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Potential adoption of plug-in electric vehicles by the UK mass-market

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Summary

Emissions from road transport contribute to climate change and poor urban air quality. Plug-in electric vehicles (PEVs) are one of the main contenders to replace internal combustion engines to help address these challenges. Previous PEV adoption research has typically focused on Innovators or individuals who have limited experience with PEVs. To tackle these limitations, 200 mainstream consumer drivers (i.e. current petrol or diesel vehicle users) were loaned a battery electric vehicle (BEV), a plug-in hybrid electric vehicle (PHEV), and a regular petrol vehicle (ICEV), and asked to compare them in their everyday driving. In-depth attitudinal data were collected before and after experience with the vehicles. The findings provide insight into the likely adoption of BEVs and PHEVs in the UK mass-market, and the key barriers which need to be overcome.

Keywords: BEV, PHEV, consumers, user behaviour, mass market

1 Introduction

1.1 Global environmental challenges

Climate change and poor air quality are two of the prominent environmental challenges which face the world today. Transport, and in particular, light duty road vehicles account for large proportions of greenhouse gas (GG) emissions which are driving global climate change. In the UK, for example, 27% of all GG emissions in 2016 were from transport, amounting to 126 million tonnes CO_2 equivalent ($MtCO_2e$) [1]. About 70% of those emissions were from light duty road vehicles only. The UK is legally required by the Climate Change Act (2008) to reduce CO_2 emissions in 2050 by 80% compared with levels in 1990. Major reductions in CO_2 emissions from light duty vehicles will be needed to meet this target.

Road transport is also a major contributor to poor air quality which is known to have adverse effects on human health [2, 3]. Rural and urban air pollution increases the risk of health conditions such as cardiovascular and respiratory diseases, strokes and cancer and has been associated with over 4 million premature deaths worldwide per year [4]. Air quality in the UK has improved considerably in recent years; since 1970 sulphur dioxide emissions have reduced by 95%, particulate matter by 73% and nitrogen oxides 69% [5]. Nevertheless, poor air quality in the UK remains the most significant risk to public health [3].

1.2 The role of plug-in electric vehicles

Plug-in Electric Vehicles (PEVs) have a potentially major role to play in addressing these environmental challenges. PEVs are defined here as any vehicles which have an electric motor powered by a battery which can be charged directly by plugging into a normal electrical socket or dedicated EV charging point. PEVs include Plug-in Hybrid Electric Vehicles (PHEVs) and Battery Electric Vehicles (BEVs). PHEVs are similar to traditional Hybrid Electric Vehicles (HEVs) in that they run off a petrol/diesel engine and an electric motor which is powered by a battery, but have an advantage over HEVs in that their batteries can be charged by electricity from an external source. BEVs are powered only by a battery.

Crucially, both BEVs and PHEVs are able to run on electric power while producing no emissions of local air pollutants. Thus, direct reductions in tailpipe emissions (and improvements in air quality) can be achieved by replacing conventional internal combustion engine vehicles (ICEVs) with electric alternatives; the greatest reductions in this case are realised with BEVs since they are zero emission for all journeys. The contribution of PEVs to reducing overall CO_2 emissions (and net contributions to global GG emissions) is, however, more complex. Estimates here must be undertaken on a life-cycle basis that considers the amount of CO_2 emitted in the manufacture and disposal of the vehicle itself, as well as the CO_2 emitted during the process of generating, transmitting and distributing the electricity used to charge their batteries. Some such estimates suggest use of a BEV may result in 50-80% less CO_2 emitted than a comparable ICEV over the life-cycle of the vehicle [6]. Generally, the carbon intensity of PEVs has improved considerably in recent years; for example, charging a small BEV like a Nissan Leaf or BMW i3 produces around half the CO_2 per km driven compared to the similar but non-plug-in Toyota Prius Hybrid [7]. In recognition the UK government has set a target that no ICEVs should be sold from 2040 onwards. PEVs are expected to be the major alternative.

1.3 Previous research on consumer adoption

In 2013, registrations of new BEVs in the UK represented a market share of 0.11% and PHEVs a share of 0.04% [8]. These shares rose in 2018 to 0.7% for BEVs and 1.9% for PHEVs. The PEV market in the UK is in an early stage of development; as technological improvements are made, and costs are reduced, PEVs are likely to become more competitive options for the mass-market. The upward trend in PEV sales in the UK is clear, yet overall numbers remain low, and extrapolation of the growth seen to date to levels of adoption in the coming decades is not straight-forward. Research on attitudes to PEVs can yield important information about what aspects of PEVs remain the key barriers to adoption, and therefore can guide what types of improvements, and to which attributes, could help increase potential mass-market adoption.

1.3.1 Attitudes towards PEVs

A comprehensive literature review was undertaken to understand the state of knowledge with regards to attitudes towards PEVs [9]. The review identified several key gaps in previous research into consumer attitudes to adoption of PEVs in the UK.

Firstly, most previous research has been conducted with people who had already adopted a PEV, or were willing to adopt one as part of a trial, e.g. by leasing a vehicle at their own expense. By definition, according to Rogers' (2003) diffusion model [10], such individuals may be classified as 'Innovators'. These are the first people to adopt innovations, and they adopt largely without direct social influence from others because they have particular personal motivations that are supported by such behaviour. Defined statistically, Innovators are those whose time to adoption lie earlier than two standard deviations before the population mean time to adoption; that is, they represent the first 2.5% (approximately) of the eventual adopter population. Assuming an eventual transition to close to 100% PEV adoption, all those who have already adopted a PEV at the time of writing (2018) are Innovators in diffusion model terms. A previous consumer segmentation study [11] showed that the attitudes of Innovators were unrepresentative of those of the other segments, being much more favourably disposed towards BEVs and PHEVs. This suggests that the attitudes of PEV Innovators are not representative of the attitudes of consumers in the mass-market.

Secondly, where Innovators were not used for research samples, the literature review [9] identified that most previous survey research has been conducted with people who had not experienced PEVs. The limitation in this regard is that the novelty and unfamiliarity of PEVs make these individuals

psychologically distant from them as a category of vehicles [12]. According to Construal Level Theory [12, 13, 14] a psychologically distant object is construed in higher-level, more abstract terms, while a psychologically close object is construed in lower-level, more concrete terms. Psychological distance thus distorts the attitudes that individuals without direct experience of PEVs have towards PEVs.

Lastly, the review also showed that very little research has been conducted on attitudes to PHEVs. Given that, in 2018, PHEV sales in the UK led BEV sales by a ratio of more than 2:1, this represents a substantial gap in knowledge.

1.4 Objectives of this research

The objectives of this trial were to address the three principal limitations identified in previous literature:

1. To explore attitudes to PHEVs as well as BEVs;
2. To recruit a stratified sample of mainstream consumers rather than Innovators; and,
3. To reduce the psychological distance of participants from PEVs by giving them direct experience of using both a BEV and a PHEV.

The research trial described in this paper formed part of the Consumers, Vehicles and Energy Integration (CVEI) project, funded by the Energy Technologies Institute (ETI) in the UK. The trial sought to answer a total of twelve research questions. This paper however presents the results relevant to answering the following selected list of research questions:

- How likely are mass market consumers in the UK to choose a PEV in the next 5 years?
- How does likelihood to choose a PEV change after experience of using one?
- How do functional attributes of PEVs affect likelihood to choose a PEV?
- How do financial factors and incentives affect likelihood to choose a PEV?

2 Method

2.1 Experimental design

The trial utilised a within-participants experimental design. All participants were given direct experience of three types of vehicle to use as a replacement for their own vehicle:

- A **Battery Electric Vehicle (BEV)**
- A **Plug-in Hybrid Electric Vehicle (PHEV)**
- An **Internal Combustion Engine vehicle (ICEV)** for control purposes

Participants were given each vehicle for four days. Each four day period ran back-to-back, totalling 12 days. Participants left their own personal vehicle with the research team for this period. The order in which participants experienced each vehicle was counterbalanced using a Latin square design. A mixture of weekday and weekend usage was covered by varying the day of the week on which participants collected their first vehicle.

A before-after approach was adopted to understand changes in participants' attitudes towards PEVs following experience with them. This was principally addressed through completion of a series of questionnaires before and after experience with the vehicles.

2.2 Participants

Two-hundred mainstream consumers were recruited for the trial. 'Mainstream consumers' were defined as all consumers in Rogers' (2003) Diffusion Model [10] segments except for Innovators; that is the Early Adopter, Early Majority, Late Majority, and Laggard segments. Innovators were thus excluded at the recruitment phase, defined as individuals who'd had regular experience driving a PEV in the last five years, and those who were currently considering acquiring a PEV in the next six months.

A stratified sampling approach was taken, using driving licence data from the Driver and Vehicle Standards Agency (DVSA) and population and travel data from the National Travel Survey (NTS) and Office of

National Statistics). This ensured the sample was representative of drivers in Great Britain in terms of their age, gender and resident area (Urban/Rural).

Participants were recruited from within the 50-mile radii surrounding two research offices in the UK from which the trial operations were based; TRL's head office in Crowthorne, Berkshire, and Cenex's head office in Loughborough, Leicestershire.

2.3 Vehicles

The trial used three variants of the Volkswagen (VW) Golf, selected because this was the only vehicle model that was commercially available (at the time of trialling) with all three drivetrains; the VW e-Golf (BEV), the VW Golf GTE (PHEV) and a petrol VW Golf hatchback GT Edition (ICEVs).

The three models were similar in functional capability (other than the drivetrain differences). All models obtained for the trial were identical in colour (silver) and (as closely as possible) matched in trim and accessories. This minimised the impact of any differences between vehicle types that were associated with vehicle characteristics other than the powertrain configuration. The PHEV had a nominal battery capacity of 8.7kWh and a maximum reported All-Electric Range (AER) of 31 miles (NEDC). At the time of running the trial, the BEV had a nominal battery capacity of 35.8kWh and a maximum reported AER of 186 miles (NEDC), however this has since been updated under the Worldwide Harmonised Light Vehicle Test Procedure (WLTP) to 125 miles.

2.4 Chargepoints

A Mode 2 charging socket on a dedicated circuit was installed in each participant's home to enable them to safely charge the BEV and PHEV during the trial. This limited the charging rate to 2.3kW. Mode 2 charging involves the use of a dedicated charging cable equipped with a residual current device (RCD) that can be connected to a domestic 3-pin socket, and which is suitable for occasional use. Participants were also given free access to the UK's 'POLAR Plus' public charging network for the duration of the trial.

2.5 Data collection

The trial utilised three approaches for collecting data:

1. Participants completed a series of questionnaires providing information on socio-demographics, vehicle ownership, attitudes towards new technology, the environment, driving and PEVs
2. At the end of the trial, participants completed a choice experiment which examined the influence of various factors on consumer choice between ICEVs, BEVs and PHEVs.
3. Data on vehicle journey patterns and charging behaviours were captured using vehicle telematics data loggers fitted to the trial vehicles.

This paper focuses only on the first of these; the attitudinal data collected from questionnaires. Full results from analysis of the other datasets are reported elsewhere.

2.5.1 Questionnaires

Participants completed a total of six questionnaires during the trial:

1. A **Pre-trial questionnaire** containing questions on the participant's household, vehicle ownership history, travel patterns, attitudes about owning and driving a car, driving style, attitudes about new technology, personal travel and the environment
2. A **Time Point 1 (TP1) questionnaire** containing questions on participants' attitudes towards BEVs and PHEVs, including how they compared with conventional cars, affective, symbolic and instrumental attitudes towards BEVs and PHEVs, and willingness to consider a BEV or PHEV as a main or second car;
3. Three **Interim questionnaires** on perceptions of vehicle performance (vehicle acceleration, responsiveness, comfort, noise etc.), and in the case of Interim questionnaire 1, a repeat of the willingness to consider questions from the Time Point 1 questionnaire to allow testing of Hawthorne effects, and;

4. A **Time Point 2 (TP2) questionnaire** which repeated all the questions in the Time Point 1 questionnaire, along with additional items on preferred charging locations, a personality inventory, and the choice experiment.

The trial process is illustrated in Figure 1, showing the point at which each of these questionnaires was administered to participants.

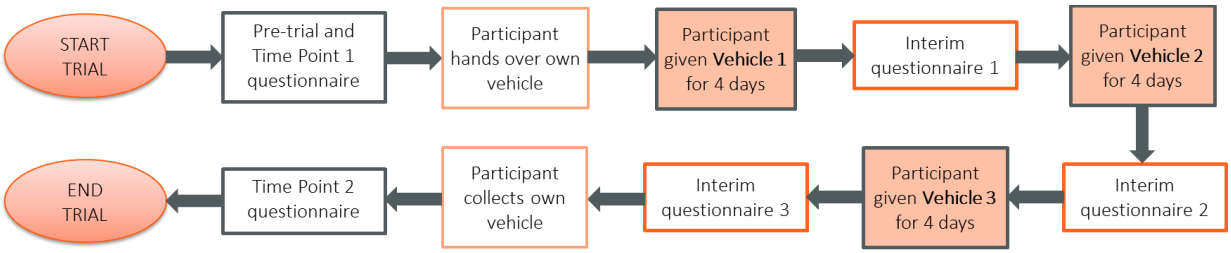

Figure 1: Trial process

3 Results and discussion

3.1 Overview of participant sample

The final sample of participants is shown by age, gender and resident area in Table 1.

Table 1: Stratified sample of mainstream consumer participants

Resident area	Age group	Gender		Total
		Male	Female	
Urban	19-29	13 (-1)	9 (-3)	**22 (-4)**
	30-49	33 (-1)	29 (-1)	**62 (-2)**
	50+	40 (-1)	33 (+1)	**73 (-2)**
Rural	19-29	3 (+1)	3 (+1)	**6 (+2)**
	30-49	8 (+2)	6 (0)	**14 (+2)**
	50+	14 (+2)	9 (-2)	**23 (0)**
Total		111 (+4)	89 (-4)	**200 (0)**

The sample closely matched the target stratification criteria for age, gender and resident area, meaning the sample was representative, on these factors, of the driving population in Great Britain. The characteristics of the final sample were assessed against national statistics for the UK in order to examine the extent to which the sample was representative of the wider population on other metrics. The sample was found to be broadly representative of mainstream consumers in the UK in terms of household vehicle ownership and use, income, education and relationship status. However, some key differences between the sample and the UK population were identified (see Table 2). Caution should therefore be exercised in applying the findings from this trial to households with only one car, households with annual mileage of less than 5,000 miles, and households with annual gross incomes of less than £30,000.

Table 2: Key differences in socio-demographics identified between trial sample and UK national averages

Socio-demographic metric	Trial sample	National average	Source
Proportion of 1 car households	28.5%	41%	National Travel Survey (NTS, 2017)
Proportion of 2+ car households	71.5%	35%	National Travel Survey (NTS, 2017)
Proportion annual mileage <5,000	11%	28%	National Travel Survey (NTS, 2017)
Proportion total household annual income <£30,000	21%	46%	Office for National Statistics (ONS, 2018)

3.2 How likely are mass market consumers in the UK to choose a PEV in the next 5 years?

Participants were asked to indicate the likelihood that they would choose a BEV or PHEV (as a main or second car) in the next five years, using a scale from 1 (very unlikely) to 5 (very likely). Figure 2 shows the results; these data show the ratings given by participants after they had experienced the PEVs in the trial.

A repeated measures non-parametric Friedman test revealed that likelihood to choose differed significantly between the four categories (BEV-Main, BEV-Second, PHEV-Main and PHEV-Second) (χ^2 = 70.644, p < 0.001). Non-parametric Wilcoxon signed ranks tests revealed that likelihood to choose a BEV as a main car (M = 2.465) was significantly lower than likelihood to choose a BEV as a second car (M = 3.342, Z = -5.790, p < 0.001) and significantly lower than likelihood to choose a PHEV as a main car (M = 3.350, Z = -6.731, p < 0.001). There were no significant differences in the reported likelihood to choose a PHEV as a main car (M = 3.350) compared with a second car (M = 3.331, Z = -0.298, p = 0.766), or between the likelihood to choose a BEV or PHEV as second car (Z = -0.080, p = 0.936).

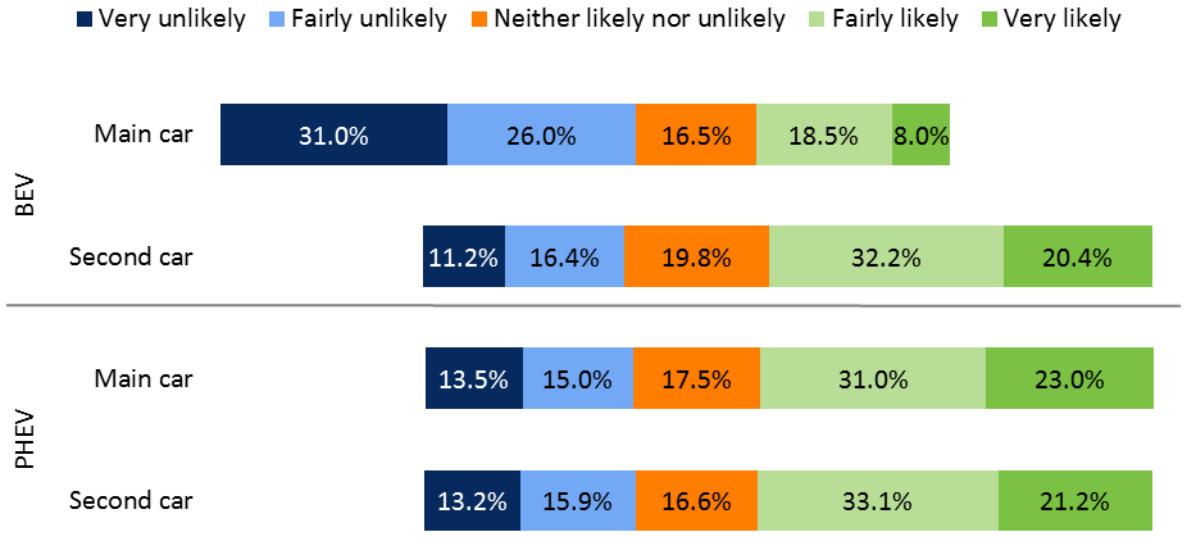

Figure 2: Proportion of mainstream consumers' who reported they were likely or unlikely to choose a PEV in the next five years, after experience with using a BEV and PHEV

About 50% of mainstream consumers reported they would be fairly or very likely to choose a PHEV as a main or second household car in the next five years. A similar proportion indicated they would be likely to choose a BEV in that time frame, but only as a second car. Conversely, about half as many (26.5%) indicated they would consider a BEV as a main car in the next five years, suggesting the majority of the mass-market do not yet consider the specification of BEVs to be suitable for replacement of ICEV main cars.

3.3 How does likelihood to choose a PEV change after experience of using one?

Figure 3 shows participants' reported likelihood to choose a BEV as a main or second car at Time Point 1 (before experience) and Time Point 2 (after experience). Non-parametric Wilcoxon signed ranks tests were used to examine whether the differences in the likelihood to choose a BEV and PHEV between TP1 and TP2 were significant. Overall, the TP1 and TP2 responses for BEV as a main car, PHEV as a main car and PHEV as a second car were not significantly different; suggesting experience with the vehicles did not greatly influence the reported likelihood to choose. Likelihood to choose a BEV as a second car, however, was slightly but significantly higher after experience with the vehicles (TP2, M = 3.342) than before experience with the vehicles (TP1, M = 3.099, Z = -2.607, p = 0.009).

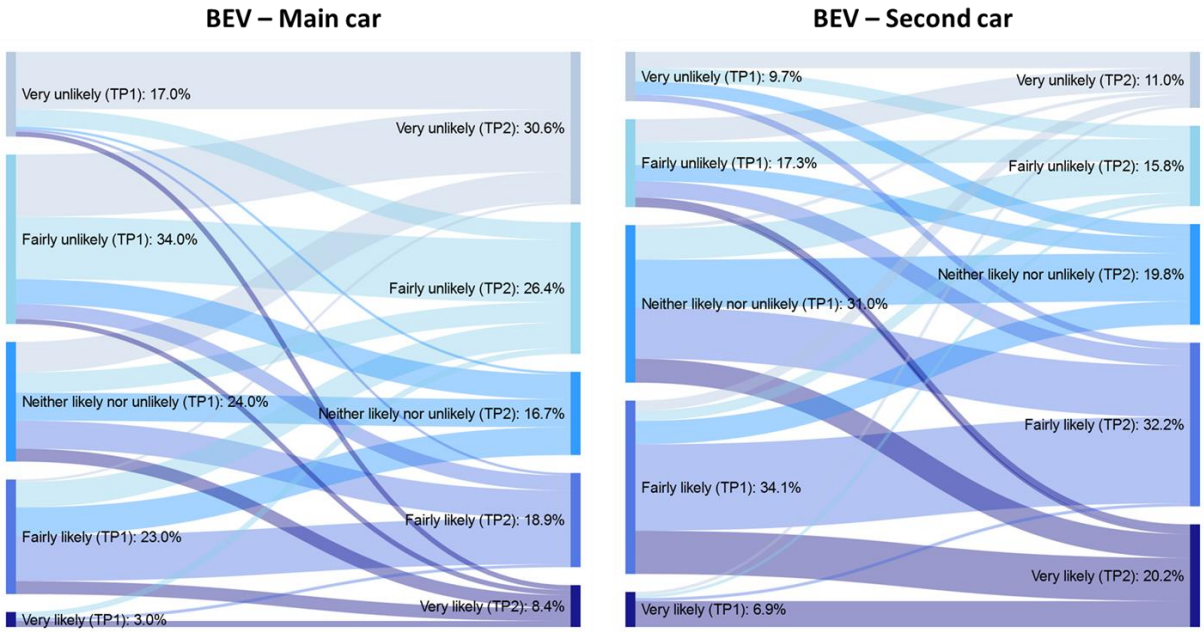

Figure 3: Impact of experience with PEVs on mainstream consumer likelihood to choose a BEV

Despite the similarities in overall likelihood to choose a PEV before and after experience, examination of Figure 2 shows some apparent shifts in the attitudes of groups of participants. Notably, for example, there was an increase in the proportion of mainstream consumers who indicated they would be very unlikely to choose a BEV, which almost doubled, from 17% to 31%. This finding is consistent with a previous mainstream consumer trial of BEVs [15]. At the other end of the scale, however, there was also an increase in the proportion of mainstream consumers who were very likely to choose a BEV, from 3% to 8%. This suggest that experience with PEVs had a polarising effect; increasing participants' certainty at either end of the likelihood scale at the expense of reducing responses in the middle of the scale.

A different pattern can be seen when comparing before and after responses on likelihood to choose a BEV as a *second* car. Here the negative responses remained relatively unchanged after experience, but the proportion of mainstream consumers who indicated they were very likely to choose a BEV as a second car increased from 7% to 20%. This appeared to be largely at the expense of the 'neither likely nor unlikely' responses, which decreased from 31% to 20%, suggesting that experience with PEVs convinced those who were previously unsure that a BEV would be suitable for them as a second car.

Figure 4 shows the same before-after comparisons for likelihood to choose a PHEV. Most notable was a large increase in the proportion of participants who reported they were very likely to choose a PHEV after experience of using one, increasing from 6% to 23% (main car) and 7% to 21% (second car). The proportion of mainstream consumers who reported they were 'fairly' likely to choose a PHEV decreased after experience; but the largest share of those respondents increased their ratings, and reported they were very likely to choose a PHEV after experience. These patterns suggest the experience in the trial served to solidify the positive appraisals of PHEVs which were held before participants had had experience of using one.

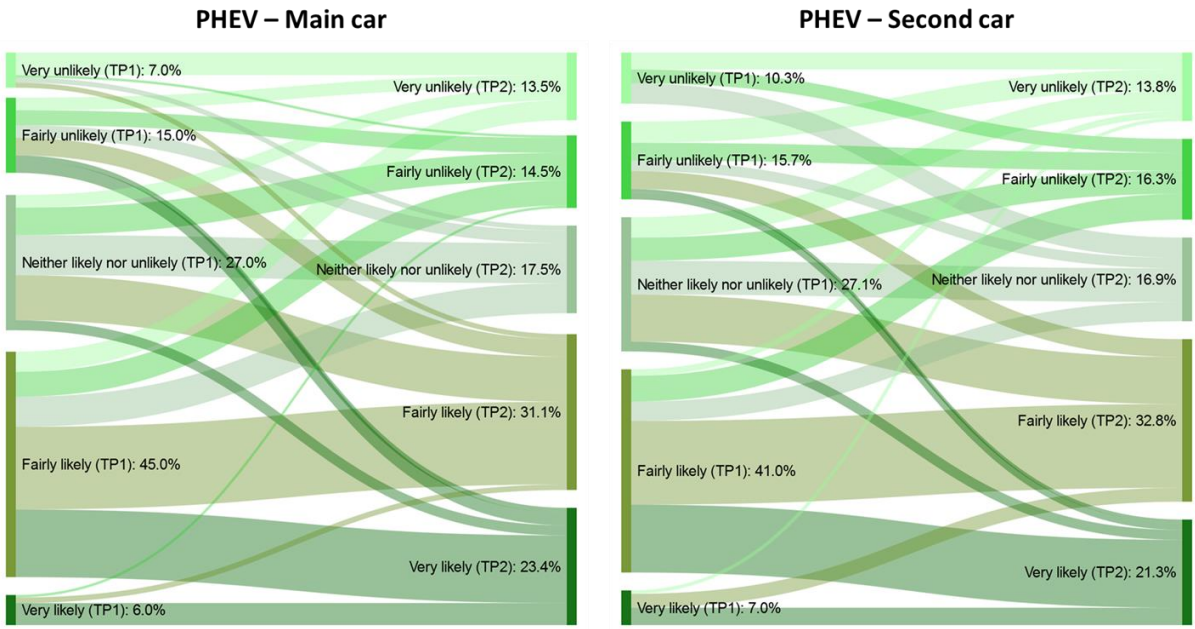

Figure 4: Impact of experience with PEVs on mainstream consumer likelihood to choose a PHEV

The proportions of consumers 'likely' to purchase a BEV and PHEV, before they had experienced the vehicles, were higher than those observed in previous studies conducted in 2011/12 [11, 15]. This suggests that even without direct experience of PEVs, the likelihood of mainstream consumers to purchase them has increased over the last circa. 7 years. A number of factors may explain this: 1) the increasing publicity surrounding PEVs in today's market; 2) increased focus on environmental issues such as poor air quality; 3) the substantially larger number of PEV models available in the market in 2018/19 compared with 2011/12; 4) the emergence of PHEVs in the UK market; 5) public awareness of improvements in the utility of BEVs over this period, especially their AER, and 6) differences in the method, including the specific question(s) asked and the sampling of participants (for instance, the use of a stratified sample in the current trial).

3.4 How do the functional attributes of PEVs (AER and charging time) affect likelihood to choose a PEV?

3.4.1 Effect of AER

The TP2 questionnaire asked participants to rate how important range was when considering purchasing a BEV and PHEV using a scale from 1 (not at all important) to 5 (extremely important). The majority of participants reported that range was at least "Very important" when considering purchasing both a BEV (98.5%) and a PHEV (83%). A non-parametric repeated measures Wilcoxon signed ranks test showed that range was rated as significantly more important when considering choosing a BEV (M = 4.700) compared with a PHEV (M = 4.200, Z = -7.541, $p < 0.001$).

The impact of AER on likelihood to choose a BEV and PHEV was also assessed through the TP2 questionnaire. Participants were asked whether or not they would consider purchasing a BEV and PHEV as a main and second car for five alternative AER levels; the results are shown Figure 5.

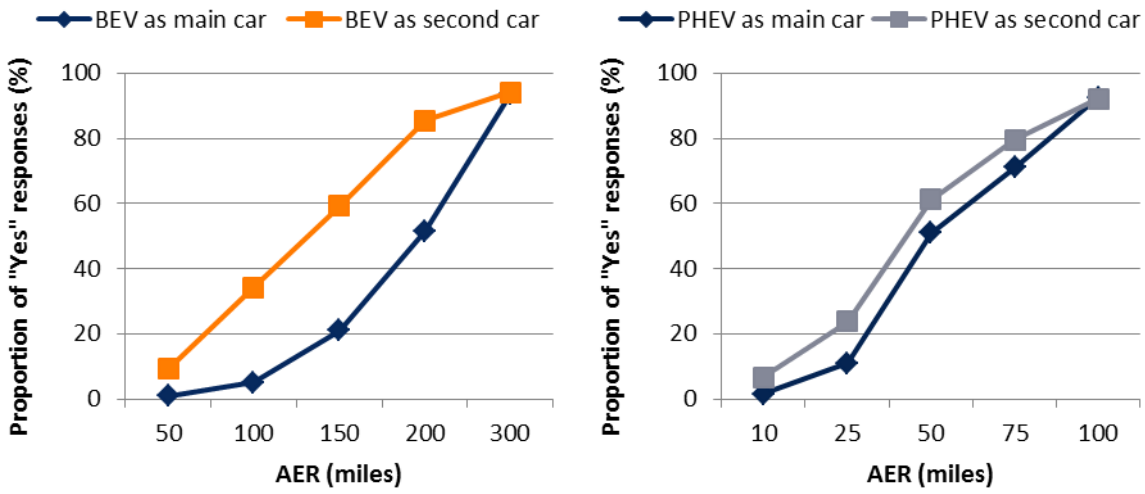

Figure 5: Impact of AER on proportion of mainstream consumers who would choose a BEV or PHEV

The findings confirmed that the range of BEVs remains a critical factor for uptake. An AER of 200 miles is needed for 50% of participants to consider owning a BEV as a main car. An AER of 300 miles increased that proportion to over 90%. About 50% would consider owning a BEV as a second car if it had a lower AER, nearer to 150 miles, and almost 90% would consider it with a range of 200 miles.

As with BEVs, the proportion of consumers who would consider a PHEV increased with increasing AER; this suggests that consumers understood the value of potential fuel cost savings which can be made by driving a PHEV on electric power. Around 50% of participants would consider owning a PHEV as a main or second car if it had an AER of 50 miles. Increasing the AER to 100 miles led to 70% considering a PHEV as a second car, and over 90% as a main car. Even a range of 50 miles is higher than PHEVs on the UK market in 2018, suggesting that PHEV AER will need to increase from 2018 values for these vehicles to have greater mass-market appeal.

3.4.2 Effect of charging time

Time required to charge a PEV was also found to have a substantial impact on likelihood to choose a BEV. The impact of charge time on likelihood to purchase a BEV and PHEV was assessed through the TP2 questionnaire. Participants were asked whether or not they would consider purchasing a BEV and PHEV as main and second car for five alternative charge times varying between 8 hours and 1 hour of charging for 100 miles of range. Non-parametric Wilcoxon signed ranks tests revealed that the average charge times accepted by participants (for delivering 100 miles of range) were significantly higher for a PHEV compared with a BEV (main car; $Z = -6.410$, $p < 0.001$, second car; $Z = -3.137$, $p = 0.002$), and for a second car compared with a main car, for both the BEV ($Z = -6.907$, $p < 0.001$) and the PHEV ($Z = -5.819$, $p < 0.001$).

The results (see Figure 6) showed that if the time required to deliver 100 miles of range was eight hours (about the time required with Mode 2 charging), only 6.5% of participants would be likely to choose a BEV as a main car, and 17% as a second household car. Reducing the charge time to four hours (about the charge rate achieved with 7.2 kW Mode 3 chargers) led to about 50% of participants indicating they would be fairly or very likely to choose a BEV as a second car. Charge times of two hours were required, however, for 50% of mainstream consumers to be fairly or very likely to choose a BEV as a *main* car. For BEVs to appeal to over 90% of the mass-market as either a main or a second car, charge rates which can deliver 100 miles of range in one hour are required. This rate of charge is beyond the capability of present home chargers, but can be delivered by rapid chargers at public locations

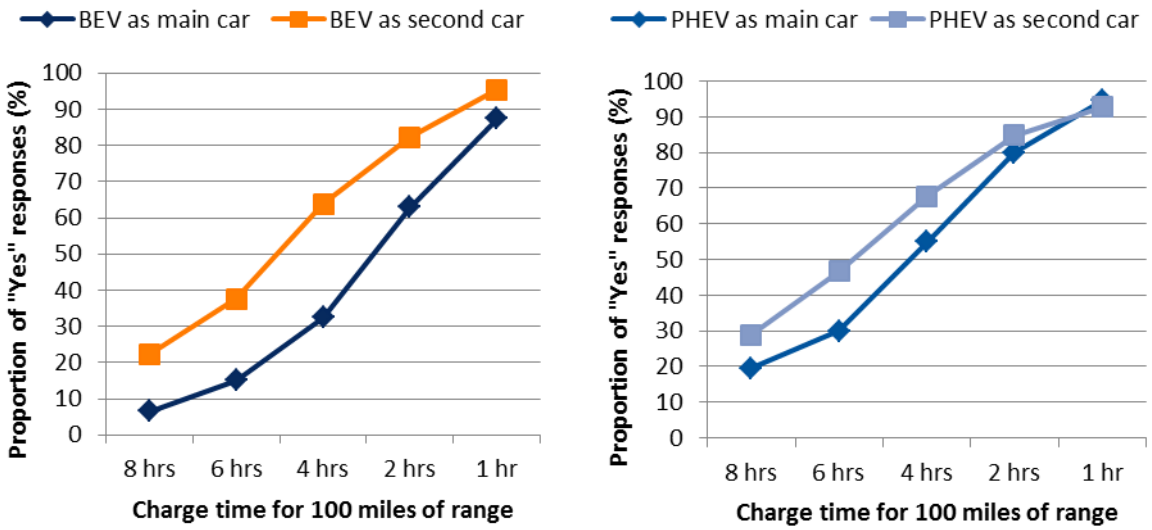

Figure 6: Impact of charge time on proportion of mainstream consumers who would choose a BEV or PHEV

Charging time also affected likelihood to choose a PHEV. Around 20% of mainstream consumers indicated they would be likely to choose a PHEV (as either a main or second car) if the time required to deliver 100 miles of range was eight hours. To increase this share to 50% of mainstream consumers, charge times need to reduce to four hours. This is comparable with the charge rate achievable with 7.2 kW Mode 3 chargers which are compatible with installation in homes.

3.5 How do financial factors and incentives affect likelihood to choose a PEV?

Purchase price of BEVs and PHEVs was considered "very important" or "extremely important" by over 85% of participants. When presented with a range of alternative PEV benefits, a government grant towards the purchase price was found to yield the highest average likelihood to adopt a BEV or PHEV (4.1 on a 5-point scale). Here, about 80% of participants reported being "fairly likely" or "very likely" to choose a PHEV in the household in the next five years if government grants were available to reduce purchase costs. Indeed, incentives which have a direct financial (positive) impact were rated highest in importance by mainstream consumers. Aside from the grant which reduced the purchase price, the next three most highly rated incentives were exemption from Vehicle Excise Duty, access to free parking and provision of a free home chargepoint. A previous literature review showed that PEV owners typically do not state purchase price incentives as the reason for adopting, but that most indicated they would not have adopted without an incentive [9]. A positive relationship between financial incentives and PEV uptake is often cited, although direct causal relationships are difficult to prove and impact varies widely [e.g. 9, 16]. At least in terms of stated likelihood to choose, this study provides evidence that financial incentives can have a positive impact.

Depreciation rate also had a significant impact on likelihood to choose a PEV in the next five years; 67% and 73% reported being either fairly or very likely to choose a BEV or PHEV, respectively, if the depreciation after three years was 40%, but these figures dropped to 25% and 23%, respectively, if the depreciation after three years was 60%. Relative to ICEVs, BEVs and PHEVs are new to the market and so data on the real-world rate of depreciation of residual value is limited. Some studies suggest that the resale value of PEVs is a concern for a significant number of PEV owners [17], but purchase price and other cost factors are generally considered as more important motivators for purchasing [18]. The current study suggests that depreciation is an important factor in mainstream consumers' decision to adopt PEVs.

3.6 Research limitations

A number of limitations with the study should be acknowledged:

1. The recruitment criteria for the trial required that participants: had access to their own private vehicle; were not company car drivers; had off-street parking for at least one vehicle, and were current car owners who drive regularly (at least once every two or three days). These criteria likely led to some systematic differences in the characteristics of the sample, compared with national averages. In particular, they meant that the majority of participants lived in houses with driveways and/or garages where it is common for there to be multiple vehicles.
2. The trial under-represented particular demographic groups, namely households with only one car, households with annual mileage of less than 5,000 miles or more than 15,000 miles (company car drivers), and households with annual gross incomes of less than £30,000. This means that caution should be exercised in applying the findings from this trial to those types of households.
3. Permission from the home owner to install a chargepoint for the purposes of the trial was required. Over 85% of participants were home owners. About 8% of the sample lived with their parents, and 6.5% of the sample were tenants. These biases mean that occupiers of houses or apartments without access to dedicated off-street parking were under-represented in the sample.
4. Participants were provided with each type of vehicle for four days each. Whilst greater than previous BEV only trials; for example, Schmalfuß et al.'s (2017) 24-hour BEV trial and Skippon et al.'s (2016) 36-hour BEV trial, it is possible that increasing the experience to one week or even one month might have increased the validity of the trial, as participants would have had more time to get used to the novel types of PEV. However, before-after comparisons in this trial showed that the reported likelihood to choose a BEV or PHEV changed significantly following the four-day experience. This suggests that psychological distance was reduced through experience.

4 Conclusions

This study represented the first real-world trial that provided a mainstream consumer sample with experience of using both a BEV and a PHEV for their everyday driving needs. The study provides valuable insight into the likely adoption of PEVs by the UK mass-market, and the most important barriers which need to be overcome.

The key conclusions from the trial were as follows:

1. Mainstream consumers are more likely to adopt PHEVs in the next five years than BEVs; about 23% of participants reported being very likely to choose a PHEV as a main car in the next five years compared with only 8% who were very likely to choose a BEV.
2. BEVs are currently unsuitable for mainstream consumers to adopt as main cars in the next five years. BEVs appeal to a greater share of consumers as second cars, where the range requirements are likely to be less.
3. The range of PEVs remains a critical barrier to adoption. Increasing the AER of PHEVs to around 80km increases the appeal to about 50% of mainstream consumers; increasing AER to 160km leads to about 90% of mainstream consumers being likely to choose one. Increasing the AERs of BEVs to 200 miles would enable them to appeal to 50% of mainstream consumers as main cars, whilst AERs of 300 miles would enable them to appeal to over 90%. BEV models with 150 mile ranges would appeal to 50% of mainstream consumers as *second* cars.
4. Mode 2 charging rates are insufficient for encouraging mass-market adoption. About 50% of mainstream consumers would be likely to choose a PHEV or a BEV as a second car with charging times offered by Mode 3 7.2kW chargers. For BEVs to appeal to over 90% of the mass-market as either a main or a second car, charge rates which can deliver 100 miles of range in one hour are required. This rate of charge is beyond the capability of present home chargers, but can be delivered by rapid chargers at public locations.
5. Incentives which have a direct financial (positive) impact were rated highest in importance by mainstream consumers. In particular, a grant which reduced the purchase price was rated most important, likely reflecting the relatively high prices of PEVs in the present (2018) market. The next three most highly rated incentives were exemption from Vehicle Excise Duty, access to free parking and provision of a free home chargepoint.

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