with 77% accuracy. Home charges were able to be predicted much more accurately by the model as they made up the majority of charge events and hence the model is weighted towards predicting these charge types. As shown in Table 53 some types of charge were not predicted at all by the model.

Table 53: Model accuracy for predicting PHEV charge cluster using data from previous journey

Observed cluster	Predicted cluster								Percentage Correct
	H1	H2	L1	L2	L3	L4	D1	D2	
H1	2467	128	25	1	13	0	3	0	**93.6%**
H2	403	1322	39	0	3	0	1	0	**74.8%**
L1	53	48	93	0	0	0	0	0	**47.9%**
L2	92	59	4	0	0	0	0	0	**0.0%**
L3	62	0	12	0	15	0	0	0	**16.9%**
L4	41	87	12	0	1	0	0	0	**0.0%**
D1	36	13	6	0	0	0	0	0	**0.0%**
D2	10	6	2	0	0	0	0	0	**0.0%**
Overall	**62.6%**	**32.9%**	**3.8%**	**0.0%**	**0.6%**	**0.0%**	**0.1%**	**0.0%**	**77.1%**

Although each variable was significant in the overall model, not all variables were significant for predicting each of the charge type clusters. These results are shown in Table 54.

[42] The journeys maximum speed was also considered as a predictor variable for these models; however, it had a very high correlation coefficient (between 0.854 and 0.883) with the journey distance variable, hence only journey distance was included.

Table 54: Significant variables for predicting PHEV charge cluster using data from the previous journey

Location	Charge cluster	Significant predictors	*P*-values
Home	H1 = 75% + SOC added	*Reference*	*N/A*
	H2 = <75% SOC added	Weekday	$p < 0.001$
		Start time	$p < 0.001$
		Distance	$p < 0.001$
		MPG	$p = 0.034$
		End SOC	$p < 0.001$
Local	L1 = Mid-length morning fill-ups	EV fraction	$p = 0.033$
		Start time	$p < 0.001$
		MPG	$p = 0.017$
		End SOC	$p < 0.001$
	L2 = Mid-length afternoon fill-ups	Start time	$p < 0.001$
		End SOC	$p < 0.001$
	L3 = Long morning charges	Weekday	$p < 0.001$
		Start time	$p < 0.001$
		Distance	$p = 0.004$
		End SOC	$p < 0.001$
	L4 = Short morning 'top-ups'	Weekday	$p < 0.001$
		Start time	$p < 0.001$
		End SOC	$p < 0.001$
Distant	D1 = Fill-ups	EV fraction	$p = 0.023$
		Start time	$p < 0.001$
		Distance	$p < 0.001$
		End SOC	$p < 0.001$
	D2 = 'Top-ups'	Start time	$p < 0.001$
		Distance	$p = 0.001$
		End SOC	$p < 0.001$

To summarise the results shown above, the journey start time and end SOC were able to significantly predict the charge type of each charge cluster. Broadly speaking, the journey start time can be associated with the charge location and the end SOC was associated with the charge duration and added SOC. The directions of these results are shown in Table 55.

Table 55: PHEV charge cluster model predictor descriptive

Charge type	Average start time	Average trip distance	Average EV-fraction	Average MPG	Average trip end SOC (%)	Average max speed (MPH)	% on weekdays
H1	16:42:09	12.64	50.47	284.52	9.75	55.95	76%
H2	15:27:41	7.85	73.61	691.28	39.80	49.82	80%
L1	07:15:54	13.92	77.04	751.71	31.71	61.22	100%
L2	13:25:48	11.47	70.93	247.23	20.61	54.73	63%
L3	09:24:04	8.89	61.44	37.75	5.14	48.13	96%
L4	11:54:14	11.01	66.87	268.75	42.65	52.57	89%
D1	14:05:03	27.76	41.22	32.96	19.32	62.13	72%
D2	12:57:07	23.51	50.86	78.87	28.14	55.13	64%

In every case, having an earlier journey start time predicted that the charge type wouldn't be a home fill-up charge. This is in line with the cluster characteristics which showed that most home charges occur overnight whereas local and distant charges take place during the day. This is also in line with result in B.5.1.

A low SOC at the end of the previous journey tended to predict that the next charge would be a home fill-up instead of one of the other charge types, except for local long morning charges (L3) where the previous journey tended to end on a much lower SOC.

The results were as expected for journey distance with longer journeys being more likely to be followed by a distant charge than a home fill-up. The trip distances tended to be similar for home and local charge events, hence why distance was not a significant predictor for local charges. Distant charges also had journeys preceding them with much lower EV-fractions than the other charge types.

Data from subsequent journeys

This analysis was completed to understand if the charging behaviour of participants was a result of their previous journeys or those they were planning to undertake. This time the data used was taken from the journey that occurred immediately after each charge[43].

Using the data from the subsequent journey to predict the charge type created a significant model ($\chi^2(49) = 1153.373$, $p < 0.001$) with all variables have a significant main effect. However, this model was only able to predict with 58% accuracy with a similar bias towards the most common types of charge.

Table 56: Model accuracy for predicting PHEV charge cluster using data from the following journey

Observed cluster	Predicted cluster H1	H2	L1	L2	L3	L4	D1	D2	Percentage Correct
H1	2428	281	1	7	0	0	0	0	**89.4%**
H2	1189	511	0	2	0	0	0	0	**30.0%**
L1	128	66	0	0	0	0	0	0	**0.0%**
L2	75	76	3	1	0	0	0	0	**0.6%**
L3	55	36	0	0	0	0	0	0	**0.0%**
L4	58	67	0	1	0	0	0	0	**0.0%**
D1	44	9	0	0	0	0	0	0	**0.0%**
D2	7	9	0	0	0	0	0	0	**0.0%**
Overall	**78.8%**	**20.9%**	**0.1%**	**0.2%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**58.2%**

Although each variable was significant in the overall model, not all variables were significant for predicting each of the charge type clusters. These results are shown in Table 57.

[43] Only charges that were followed by a journey when all charge and journey data was combined ad ordered chronologically were used. A small proportion of events were excluded by process as they were followed by another charge event.

Table 57: Significant variables for predicting PHEV charge cluster using data from the following journey

Location	Charge cluster	Significant predictors	*P*-values
Home	H1 = 75% + SOC added	*Reference*	*N/A*
	H2 = <75% SOC added	Weekday	$p = 0.011$
		EV fraction	$p < 0.001$
		Start time	$p < 0.001$
		Distance	$p < 0.001$
		MPG	$p = 0.008$
		End SOC	$p < 0.001$
Local	L1 = Mid-length morning fill-ups	Start time	$p < 0.001$
	L2 = Mid-length afternoon fill-ups	Weekday	$P < 0.001$
		Start time	$p < 0.001$
		End SOC	$p < 0.001$
	L3 = Long morning charges	Weekday	$p < 0.001$
		EV fraction	$p = 0.002$
		Start time	$p < 0.001$
		MPG	p = 0.049
	L4 = Short morning top-ups	Weekday	$p = 0.003$
		EV fraction	$p < 0.001$
		Start time	$p < 0.001$
		Distance	$p < 0.001$
		End SOC	$p < 0.001$
Distant	D1 = Fill-ups	Start time	$p < 0.001$
		Distance	$p = 0.017$
	D2 = 'Top-ups'	Start time	$p = 0.004$
		Distance	$p = 0.008$
		End SOC	$p < 0.001$

To summarise the results shown above, the journey start time and end SOC able to significantly predict the charge type of each charge cluster. Table 58 shows the predictor descriptives for each type of charge.

Table 58: PHEV charge cluster model predictor descriptive

Charge type	Average start time	Average trip distance	Average EV-fraction	Average MPG	Average trip end SOC (%)	% on weekdays
H1	10:13:17	13.02	79.51	1018.89	61.30	77%
H2	11:45:05	9.41	68.56	586.04	53.70	80%
L1	14:58:27	10.58	81.37	1288.05	58.04	100%
L2	15:28:22	11.22	80.34	737.38	43.72	63%
L3	15:05:59	8.64	90.19	39.55	61.66	93%
L4	14:34:34	8.96	56.85	93.04	39.04	87%
D1	13:24:49	21.09	56.02	84.84	43.19	68%
D2	13:15:43	6.62	56.95	20.75	23.86	70%

In every case, the earlier the journey start time the more likely the charge was a home fill-up. This is in line with the cluster characteristics which showed that most home charges occur overnight and hence would be followed by the first journey of the day whereas local and away from home charges take place during the day.

A high SOC at the end of the previous journey tended to predict that the charge would be a home fill-up instead of one of the other charge types. The exception to this was for local long morning charges (L3). In this case, the earlier the journey, the more likely it was a long morning charge (L3) where the previous journey tended to end on a similar SOC. The results were as expected for journey distance with longer journeys being more likely to be followed by a charge more than 50 miles away from home than a home fill-up (H1) charge.

B.5.2.2 *Comparison of attitudes towards electric vehicles before and after experience*

- → **Participants said they would be more likely to buy a BEV or a PHEV as a second car after the trial than before.**
- → **Positive changes in attitudes included BEV rating on the vehicle's pleasantness, cost depreciation and performance.**
- → **There were mixed changes in attitudes around BEVs' range, charging capabilities, and environmental benefits.**
- → **Attitudes towards PHEVs showed less change.**
- → **The only theme that showed a consistent result was vehicle performance where attitudes improved over the course of the trial across a wide range of performance aspects.**

Likelihood to purchase a PiV

Participants were asked to indicate how likely or unlikely they were to consider buying a BEV and PHEV in the next five years as either a main or second car (on a scale from (1) "Very unlikely" to (5) "Very likely"). The Wilcoxon Signed Ranks Test was used to compare responses between TP1 and TP2 to see if likelihood to purchase changed following experience in the trial.

Ratings of likelihood to purchase a BEV before and after the trial are shown in Figure 149. Participants' opinions become more polarised over time; fewer participants reported they were neither likely nor unlikely to purchase a BEV after experience in the trial. A greater share of participants said they'd be likely or very likely to buy a BEV as a second car after the trial than before ($Z = -1.873$, $p = 0.061$). No significant differences in likelihood to purchase a BEV as a main car were found.

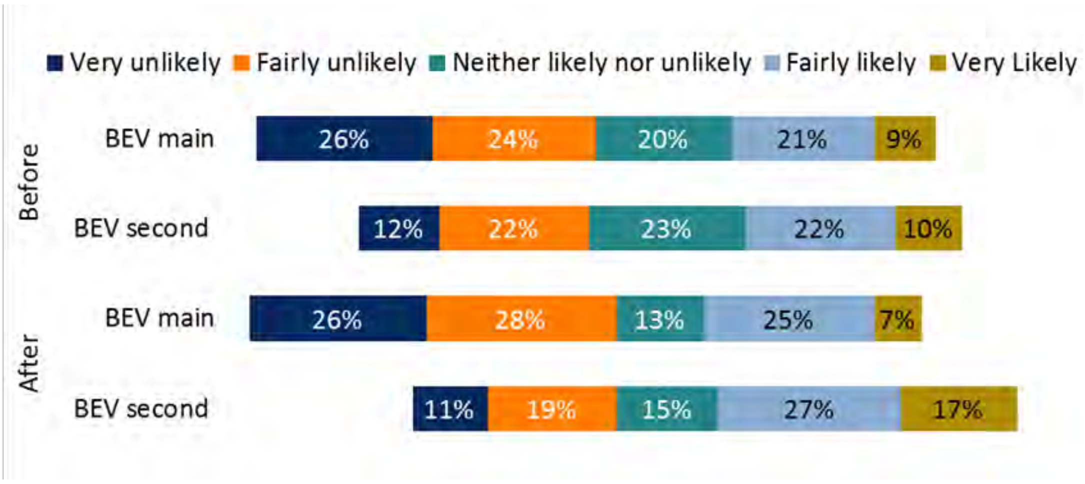


Figure 149: Likelihood to purchase a BEV – results from before and after the trial (N = 127)

Ratings of likelihood to purchase a PHEV before and after the trial are shown in Figure 150. Likelihood to purchase a PHEV as a second car increased significantly after the trial (Z = -2.303, *p* = 0.021). The pattern of responses for PHEVs as a main car was similar, but not statistically significant.

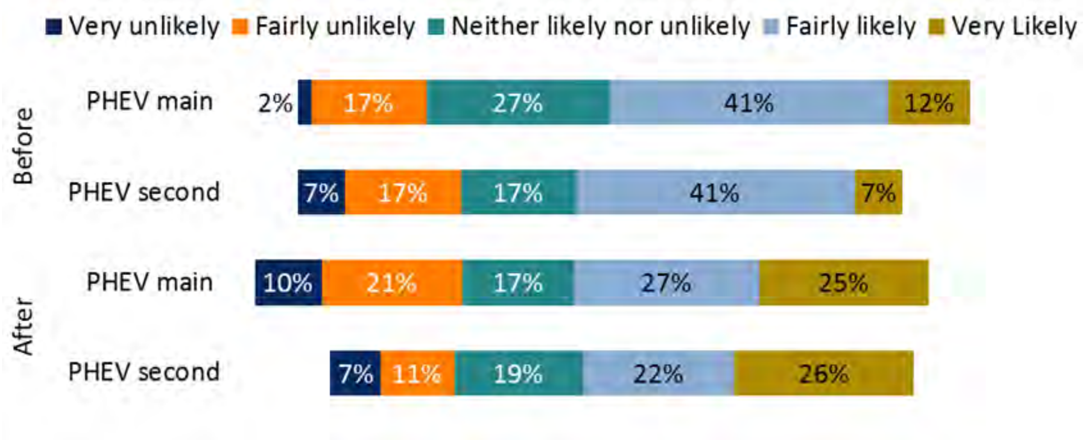


Figure 150: Likelihood to purchase a PHEV – results from before and after the trial (N = 127)

Attitudes towards BEVs

This section summarises the attitudes towards BEVs of the participants from the PHEV trial; they had not experienced a BEV. Participants were asked a set of questions about their attitudes towards BEVs and PHEVs before and after the trial. These questions covered the following themes:

- Affective attitudes
- Cost
- Environmental benefits
- Independence from oil companies
- Vehicle performance

- Range and charging capabilities
- Reliability
- Safety
- Symbolic attitudes (i.e. the level to which the participant thinks they are similar to someone who would own a BEV or PHEV)
- Travel needs

To examine whether these items could be reduced into a smaller list of related factors, a factor analysis was first conducted. Whilst reliable factors were identified, the factor structure differed between TP1 responses and TP2 responses. As such, comparison of the factors between TP1 and TP2 was not possible. Instead, direct comparisons of responses between TP1 and TP2 were undertaken; the statistically significant results from these comparisons are presented below. The full set of results is shown in Table 59.

Affective

Participants rated BEVs as being more pleasant to drive relative to conventional cars after the trial than they did before the trial. This was the only affective attitude to show a significant change over time.

Cost

The results were mixed for the attitudes around the cost of BEVs. Participants rated BEVs as more expensive to buy after the trial relative to a conventional car but they also agreed more that BEVs would depreciate in value slower than a conventional car.

Environmental benefits

After the trial, the participants were less likely to agree that the environmental benefits of BEVs have been over-exaggerated. This was the only significant change for questions about the environmental benefits of BEVs.

Performance

The attitudes towards the performance of BEVs improved across the board with the changes being significant in all but one case (BEVs being more powerful than a conventional car). This implies that experience of a PHEV impacted attitudes towards BEV performance as participants tended to give higher ratings for the performance of BEVs relative to a conventional car after the trial than they did before the trial.

Range and charging capabilities

Participants' attitudes towards range-anxiety significantly improved over the trial with the level of agreement to the following statement significantly decreasing between the TP1 and TP2 questionnaires: "When driving a BEV, I would always be worried about running out of charge". However, participants also more strongly agreed that they would want to have rapid charging capability if they owned a BEV after the trial than they did before. This may be related to PHEVs used in the trial not having this capability.

Reliability

The level of agreement that BEVs are more likely to break down than a conventional car significantly decreased over the trial period. This was the only significant change related to BEV reliability.

Safety

There was a significant improvement in the level of agreement that BEVs are similar to PHEVs between start and end of the trial. No other attitudes related to BEV safety appeared to change significantly.

Table 59: Changes in attitudes towards BEVs over time[44]

Theme	Attitude	Z score	*p*-value	Before (TP1) Mean	Before (TP1) SD	After (TP2) Mean	After (TP2) SD	Direction of change[45]
Affective	BEVs are pleasant to drive	-7.932	< 0.001	3.41	0.63	4.13	0.64	Positive
	BEVs are a very exciting new technology	-1.184	0.236	3.93	0.78	4.02	0.77	Positive
	I would prefer to drive a conventional car than a BEV	-0.838	0.402	2.85	0.94	2.8	0.97	Positive
	BEVs are a current fad which will soon disappear	-0.350	0.726	2.04	0.78	2.02	0.85	Positive
Cost	BEVs are more expensive to buy than conventional cars	-2.314	0.021	4.09	0.58	4.26	0.64	Negative
	BEVs will lose value more quickly than a conventional car	-2.175	0.03	3.04	0.79	2.87	0.84	Positive
	I would be prepared to pay more for a BEV than a conventional car	-1.719	0.086	2.53	0.90	2.68	0.92	Positive
	BEVs are a cheaper option over the longer term	-1.260	0.208	3.26	0.84	3.15	0.90	Negative
	BEVs are more expensive to run than conventional cars	-0.686	0.493	2.28	0.77	2.23	0.79	Positive
	BEVs will hold its value better than a conventional car	-0.564	0.573	2.97	0.83	2.92	0.74	Negative
Environmental Benefits	The environmental benefits of BEVs have been over-exaggerated	-1.989	0.047	2.71	0.83	2.88	0.94	Positive
	BEVs offer environmental benefits	-1.608	0.108	4.16	0.75	4.06	0.80	Negative
	Driving a BEV would give me a ‘feel good factor’ because of its green credentials	-1.404	0.160	3.5	0.89	3.62	0.84	Positive

[44] Statistically significant results have been shaded.

[45] For this table, a positive change indicates either an increase in a desirable attitude towards EVs or a reduction in an undesirable attitude whereas a negative change signifies either a reduction in a desirable attitude or an increase in an undesirable attitude.

Theme	Attitude	Z score	*p*-value	Before (TP1) Mean	Before (TP1) SD	After (TP2) Mean	After (TP2) SD	Direction of change[45]
	BEVs emit less carbon dioxide than conventional cars	-1.042	0.297	4.24	0.81	4.31	0.78	Positive
	BEVs are good for the environment	-0.379	0.705	3.99	0.91	3.99	0.85	Negative
	BEVs are a really good idea	-1.228	0.219	3.98	0.82	4.05	0.72	Positive
Independence from oil	BEVs are a good thing because they make us less dependent on oil	-0.795	0.427	3.83	0.84	3.89	0.85	Positive
	Not having to go to a petrol station to refuel would make me more likely to buy a BEV	-0.553	0.580	3.37	0.96	3.33	1.03	Negative
	I would like to be less dependent on oil companies for fuelling my car	-0.329	0.742	3.93	0.72	3.95	0.74	Positive
	I like the idea of being able to ‘refuel’ at home rather than have to go to petrol stations	-0.089	0.929	4.05	0.72	4.05	0.80	Negative
Performance	BEVs would be less responsive when accelerating than a conventional car	-4.436	< 0.001	2.36	1.02	1.92	0.78	Positive
	BEVs would be less comfortable than a conventional car	-4.299	< 0.001	2.02	0.78	1.72	0.65	Positive
	BEVs would have worse acceleration from 30-50mph compared with a conventional car	-3.826	< 0.001	2.55	0.89	2.19	0.79	Positive
	BEVs would be noisier when pulling away than a conventional car	-3.182	0.001	1.66	0.69	1.44	0.66	Positive
	BEVs would be smoother to drive when accelerating than a conventional car	-3.285	0.001	3.69	0.73	3.96	0.77	Positive
	BEVs would be less smooth to drive when cruising	-3.417	0.001	2.05	0.78	1.8	0.67	Positive
	BEVs would have better acceleration from 0-30mph compared with a conventional car	-2.816	0.005	3.49	0.95	3.74	0.96	Positive

Theme	Attitude	Z score	*p*-value	Before (TP1) Mean	Before (TP1) SD	After (TP2) Mean	After (TP2) SD	Direction of change[45]
	BEVs perform better than a conventional car	-1.785	0.074	3.1	0.74	3.23	0.80	Positive
	BEVs would be more powerful than a conventional car	-1.730	0.084	2.94	0.80	3.08	0.84	Positive
	BEVs would be quieter when cruising than a conventional car	-0.400	0.689	4.09	0.74	4.05	0.86	Negative
Range and charging	When driving a BEV, I would always be worried about running out of charge	-2.547	0.011	3.78	1.05	3.53	1.13	Positive
	I would only consider a BEV if I knew I had access to a rapid charging point (i.e. somewhere it would charge to 80% in around 30 minutes)	-2.242	0.025	3.6	0.99	3.86	1.02	Negative
	Having to remember to plug in a BEV would put me off buying one	-1.557	0.119	2.24	0.92	2.38	1.04	Negative
	Adapting to charging a BEV would be difficult for me	-1.499	0.134	2.36	0.89	2.23	0.97	Positive
Reliability	The chances of breaking down in a BEV are higher than in a conventional car	-2.040	0.041	2.81	0.99	2.64	0.88	Positive
	BEVs are too new to be reliable	-1.667	0.096	2.61	0.84	2.48	0.81	Positive
	BEVs are more complicated than a conventional car	-1.365	0.172	2.67	0.94	2.8	1.03	Negative
	BEVs would be more reliable than a conventional car	-0.502	0.616	3.14	0.76	3.18	0.69	Positive
Safety	BEVs are similar to a conventional car in most respects	-1.989	0.047	3.69	0.72	3.88	0.75	Positive
	BEVs are as safe for the driver and passengers as conventional cars	-1.210	0.226	4.01	0.78	4.09	0.82	Positive
	BEVs are a danger to people outside the car because of the lack of engine noise	-1.089	0.276	3.27	0.98	3.18	0.93	Positive
Symbolic	I am the type of person who would drive a BEV	-1.500	0.134	3.42	0.90	3.55	1.00	Positive

				Before (TP1)		After (TP2)		
Theme	**Attitude**	**Z score**	***p*-value**	**Mean**	**SD**	**Mean**	**SD**	**Direction of change[45]**
	I would feel embarrassed to drive a BEV	-1.013	0.311	1.68	0.69	1.76	0.76	Negative
	Many people I know would be attracted to owning a BEV	-0.947	0.344	2.93	0.81	2.98	0.87	Positive
	I would only consider a BEV if there were plenty to choose from among the main car manufacturers	-0.909	0.363	3.34	0.88	3.45	0.98	Negative
	I would feel proud of having a BEV outside my house	-0.004	0.996	3.57	0.75	3.58	0.82	Positive
Travel needs	If I had a BEV, it would be unlikely to be my main or only car	-1.848	0.065	3.31	1.04	3.52	1.17	Negative
	A BEV would suit my daily travel patterns	-1.703	0.089	3.5	1.02	3.37	1.17	Negative
	BEVs are suitable for my lifestyle	-0.544	0.587	3.27	1.05	3.34	1.10	Positive
	BEVs are impractical	-0.046	0.963	2.52	0.92	2.53	0.92	Positive
	Having a BEV would mean I would have to plan journeys carefully	-0.005	0.996	4.18	0.74	4.17	0.79	Positive

Attitudes towards PHEVs

This section summarises the attitudes towards PHEVs of the participants from the PHEV trial. This section describes the significant changes in attitudes shown in Table 60. Overall there were mixed results with some attitudes improving such as those towards the vehicles performance, and some decreasing such as the attitudes around PHEV environmental benefits.

Affective

As with the affective attitudes towards BEVs, the only significant change for PHEVs was an increase in the level of agreement that PHEVs are pleasant to drive.

Cost

The level of agreement that PHEVs are more expensive than conventional cars significantly increased, and the level of agreement that PHEVs are cheaper over the long run significantly decreased between the TP1 and TP2 questionnaires. These results suggest that the trial had a negative impact on how the participants viewed the cost of PHEVs.

Environment

There was generally a negative change in attitudes around the environmental benefits that PHEVs offer. There was a significant reduction in the level of agreement for the following two statements:

- PHEVs offer environmental benefits
- PHEVs are good for the environment

This may suggest that PHEVs did not meet the participants' expectations on the environmental benefits they offer.

Independence from oil companies

Again, the independence from oil attitudes generally changed in a negative way over the trial although the only result that saw a significant reduction was about the appeal of being able to refuel at home.

Performance

The perceptions of the performance of PHEVs improved across the board with the changes being significant in all but two cases:

- PHEVs are more powerful than a conventional car
- PHEVs perform better than a conventional car

Symbolic

In general, after the trial, participants rated themselves as being more similar to the type of person who would own a PHEV than they did before the trial. Specifically, participants saw themselves as being significantly less embarrassed and more proud of owning a PHEV after the trial.

Table 60: Changes in attitudes towards PHEVs over time[46]

Theme	Attitude	Z score	*p*-value	Before (TP1)		After (TP2)		Direction of change[47]
				Mean	SD	Mean	SD	
Affective	PHEVs are pleasant to drive	-7.077	< 0.001	3.53	0.61	4.26	0.70	Positive
	PHEVs are a very exciting new technology	-1.797	0.072	4.02	0.74	3.91	0.87	Negative
	I would prefer to drive a conventional car than a PHEV	-1.004	0.315	2.42	0.76	2.33	1.03	Positive
	PHEVs are a current fad which will soon disappear	-0.449	0.654	2.1	0.74	2.14	0.92	Negative
Cost	PHEVs are more expensive to buy than conventional cars	-3.052	0.002	4.04	0.57	4.23	0.60	Negative
	PHEVs are a cheaper option over the long term	-2.015	0.044	3.32	0.80	3.13	0.94	Negative
	PHEVs will lose value more quickly than a conventional car	-1.565	0.118	2.77	0.75	2.91	0.82	Negative
	I would be prepared to pay more for a PHEV than a conventional car	-1.446	0.148	3.1	0.90	2.94	0.97	Negative
	PHEVs will hold its value better than a conventional car	-1.448	0.148	3.13	0.81	3.02	0.78	Negative
	PHEVs are more expensive to run than conventional cars	-0.547	0.585	2.46	0.65	2.43	0.84	Positive
Environmental Benefits	PHEVs offer environmental benefits	-2.32	0.020	4.1	0.64	3.95	0.79	Negative
	PHEVs are good for the environment	-2.308	0.021	3.96	0.74	3.8	0.81	Negative
	The environmental benefits of PHEVs have been over-exaggerated	-1.863	0.062	2.73	0.86	2.9	0.95	Negative

[46] Statistically significant results have been shaded.

[47] For this table, a positive change indicates either an increase in a desirable attitude towards EVs or a reduction in an undesirable attitude whereas a negative change signifies either a reduction in a desirable attitude or an increase in an undesirable attitude.

Theme	Attitude	Z score	*p*-value	Before (TP1) Mean	Before (TP1) SD	After (TP2) Mean	After (TP2) SD	Direction of change[47]
	Driving a PHEV would give me a ‘feel good factor’ because of its green credentials	-1.374	0.169	3.55	0.89	3.68	0.88	Positive
	PHEVs emit less carbon dioxide than conventional cars	-0.517	0.605	4.01	0.68	3.98	0.74	Negative
	PHEVs are a really good idea	-1.745	0.081	4.12	0.68	4.01	0.86	Negative
Independence from oil	Not having to go to a petrol station to refuel would make me more likely to buy a PHEV	-2.378	0.017	3.9	0.82	3.73	0.92	Negative
	I would like to be less dependent on oil companies for refuelling my car	-0.906	0.365	4.01	0.76	4.07	0.75	Positive
	PHEVs are a good thing because they make us less dependent on oil	-0.544	0.587	3.91	0.84	3.88	0.91	Negative
	I like the idea of being able to ‘refuel’ at home rather than have to go to petrol stations	-0.514	0.607	4.02	0.71	4.07	0.70	Positive
Performance	PHEVs would be less responsive when accelerating than a conventional car	-4.592	< 0.001	2.44	0.77	1.99	0.75	Positive
	PHEVs would be noisier when pulling away than a conventional car	-4.099	< 0.001	2.03	0.61	1.72	0.60	Positive
	PHEVs would be smoother to drive when accelerating than a conventional car	-3.597	< 0.001	3.43	0.68	3.73	0.82	Positive
	PHEVs would have worse acceleration from 30-50mph compared with a conventional car	-4.331	< 0.001	2.56	0.81	2.18	0.77	Positive
	PHEVs would be less smooth to drive when cruising	-3.061	0.002	2.07	0.67	1.83	0.63	Positive
	PHEVs would be less comfortable than a conventional car	-2.948	0.003	1.98	0.72	1.75	0.63	Positive
	PHEVs would be quieter when cruising than a conventional car	-2.683	0.007	3.53	0.83	3.75	0.90	Positive

Theme	Attitude	Z score	*p*-value	Before (TP1) Mean	Before (TP1) SD	After (TP2) Mean	After (TP2) SD	Direction of change[47]
	PHEVs would have better acceleration from 0-30mph compared with a conventional car	-2.096	0.036	3.29	0.88	3.48	0.94	Positive
	PHEVs would be more powerful than a conventional car	-1.623	0.105	2.95	0.74	3.1	0.89	Positive
	PHEVs perform better than a conventional car	-0.38	0.704	3.26	0.68	3.24	0.82	Negative
Range and charging	Adapting to charging a PHEV would be difficult for me	-1.744	0.081	2	0.81	1.84	0.89	Positive
	When driving a PHEV, I would always be worried about running out of charge	-1.742	0.081	2.13	0.88	1.98	0.95	Positive
	I would only consider a PHEV if I knew I had access to a rapid charging point (i.e. somewhere it would charge to 80% in around 30 mins)	-1.135	0.256	3.21	1.12	3.09	1.16	Positive
	Having to remember to plug in a PHEV would out be off buying one	-0.336	0.737	1.99	0.68	2.02	0.92	Negative
Reliability	PHEVs are too new to be reliable	-1.754	0.079	2.45	0.65	2.32	0.78	Positive
	The chances of breaking down in a PHEV are higher than in a conventional car	-1.593	0.111	2.63	0.73	2.5	0.86	Positive
	PHEVs are more complicated than a conventional car	-1.345	0.179	3.4	0.93	3.27	1.09	Positive
	PHEVs would be more reliable than a conventional car	-0.977	0.328	2.85	0.59	2.92	0.72	Positive
Safety	PHEVs are similar to conventional cars in most respects	-1.756	0.079	3.98	0.59	4.1	0.69	Positive
	PHEVs are as safe for the driver and passengers as conventional cars	-1.503	0.133	4.05	0.78	4.21	0.70	Positive
	PHEVs are a danger to people outside the car because of the lack of engine noise	-0.581	0.562	2.94	0.97	3.01	1.00	Negative
Symbolic	I would feel proud of having a PHEV outside my house	-3.646	< 0.001	3.6	0.83	3.9	0.82	Positive

Theme	Attitude	Z score	*p*-value	Before (TP1) Mean	Before (TP1) SD	After (TP2) Mean	After (TP2) SD	Direction of change[47]
	I would feel embarrassed to drive a PHEV	-3.138	0.002	1.69	0.67	1.49	0.58	Positive
	I am the type of person who would drive a PHEV	-1.454	0.146	3.91	0.72	4	0.81	Positive
	Many people I know would be attracted to owning a PHEV	-0.898	0.369	3.4	0.81	3.48	0.79	Positive
	I would only consider a PHEV if there were plenty to choose from among the main car manufacturers	-0.086	0.931	3.5	0.87	3.5	0.93	Positive
Travel needs	A PHEV would suit my daily travel patterns	-1.542	0.123	4.06	0.73	3.89	1.01	Negative
	Having a PHEV would mean I would have to plan journeys carefully	-1.503	0.133	2.63	0.98	2.46	1.17	Positive
	If I had a PHEV, it would be unlikely to be my main or only car	-0.901	0.368	2.56	1.03	2.71	1.26	Negative
	PHEVs are impractical	-0.177	0.859	2	0.72	1.97	0.84	Positive
	PHEVs are suitable for my lifestyle	-0.14	0.888	3.96	0.70	3.98	0.88	Positive

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