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A systematic review of the evidence on plug-in electric vehicle user experience

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Plug-in electric vehicles (PEV), comprising both battery and plug-in hybrid electric vehicles (BEVs and PHEVs), are innovations central to the low-carbon mobility transition. Despite this, there has not been a review of users' experiences of them; we address this through this systematic review. Of 6,492 references located from diverse sources, we synthesised and thematically organised findings from 75. We found a wide range of themes relating to user experiences, characterised broadly under driving and travel behaviours, interactions with the vehicle and subjective aspects of the user experience. Most of the evidence pertained to BEVs. Specific findings were as follows. The limited electric range of the BEV was not debilitating and users valued the limited electric-only range in PHEVs. In terms of journey-making, BEVs can fit into users' lives. Regarding interactions with specific vehicle attributes, regenerative braking and low noise were very popularly received, although the in-vehicle instrumentation not universally so. Users freely offered wide-ranging improvements for future vehicles. There were important symbolic and social aspects of user experience. Themes relating to the former included environmentalism, futurism, and status/identity; to the latter, social influence and gender-distinct experiences. Overall, we qualifiedly conclude that PEVs can play an effective role in the transition: they can meet users' travel needs satisfactorily, thereby being acceptable to them, and are used at least as intensively as conventionally-fuelled vehicles, being an effective substitute away from more energy-intensive vehicle mileage. **(232 words)**

Keywords: plug-in electric vehicle; plug-in hybrid electric vehicle; battery electric vehicle; users; experience; systematic review

1. Introduction

Compared to conventional vehicles, plug-in electric vehicles (PEVs) are innovations because they can transport their users exclusively using electricity from the grid; potentially, from zero-CO_2 renewables (Kurani et al., 2009). They are therefore central to the low-carbon mobility transition, which is itself important because transportation contributes significantly towards global greenhouse gas emissions (Anable et al., 2012). PEVs encompass battery electric vehicles (BEVs), which rely solely on batteries, and plug-in hybrid electric vehicles (PHEVs), which combine batteries with the drivetrain of a conventionally-fuelled internal-combustion-engine vehicle (ICEV).

Their success in facilitating this transition is not certain, however. Innovation implies change and uncertainty. It may not be possible to know how users will respond to an innovation merely based on information collected from them before they have experienced it (a priori); rather, examination of first-hand evidence from users after they have experienced it (a posteriori) may be needed. It must be noted that both approaches have their strengths and weakness, particularly as regards the possibility of biased samples for the latter. As PEVs are central to the low-carbon mobility transition, understanding how users respond to them is therefore particularly important. It is particularly so given that PEVs, unlike other low-carbon innovations such as renewable energy generation technologies, are direct ‘end-user products’, or ‘consumer durables’. Users play a critically important role in this aspect because they would have to pay a direct, and potentially substantial, cost to adopt the innovation, and on doing so they would be expected to interact with this innovation on a fairly frequent and intensive basis.

An increasing number of PEV trials have been conducted and more people are becoming PEV owners, but there has not been a synthesis of the accumulated evidence from these users. Reviews of the relevant literature have tended to focus on the uptake decision rather than user experiences per se. Rezvani et al. (2015) review factors affecting the adoption decision; Liao et al. (2017) build on this by considering factors beyond psychological constructs (see also Anable et al. (2014). Also, many of the included studies in those reviews evaluate PEVs' likely success based on users who have not experienced them (e.g. stated preference studies, surveys).

This research aims to address this gap by synthesising the experiences of PEV users, improving understanding of them by reviewing empirical outcomes. Recognising that user experiences could be studied in a diverse and heterogeneous set of ways, it will take the approach of a systematic review. It will seek to inform the transition to low-carbon mobility in the following ways. Firstly, by compiling relevant references and marking out salient themes of PEV user experience, it will serve as a helpful introductory point to stakeholders, both policy and academic, who are seeking to understand this area of research. Secondly, it will identify areas of research for academic researchers. Finally, it will assess what the evidence from users says about PEVs' role in the success of this transition. It will aim to answer the research question: What themes emerge from user experiences of plug-in electric vehicles?

2. Method

2.1 Search Strategy

We describe the search strategy here. We chose the following sources to search for references: academic databases, grey literature (Google), own electronic libraries and expert recommendations. We used a set of inclusionary and exclusionary keywords for academic databases. We used two exclusion criteria in particular: we restricted searches to references in the English language and to those dating from the year 2000. We searched three academic databases on 09/11/2017: Ovid Transport, Web of Science and

Science Direct. A combination of four sets of keywords was used, respectively pertaining to electric vehicles, users, individuals, and some exclusionary keywords. The third set of keywords was used to omit studies that might have investigated usage, but from a modelling or simulation perspective, as the focus of this review was on first-hand, personal, or lived experience with the vehicles, whether in a trial situation or real-world uptake. The fourth set of exclusionary keywords was comparatively large and was used to exclude studies from unrelated disciplines, such as engineering and computer science. It was developed iteratively after a series of scoping searches. For the first set of keywords, the use of the proximity operator was important to exclude studies in which elements of each subset appeared anywhere in the title, abstract or keywords, rather than directly next to each other. Ovid Transport Database enabled the use of the "PRE/0" operator, ensuring the element of the first subset (including e.g. "alternative fuel") directly preceded the element of the second subset (containing e.g. "automobile*"); Web of Science only enabled "NEAR/0", meaning that elements in the two subsets could come in any order. Table 1 contains the sets of keywords that were used in searching academic databases. We supplemented references from these searches with existing library references, results from a grey literature search (Google), and expert recommendations.

Table 1: Keyword combinations used for searching academic databases.

Keywords for electric vehicle	**Keywords for usage**	**Keywords for individuals who have experienced the electric vehicle**	**Exclusionary keywords**
"alternative fuel" or battery or electric or “energy efficient” or hybrid or "limited range" or "low carbon" or "low emission" or "plug-in") Proximity operator (automobile* or car or vehicle*)	adapt* or behavio* or driving or experience or interview or project or questionnaire or study or survey or trial* or test or usage or use*	adopter* or buyer* or consumer* or customer* or driver* or famil* or household* or individual* or motorist* or owner* or participant* or people or person or purchaser* or user*	magnet* or flux or "non-linear" or algorithm or inductance or "ac motor*" or "traction motor*" or "neural network*" or "artificial intelligence" or "intelligent system*" or "learning system*" or robotic or fuzzy or "control strateg*" or "control system*" or induction or synchronous or "induction motor" or "load movement" or "slip control" or transformer or programming or ac or dc or "ac power flow" or "machine learning" or probabilistic* or "power electronic*" or "steering system*" or "control theory" or optimization or thermostatic or "network equilibrium" or "mathematical model" or markov or capacita*

In the context of a systematic review, we did not use quality assessment criteria. Located studies had differing methodologies and were not easily comparable. Where appropriate, we have included assessment of the implications on our findings of different approaches and sampling used in the studies reviewed. In addition, answering the research question involved 'inductively' discovering relevant themes, and discarding studies could have meant losing distinctive thematic material. Relevant to the latter point, there was not initially a clear-cut selection criterion for including studies that had passed the full-text scan phase. This was because it could not have been definitively known a priori what set of relevant concepts or themes existed.

2.2 Study inclusion and data analysis

This review aimed to synthesize user experiences; to be included, a study needed to offer valuable insight into PEV user experiences. We excluded evidence on charging behaviour, with a focus on user experiences related the vehicle itself. Although charging behaviour is certainly relevant, it itself potentially encompasses many sub-themes, reflected in a very rapidly emerging body of literature syntheses (Daina et al., 2017, Sovacool et al., 2017, Hardman et al., 2018, Sovacool et al., 2018b).

The data extraction and analysis approach involved the use of narrative synthesis and thematic saturation. Narrative synthesis is defined as an approach that relies on words and texts to organise data in the form of a 'narrative' or a 'story' (Popay et al., 2006). Thematic saturation means that data is collected until "additional data do not lead to any new emergent themes" (Saunders et al., 2018). We implemented the approach as follows. In the title and abstract screening stage, we selected studies that were judged to meet the criterion of offering valuable insight into PEV user experiences. In the full-text-scan stage, we exported these studies to a spreadsheet table and coded them using a set of open keywords, as part of an iterative process. At the start, we read the studies once, and coded them on subsequent re-readings. The set of codes to use was not decided beforehand but emerged from reading the studies. Then, we extracted data from references and deposited them by theme into a set of word processing documents, which was based on the previously used codes. We also coded sub-themes and iteratively organised the data until we judged that a coherent and meaningful framework had emerged.

3. Nature of the evidence found

We located a total of 6,492 references: 5,986 references from academic databases and 506 from additional sources. After title and abstract screening, 476 references were left. After full-text scanning we found 134 references that met the inclusion criterion. Of these, we extracted content from 75 studies. Figure 1 displays the flow of references that were processed during the review.

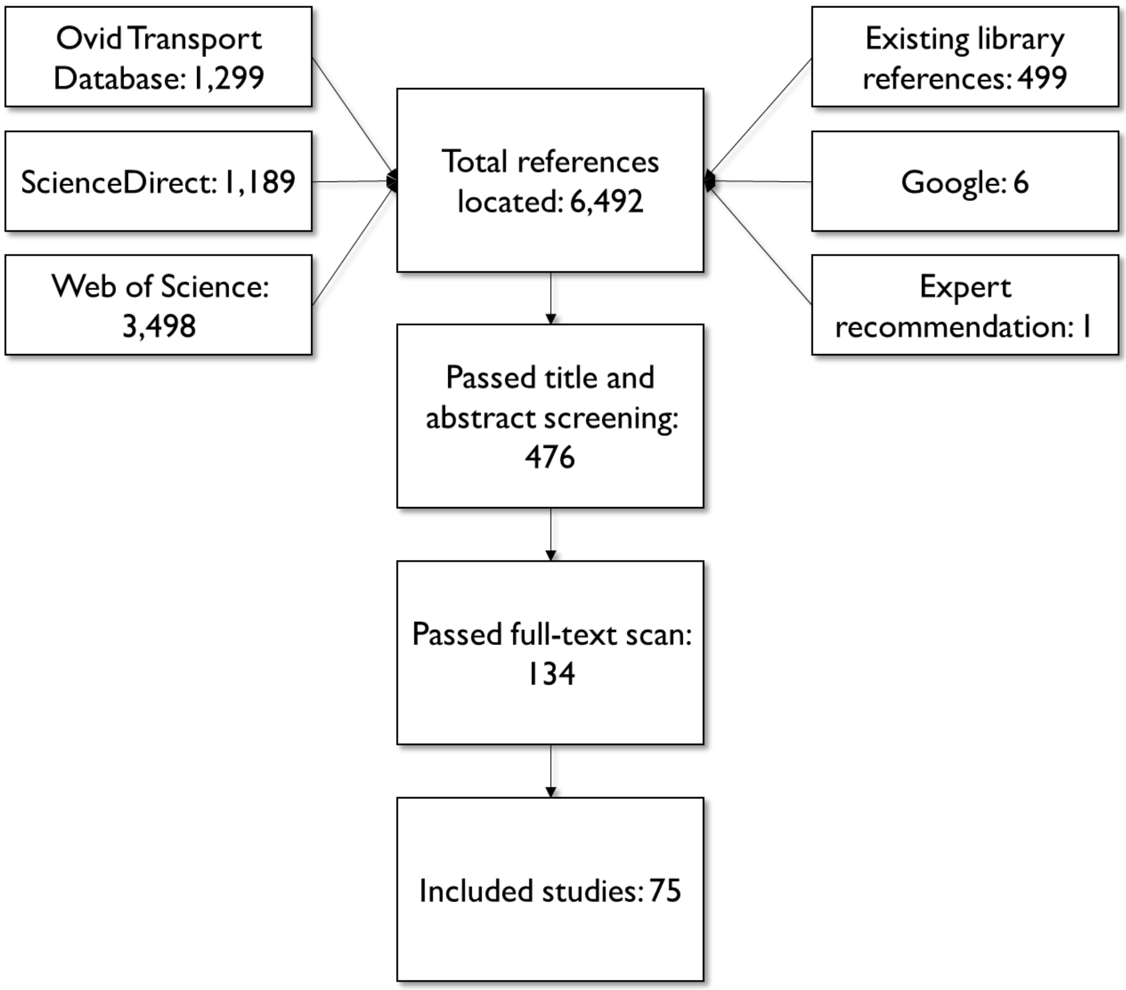

Figure 1: Flow of references processed during systematic review.

The features of the selected references are henceforth described (Figure 2 shows detailed specifics of the references found). The evidence was dominated by BEVs, featuring in 58 studies against 17 for PHEVs. Studies featuring trials and owners were split almost identically (59 vs. 17). Studies of the earliest adopters (innovators or enthusiasts according to Rogers (1962) Diffusion of Innovation Theory; herewith referred to as ‘early adopters') were much more common than those of mainstream users (34 vs. 6). Notably, no references were found which included mainstream owners. It should also be noted that other studies did not explicitly designate their sample type (i.e. using those terms) and we did not judge that we could make any robust inferences about their samples, thence leaving their samples undescribed. Nonetheless, the predominance of early adopters in the evidence potentially raises issues of early adopter or ‘enthusiast/innovator’ bias (Rogers, 1962, Morton et al., 2016a, Axsen et al., 2016). That is, evidence from these types of users and their reactions may not be fully generalizable to the population of desired PEV users: early adopters (innovators) have greater resources (both financial and social) and have more innovative dispositions, making them more tolerant of an innovation’s shortcomings or limitations; people further along the adoption curve may be more sceptical and less tolerant and accepting (Rogers, 1962). Most references pertained to Germany (29), with the USA second (19). All studies took place in developed nations; no studies were found relevant to developing or emerging societies.

Incidentally, the international BMW Mini E trial, the largest of its type in the world (Vilimek et al., 2013), contributed significantly towards the evidence. Twenty-five of the studies featured the BMW Mini E, which is more than the number of studies which included PHEVs. The Mini E study was focussed on Germany; there were almost as many German Mini E studies as there were of studies for the entire USA. The trial also focussed on early adopters as a deliberate feature of the study design (Vilimek et al., 2013, Turrentine et al., 2011), and participation was conditional on successful application and on paying a monthly lease, raising possible questions of self-selection.

Some studies did not include actual experiences of vehicles: one involved a simulated test drive and another exposure to simulated vehicle sounds. The most frequent study design was the cohort study (40). Only five of the studies involved a control and only two of those were randomized control trials. The Supplementary Material contains a detailed table of the included references.

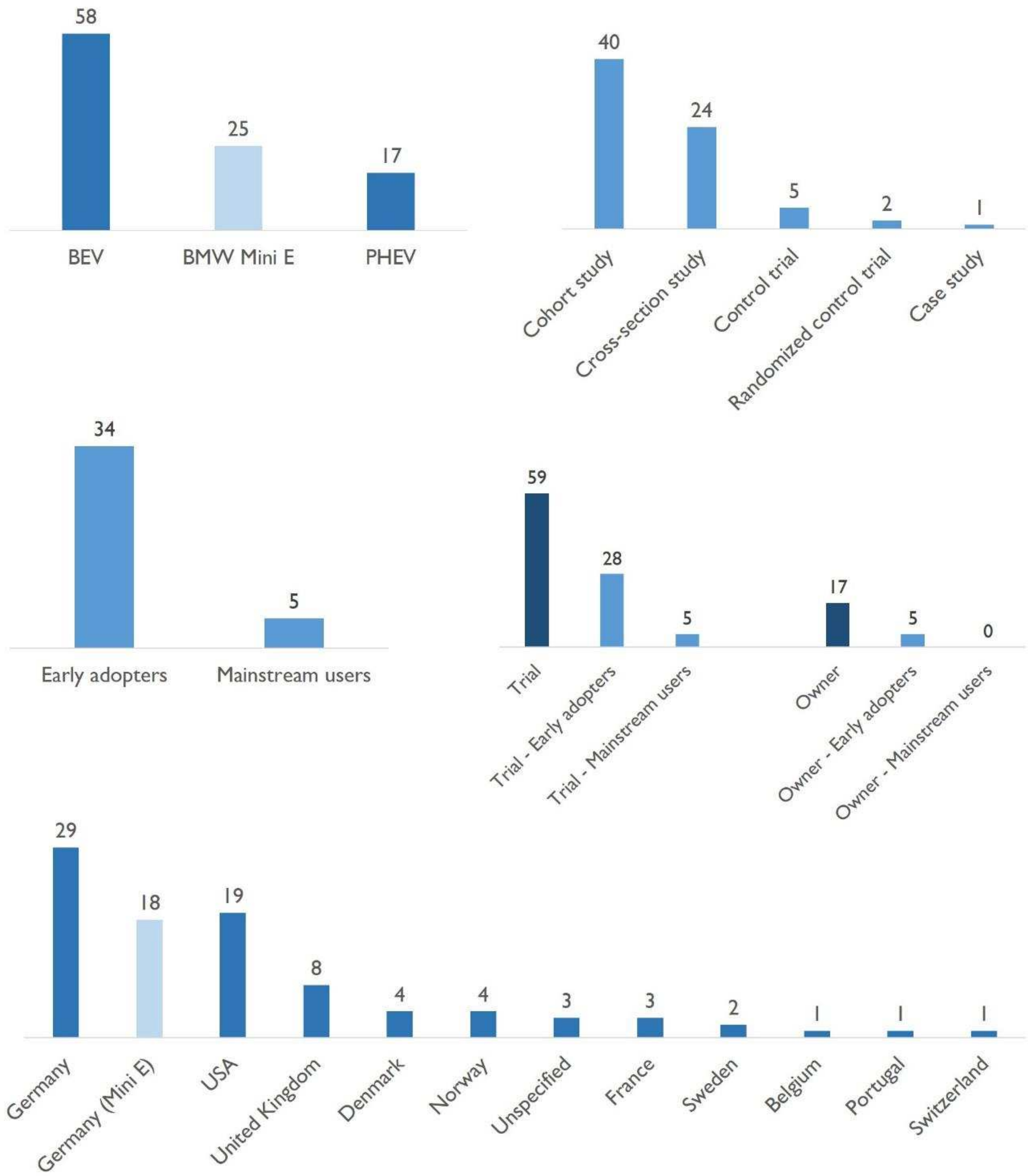

Figure 2: Some detailed specifics of the references found. Top row: number of references by PEV type; number of references by study design. Note that some references included both types of PEV. Middle row: number of references by sample type (early adopters versus mainstream users; triallists versus owners, including sub-types for each). Bottom row: number of references by country of setting. One study pertained both to Germany and the USA (Plötz et al., 2017).

As regards the themes covered by references, themes were covered fairly evenly by the references (Table 2). The least frequently referred themes were regenerative braking (6 references), in-vehicle instrumentation (9 references) and electric range in PHEVs (also 9 references).

Table 2: Themes and references covering them

Theme	References
Range satisfaction in BEVs (20 references)	(Agerskov and Høj, 2013, Bühler et al., 2014a, Bühler et al., 2014b, Carroll et al., 2013, Franke et al., 2012b, Franke and Krems, 2013b, Franke and Krems, 2013a, Franke et al., 2017, Graham-Rowe et al., 2012, Heyvaert et al., 2013, Hutchins et al., 2013, Jensen et al., 2014, Labeye et al., 2016, Magali and Fulda, 2015, Ryghaug and Toftaker, 2014, Schmalfuß et al., 2017, Skippon et al., 2016, Trommer et al., 2015, Turrentine et al., 2011, Woodjack et al., 2012)
Range anxiety in BEVs (11 references)	(Franke et al., 2012c, Franke et al., 2015, Franke et al., 2016, Friis and Gram-Hanssen, 2013, Graham-Rowe et al., 2012, Jung et al., 2015, Nilsson, 2011, Rauh et al., 2015a, Rauh et al., 2015b, Rauh et al., 2017a, Rauh et al., 2017b)
Range utilisation in BEVs (11 references)	(Carroll et al., 2013, Bourgeois et al., 2015, Franke et al., 2012a, Franke et al., 2012c, Franke et al., 2012b, Franke and Krems, 2013a, Labeye et al., 2016, Pichelmann et al., 2013, Turrentine et al., 2011, Walsh et al., 2010, Woodjack et al., 2012)

Electric range in PHEVs (9 references)	(Caperello and Kurani, 2012, Carlson, 2014, Graham-Rowe et al., 2012, Figenbaum and Kolbenstvedt, 2016, Heffner et al., 2009, Kurani et al., 2009, Plötz et al., 2017, Smart, 2013, Trommer et al., 2015)
Cognitive and behavioural driving adaptations (15 references)	(Beloufa et al., 2014, Bourgeois et al., 2015, Caperello and Kurani, 2012, Franke et al., 2012c, Friis and Gram-Hanssen, 2013, Freund, 2007, Graham-Rowe et al., 2012, Helmbrecht et al., 2014, Kurani et al., 2009, Magali and Fulda, 2015, Neumann et al., 2010, Neumann et al., 2015, Rolim et al., 2014, Ryghaug and Toftaker, 2014, Walsh et al., 2010)
Journey making (22 references)	(Agerskov and Høj, 2013, Bourgeois et al., 2015, Bühler et al., 2010, Caperello and Kurani, 2012, Caperello et al., 2014, Cellina et al., 2016, Figenbaum and Kolbenstvedt, 2016, Franke et al., 2012a, Franke et al., 2012c, Friis and Gram-Hanssen, 2013, Hutchins et al., 2013, Kurani et al., 2009, Jakobsson, 2016, Jensen and Mabit, 2017, Klockner et al., 2013, Labeye et al., 2016, Magali and Fulda, 2015, Nicholas et al., 2017, Rolim et al., 2014, Ryghaug and Toftaker, 2014, Turrentine et al., 2011, Woodjack et al., 2012)
Interaction with the vehicle – instrumentation (9 references)	(Caperello and Kurani, 2012, Caperello et al., 2014, Eisel et al., 2016, Franke et al., 2015, Graham-Rowe et al., 2012, Neumann and Krems, 2016, Kurani et al., 2009, Stillwater and Kurani, 2013, Turrentine et al., 2011)

Interaction with the vehicle – regenerative braking (6 references)	(Cocron et al., 2013, Günther et al., 2017, Helmbrecht et al., 2014, Labeye et al., 2016, Schmitz et al., 2013, Turrentine et al., 2011)
Interaction with the vehicle – noise (10 references)	(Agerskov and Høj, 2013, Bühler et al., 2014a, Carroll et al., 2013, Cocron et al., 2010, Cocron and Krems, 2013, Cocron et al., 2014, Friis and Gram-Hanssen, 2013, Graham-Rowe et al., 2012, Magali and Fulda, 2015, Swart et al., 2018)
Symbolic aspects (20 references)	(Bühler et al., 2014a, Burgess et al., 2013, Caperello and Kurani, 2012, Caperello et al., 2014, Cellina et al., 2016, Figenbaum and Kolbenstvedt, 2016, Freund, 2007, Friis and Gram-Hanssen, 2013, Graham-Rowe et al., 2012, Hardman et al., 2016, Hardman and Tal, 2016, Haugneland and Hauge, 2015, Heyvaert et al., 2013, Hutchins et al., 2013, Neumann et al., 2010, Rolim et al., 2014, Ryghaug and Toftaker, 2014, Skippon and Garwood, 2011, Skippon et al., 2016, Trommer et al., 2015)
Social aspects (13 references)	(Axsen and Kurani, 2011, Axsen and Kurani, 2012, Axsen and Kurani, 2013, Axsen and Kurani, 2014, Burgess et al., 2013, Caperello and Kurani, 2012, Caperello et al., 2014, Friis and Gram-Hanssen, 2013, Graham-Rowe et al., 2012, Hutchins et al., 2013, Ryghaug and Toftaker, 2014, Stillwater and Kurani, 2013, Woodjack et al., 2012)

User feedback for future PEVs (17 references)	(Bourgeois et al., 2015, Burgess et al., 2013, Cocron et al., 2010, Cocron and Krems, 2013, Cottrell and Barton, 2012, Franke et al., 2012b, Franke et al., 2015, Graham-Rowe et al., 2012, Neumann et al., 2010, Neumann and Krems, 2016, Rauh et al., 2015b, Skippon and Garwood, 2011, Schmitz et al., 2013, Skippon et al., 2016, Stillwater and Kurani, 2013, Trommer et al., 2015, Turrentine et al., 2011)

4. Results: systematic review

4.1 Driving and travel behaviours

4.1.1 Range satisfaction in BEVs

For BEVs, the all-electric range, and the associated 'refuelling' regime, is the biggest single difference to ICEVs, and certainly from PHEVs, which do have ranges comparable to the latter. Studies of intention to adopt BEVs have invariably found perceived or actual limited range to be the single biggest barrier to uptake (Egbue and Long, 2012).

In this review, with respect to post adoption or user experience, mixed results were found regarding users' satisfaction with the range. Studies from the international Mini E trial found that users, who were 'early adopter' or 'innovator' types who voluntarily participated in the trial, were not hindered by the limited range. Rather, they felt that BEVs were suitable for their daily use, were willing to adapt and did not feel a loss of mobility. They mostly saw limited range as a problem to be solved, rather than as a cause for stress, with limited seating and storage (due to the battery) experienced as a greater inhibitor on usability than limited range (Franke and Krems, 2013a, Turrentine et al., 2011, Woodjack et al., 2012). These users become more satisfied with range with experience and more willing to accept a lower range, finding that having to plan was less difficult than initially expected (Franke et al., 2012b, Franke and Krems, 2013b). Other studies had similar findings (Bühler et al., 2014b, Schmalfuß et al., 2017, Ryghaug and Toftaker, 2014); elsewhere, a timeframe of up to two weeks was indicated for people to adapt to the range. Users referred to it as mere 'mental blocking' they needed to get over (Agerskov and Høj, 2013), and Labeye et al. (2016) found that 10% could adapt immediately. Range satisfaction was also higher with more regular and predictable daily mobility patterns (Franke et al., 2017).

Some studies, however, found dissatisfaction amongst users. Early adopter owners found that only of third of them were satisfied with their range (Trommer et al., 2015), and that they were concerned about disparities between the range as advertised and as achieved in real life (Hutchins et al., 2013). Some trials, some of which included mainstream users, also discovered concerns of being unable to meet mobility needs (Jensen et al., 2014, Graham-Rowe et al., 2012) and that not only was range the main barrier to acceptance but it became a barrier to more people over time (Bühler et al., 2014a). Other trials found that hands-on experience of range reduced range satisfaction amongst users (Carroll et al., 2013, Heyvaert et al., 2013) or made them less willing to accept a BEV, either as a first or second car (Skippon et al., 2016). And even users satisfied with vehicle range tended to regret its limitations (Magali and Fulda, 2015) and wanted it to be higher (Franke et al., 2012b).

4.1.2 Range anxiety in BEVs

Range anxiety is distinct from range satisfaction in referring to how users feel when they sense that their range is either not enough or only marginally enough to complete their trip – a 'critical range situation' (Rauh et al., 2017a); range satisfaction might refer to the general evaluation of the range as such. Someone who is broadly satisfied with the overall range of their BEV might experience range anxiety when, for example, they are stressed or afraid because they don't think they will be able to complete their journey; conversely, someone not satisfied with their range (feeling it is not enough and greatly wanting more) might never experience range anxiety simply because they never go anywhere near the limits of the BEV, or because they just do not get that stressed when the range is nearly depleted. Range anxiety was not found a hugely debilitating problem, principally because situations that evoked it only rarely occurred. Franke et al. (2012c) found that only 12% of drivers worried about range while driving. On average, drivers averaged one 'range-related stressful situation' per month and most drivers (75%) only experienced this once per month at most.

Range was not a particularly positive feature from an emotional perspective; contrasting responses were observed. Early adopters in a trial were at worst annoyed when in a critical range situation, and very few mentioned being so (Franke et al., 2012c). In a study of mainstream users, however, they reported a high level of anxiety, with "alarm bells" due to concern about having enough range and charging points en-route, although BEVs were mostly prototypes with a range of only 75 miles (Graham-Rowe et al., 2012). Interestingly, Nilsson (2011) found that users who actually did run out of range were frustrated with and reproachful towards themselves rather than the vehicle. Unsurprisingly, higher range anxiety in critical range situations was associated with greater dissatisfaction and lower acceptance of the vehicle (Franke et al., 2016).

Two factors linked to variations in range anxiety were experience and perceived certainty. Range anxiety was found to decrease with experience (Franke et al., 2016, Rauh et al., 2015a) due to higher subjective range competence and understanding of range dynamics (Rauh et al., 2017b). Interestingly, while Franke et al. (2016) found that having fewer range-stressful encounters reduces range anxiety, Rauh et al. (2017a) found that experiencing a ‘critical range situation’ lessens range stress. With regard to certainty, people have lower range anxiety if they trust the instrumentation (Franke et al., 2016). Rauh et al. (2015b) found that a precise range display instrumentation that changes frequently and adapts to driving style reduces stress, as well as having feedback on how to drive more efficiently and being able to clearly see that regenerative braking adds to the range. Nevertheless, Jung et al. (2015) found that displaying the range more ambiguously preserved drivers’ trust towards the car. Greater route familiarity is also helpful (Franke et al., 2016), linked to a sense of being in control (Nilsson, 2011) . Causes of stress included seeing the range depleted whilst driving and being uncertain as to whether one could complete one’s trip (Graham-Rowe et al., 2012), particularly if the rate of depletion was very rapid (Rauh et al., 2015b). Users’ uncertainty and stress in a critical range situation was exacerbated when they realised the BEV needed to consume more energy, such as when driving on motorways or on undulating, mountainous terrain (Franke et al., 2015, Rauh et al., 2015b) . Feelings of vulnerability and insecurity to elements arose, for example when turning on the heating in response to sudden cold weather caused the range indicator to fluctuate drastically (Friis and Gram-Hanssen, 2013). Failure to accurately match the advertised range while driving was quite sobering (Franke et al., 2012c). Knowing that the range buffer is positive (the displayed range being greater than the distance left to cover) reduces stress; this, rather than the absolute remaining range as such, was important. And it was very stressful when this became negative (Rauh et al., 2015b).

4.1.3 Range utilisation in BEVs

Evidence suggests that while users preferred not to use the maximum capacity of the range, they were not overly conservative. Users were generally comfortable using between 75 to 80 percent of the vehicle range for trips, preferring to reserve a fairly substantial safety buffer (Franke et al., 2012a, Franke and Krems, 2013a, Franke et al., 2012c). Elsewhere, Walsh et al. (2010) found that only 7% of trips were taken when half or less of the range remained. But Franke et al. (2012b) found that participants' comfortable range limit fell slightly after experiencing a car for three months. Pichelmann et al. (2013) found that on average, users reached their maximum available estimated range without recharging after just under 100 days. Risk-taking was found in Mini E users, who enjoyed testing the range, describing it as exploratory and as providing a sense of adventure, using discourses of discovering territory (Turrentine et al., 2011, Woodjack et al., 2012). Other studies also found between 30% and 50% of users deliberately trying to exhaust range to see how far they could go (Carroll et al., 2013, Labeye et al., 2016). Some users even claimed to have driven BEVs beyond their stated electric-only range (Bourgeois et al., 2015).

4.1.4 Electric range in PHEVs

As previously noted, PHEVs do not suffer from the same range issues as BEVs, but their users still engaged meaningfully with the electric-only range. Indeed, Graham-Rowe et al. (2012) found that PHEV users did not raise concerns about range in the same way as BEV users. Rather, users wanted to maximise the distance covered using electricity alone. Figenbaum and Kolbenstvedt (2016) found 'doing short trips on electricity' as the most important adoption factor, consistent with Carlson (2014) who found trips under thirty miles mostly powered by electricity, and trips over that by fossil fuels. Trial participants in the UK were found to deliberately stay in electric-only mode to save money (Graham-Rowe et al., 2012). Some owners went to extreme lengths to stay in electric-only mode (Heffner et al., 2009); one user was frustrated when the engine came on, even during short trips (Kurani et al., 2009). Despite its importance with respect to overall emissions, there is limited information on the overall proportion of mileage undertaken in PHEVs are carried out on the electric-only mode reduction. One study in Germany found owners run their vehicles for approximately 70% of miles in on the battery (Trommer et al., 2015). Smart (2013) also found a similar average statistic for a trial; most users were above this average (positive skew). A very large study found the share of all-electric driving (or utility factor) increasing non-linearly with the all-electric range. The lowest utility factor was with a range of 20km (12%); PHEVs with 40km and 120km ranges had utility factors of 50% and 80% respectively (Plötz et al., 2017).

However, Caperello and Kurani (2012) found that users were initially not sure about the benefits of driving the PHEV in electric-only mode; one was unsure whether the car was running on electricity or petrol and many remained uncomfortable with the technology even after using it for a month. Some were not aware of where the energy was coming from (Kurani et al., 2009). Users also felt their autonomy compromised by being unable to control whether the car ran on electricity (Graham-Rowe et al., 2012).

4.1.5 Cognitive and behavioural driving adaptations

Cognitive and behavioural adaptations while driving were found to result from limited range. Cognitive adaptations included the formation of a mental model of vehicle range and a heightened sense of awareness while driving. Ryghaug and Toftaker (2014) found respondents developing an almost intuitive, internalized understanding of vehicle range which improved with experience, which abated fear and encouraged more adventure with range. Franke et al. (2012c) found that users had more difficulty in creating an accurate mental model, because they understood that range was a function of factors that neither they nor the BEV itself could perfectly predict. A majority of them used heuristics or rules of thumb, for example assessing range with regard to sets of typical trips the EV could comfortably perform (e.g., twice to work and back and once shopping).

The limited range made users much more aware of their energy use (Bourgeois et al., 2015, Friis and Gram-Hanssen, 2013, Magali and Fulda, 2015). They became aware how their actions impacted performance and fuel efficiency and in some cases monitored their own driving behaviour on a near-constant basis (Caperello and Kurani, 2012). The heightened sense of awareness resulted in chiefly two behavioural adaptations to minimise energy use: a changed driving style and a reduced use of auxiliary features (e.g. air conditioning, heating, radio). More people became aware of these strategies after experiencing an EV (Neumann et al., 2010).

Behaviourally, two-thirds of BEV owners reported changing their driving style after adoption: three quarters drove more slowly and under a quarter drove less aggressively and more efficiently (Rolim et al., 2014). Users apply a smoother and more fluid driving style (Magali and Fulda, 2015). Strategies included anticipatory driving styles, using decelerating to recover energy from the regenerative brake and driving as economically as possible to improve the range of driving (Freund, 2007, Friis and Gram-Hanssen, 2013). Both the heightened awareness and the changed driving behaviour spilled over to when they drove their ICEVs, and they felt better drivers generally (Friis and Gram-Hanssen, 2013, Ryghaug and Toftaker, 2014, Helmbrecht et al., 2014). Changes in driving style indeed reduced energy consumption significantly compared to when drivers drove normally (Neumann et al., 2015). A study at the Millbrook Proving Ground in the UK which used telemetric data to monitor BEV driving found that drivers drove more efficiently as the remaining range fell (Walsh et al., 2010). A simulation study also found that drivers with a lower initial state of charge drove more efficiently, and actually took very slightly less time to complete the simulated course (Beloufa et al., 2014). Some drivers who changed their acceleration, speed, and use of coasting, specifically attributed this to being able to see the instantaneous fuel consumption rate on the display. They also engaged in experimental behaviour, seeing how various actions affected the economy display, such as 'flooring it' and changing auxiliary features such as air conditioning (Caperello and Kurani, 2012). One study found that after five months, drivers accelerated more smoothly and were better at driving at more consistent speeds than drivers of ICEVs, although no differences were found in average speeds (Helmbrecht et al., 2014). The curtailed use of auxiliary features was in some cases a deliberate and voluntary economising measure (Friis and Gram-Hanssen, 2013) but also a response to range anxiety, reducing driving pleasure (Graham-Rowe et al., 2012). PHEVs also were found to change driving behaviour (Kurani et al., 2009).

4.1.6 Journey making

This category includes a diverse array of possible adaptations covering aspects of journey making including the number, type and distance of journeys undertaken, use of an EV for journeys not previously undertaken or undertaken by other modes, alterations to destinations chosen, changes to the number of trip chains, alterations in routes chosen in order to optimise range and so on. These are not identified under separate headings here due to the paucity of evidence on each of these. The review found the majority of evidence of user experience to focus on range perceptions and satisfaction and alterations to driving style, with much less attention paid to trip characteristics such as frequency, car sharing or trip chaining, and whether such uses change over time as the car becomes assimilated into daily life.

Examining snapshots of travel patterns, PEVs, and BEVs in particular, appear to fulfil users' needs. Haugneland and Hauge (2015) found that households used them for mandatory and maintenance trips, such as commuting, education escort trips and small errands, and that all owners used them every day, as did Klockner et al. (2013) and Rolim et al. (2014). Hutchins et al. (2013) found that the trip purpose distribution (the share of all household trips by trip type) was not statistically significant from the UK National Travel Survey's. Figenbaum and Kolbenstvedt (2016) found BEVs were used more often than ICEVs and PHEVs for all trips types except vacations. Magali and Fulda (2015) further found that BEVs were not only used for short trips but also 'medium range' extra-urban trips on a regular basis, being the most frequently used transport mode. Families with young children also felt their PHEVs met their practical daily needs (Caperello and Kurani, 2012).

Examining modal shares, a pattern emerges of the BEV coming to a place of dominance. Many studies assess what happens after a household accesses a BEV in addition to an existing ICEV, and found the BEV becoming the primary car in multi-car households (Bourgeois et al., 2015, Nicholas et al., 2017), despite initial expectations of its being used as a 'secondary car' (Magali and Fulda, 2015). Users explicitly sought to maximise its use (Turrentine et al., 2011) and reserved the ICEV as a 'backup' for weekend trips and holidays (Agerskov and Høj, 2013, Ryghaug and Toftaker, 2014). Studies quantifying modal shares found the BEV covering 60-70% of both overall and vehicle mileages travelled, with no significant changes over the trial period (Bühler et al., 2010, Franke et al., 2012a). Cellina et al. (2016) found similar figures for mainstream households, and this did not differ greatly from a comparative sub-sample of early adopters. Jensen and Mabit (2017) however found that while the BEV constituted a majority of vehicle miles travelled, the decrease in ICEV miles after the BEV was acquired was very small. Mileage shares ended up similar across vehicles and overall vehicle mileage increased significantly. Studies also observed a significant decrease in travel using active travel and public transport (Franke et al., 2012a, Labeye et al., 2016). Friis and Gram-Hanssen (2013) provided an interesting perspective: once single-car households experience the freedom and convenience of an additional car, they become habituated to it and still retain a desire for it after returning it. Increases in total vehicle mileage at the apparent expense of environmentally-friendlier travel were also observed when a BEV replaced an existing ICEV instead of joining it in the household fleet (Figenbaum and Kolbenstvedt, 2016), although a smaller study which also examined changes after a BEV replaced an ICEV did not find any clear direction of change; 'first' cars remained first cars and 'second' cars mostly remained second cars (Jakobsson, 2016).

Other adaptations occurred over the course of people's daily lives. It was found that people were mostly willing to adapt and did not feel seriously inconvenienced, although there were exceptions, particularly among mainstream users. These adaptations included: trip chaining, trip elimination, avoiding trips, learning distances between key locations and sometimes finding alternatives, planning trips, using convenience charger at work/other destinations and charging frequently and/or during trips, and multimodal travel (Franke et al., 2012c, Woodjack et al., 2012, Turrentine et al., 2011). The most common adaptation, however, is simply to use a conventional vehicle for long trips (Caperello et al., 2014, Magali and Fulda, 2015, Woodjack et al., 2012, Figenbaum and Kolbenstvedt, 2016) and households are often able to access one even when not owned (Magali and Fulda, 2015). As with range anxiety, the need to adapt in this way happened only occasionally (Caperello et al., 2014). For example, while over 80% of drivers couldn't take their cars to some places they had wanted to, these were only visited on a monthly basis or less frequently (Woodjack et al., 2012). Households did not express an overall feeling of losing mobility (Turrentine et al., 2011) and did not begrudge the need for extra planning (Agerskov and Høj, 2013). One early adopter household commented that while they were more than willing to adapt, other people would not have the patience to perform all the planning needed (Turrentine et al., 2011). And even some early adopter owners did not regard planning positively, viewing it as ‘restrictive’; others were unwilling to compromise on functionality (Hutchins et al., 2013, Kurani et al., 2009). Mainstream users also felt it unacceptable to be unable to use a car for all household trips, particularly at a relatively high price (Cellina et al., 2016).

Interesting distinctions were found for users of the Tesla Model S, a ‘high-end’ BEV with a range comparable both to PHEVs and ICEVs. Nicholas et al. (2017) found that while most BEVs were used for around one in ten 200-mile round trips, Tesla Model Ss were used for over 60%, a figure comparable to PHEVs. Haugneland and Hauge (2015) found that half of respondents who used their BEVs for holidays owned a Tesla. Figenbaum and Kolbenstvedt (2016) found that Tesla owners were significantly more likely to report recurring round-trips of 300km or more than of owners of other BEV segments (around 70% and 40% each). Compared to other BEV owners, they almost never have to avoid certain trips (one third of a day per year compared to five days on average, and eighteen days for the other BEV owners who do have to avoid trips).

4.2 Interaction with the vehicle

The following adaptations have direct implications for the above driving and travel behaviours as already indicated in some cases. They are nevertheless identified as separate adjustments here as they relate specifically to the conscious and unconscious learning processes that result from interacting with the changing materiality of the vehicle components.

4.2.1 Instrumentation

The in-vehicle instrumentation is crucially connected with how drivers deal with the limited electric range, because that is where the very information about the range is displayed. Some aspects of instrumentation experienced were distinct from its principal function of displaying the range. Overall, users had mixed responses to it.

Regarding users' general perceptions, having an instrumentation display installed, rather than none, reduced stress (Eisel et al., 2016) and Franke et al. (2015)'s respondents generally found it trustworthy. However, Neumann and Krems (2016)'s sample of Mini E drivers did not find the instrumentation, adapted from a conventional Mini, fully reliable and helpful. There was no clear evidence that users relied on it, being just as likely to rely on intuition to estimate range; receiving information from the instrumentation became less important with experience. Caperello et al. (2014) also found that people had very little trust in the information provided.

Three specific responses to the instrumentation were found: goal-directed behaviour, confusion, and distraction. Goal-directed behaviour was mostly engaged in enthusiastically. PHEV drivers were spurred by the psychological target of seeing triple-digit fuel economy figures (100 mpg+), treating it as a game or test (Caperello and Kurani, 2012, Kurani et al., 2009). Stillwater and Kurani (2013) made the power display shine bright blue under low energy consumption which was enthusiastically received, but some were frustrated by being set an implied goal of all-electric driving they couldn't always meet. Displaying cost information didn't motivate energy savings. Confusion arose for various reasons. One was the complexity of the design and layout (Graham-Rowe et al., 2012). PHEV users felt that fairly basic variables, such as the state of charge and remaining range, were not clearly displayed, and had difficulty telling when the battery was charged or not. Likewise, the fluctuating fuel economy display was confusing and even overwhelming, (Caperello and Kurani, 2012, Kurani et al., 2009) making it hard to get a sense of overall fuel economy (Kurani et al., 2009). A power meter was divisive: people either found it very useful or not useful at all (Turrentine et al., 2011). Certain variables were also difficult to interpret, such as energy consumption displayed in electrical units (Neumann and Krems, 2016) and people found it hard to make sense of CO_2 emissions for want of a reference frame (Stillwater and Kurani, 2013). Finally, a number of people found the instrumentation distracting (Graham-Rowe et al., 2012), and adapted by watching elsewhere when they felt it to be so (Stillwater and Kurani, 2013).

4.2.2 Regenerative braking

Through regenerative braking, drivers can re-convert the kinetic energy of the vehicle into electric energy, re-stored in the battery. Overall, drivers were able to adapt very quickly to regenerative braking and regarded it very positively.

Cocron et al. (2013) found that users learnt quickly, switching rapidly from the conventional brake towards regenerative braking within the first 10km of driving; by 50 km, no more adaptation occurred. Helmbrecht et al. (2014) observed that by only the first trip, 95% of drivers positively evaluated the single-pedal accelerator and brake. Cocron et al. (2013) also found that users with the chance to experience regenerative braking were more trusting and appreciative of it. The regenerative brake changed driving styles: users drove more smoothly (Turrentine et al., 2011) and nearly a fifth reported driving more safely (Labeye et al., 2016). Günther et al. (2017) found regenerative braking the most commonly-used eco-driving strategy in a critical range scenario. However, Schmitz et al. (2013), in a simulation study, observed that people much preferred a stronger regenerative braking force and to have the regenerative brake integrated into the accelerator rather than the conventional brake pedal. With a one-pedal solution, they enjoyed not needing to brake separately, but sometimes found the ‘coasting’ region hard to find.

4.2.3 Noise

Silence is another experiential aspect specific to current PEVs and thus requires some behavioural and cognitive adjustments. The lack of noise is generally very enthusiastically received, but not without qualification. Bühler et al. (2014a) in fact found it the most important experiential advantage of BEVs, and users became significantly more enthusiastic about it with experience (Carroll et al., 2013). Users enjoyed the new driving sensations (Magali and Fulda, 2015), highlighting the ‘relaxation’ and ‘mindfulness’ of the silence and peace, the sense of a rare escape or moment of solitude and its pacifying effect on children (Friis and Gram-Hanssen, 2013, Agerskov and Høj, 2013). Swart et al. (2018) simulated augmented BEV noises and found them slightly preferred to the ‘natural’ sounds. However, Graham-Rowe et al. (2012) found that many mainstream drivers had used the engine noise in an ICE vehicle to be ‘in tune’ with the car and found it hard to adapt to its absence.

One key issue with low noise is that of its potential danger to other road users, who might not be able to hear the PEV in time. Drivers who appreciated silence were also aware of this aspect (Cocron et al., 2010). However, they were able to adapt very quickly, becoming more conscious of other road users, and driving more carefully or making visual or verbal contact with pedestrians. This means that safety incidents were found to be rare and when they happened, did not tend to be dangerous (Friis and Gram-Hanssen, 2013). Hence, after experiencing a BEV, users found low noise less problematic than initially expected (Cocron et al., 2014, Cocron and Krems, 2013, Carroll et al., 2013), with Bühler et al. (2014a) noting that virtually none reported it as a danger issue after experience. However, users weren’t always happy having to be patient and experienced insecurity when they felt other road users couldn't hear them (Friis and Gram-Hanssen, 2013).

4.3 Subjective aspects of usage experiences

4.3.1 Symbolic aspects

Three symbolic themes emerged: environmentalism, futurism, and status/identity. None had uniform meanings for PEV users. Many studies found that the environmental benefits were a valued symbolic part of using a PEV (Ryghaug and Toftaker, 2014, Skippon and Garwood, 2011, Caperello et al., 2014, Rolim et al., 2014, Neumann et al., 2010, Freund, 2007, Friis and Gram-Hanssen, 2013); others, however, found them not uniquely important (Rolim et al., 2014, Bühler et al., 2014a, Figenbaum and Kolbenstvedt, 2016, Hutchins et al., 2013, Haugneland and Hauge, 2015, Heyvaert et al., 2013, Hardman et al., 2016, Hardman and Tal, 2016), valued in a 'negative' sense of expiated guilt (Friis and Gram-Hanssen, 2013, Ryghaug and Toftaker, 2014, Bühler et al., 2014a), or not valued at all (Ryghaug and Toftaker, 2014), particularly by mainstream drivers (Cellina et al., 2016, Graham-Rowe et al., 2012). Users who felt relieved of guilt openly admitted that they drove more as a consequence, a rebound effect (Friis and Gram-Hanssen, 2013). With futurism, on the one hand, PEVs were seen as innovative (Trommer et al., 2015, Neumann et al., 2010); on the other, as 'work-in-progress' (Graham-Rowe et al., 2012) and not a technology of the 'now' (Burgess et al., 2013, Caperello and Kurani, 2012). Positive meanings of status/identity included openness (Skippon and Garwood, 2011, Skippon et al., 2016) and progressiveness (Ryghaug and Toftaker, 2014), and also related to the previous two themes (Friis and Gram-Hanssen, 2013, Trommer et al., 2015); negative ones included a sense of embarrassment and of being non-enthusiasts (Graham-Rowe et al., 2012), although a study of 'high-end' (Tesla) BEV owners found that they rated their vehicle's image as far superior to conventionally-fuelled cars (Hardman et al., 2016).

4.3.2 Social aspects

As with status/identity, a spectrum of social interactions was recorded. Positive interactions included receiving enthusiastic attention from others (Ryghaug and Toftaker, 2014, Burgess et al., 2013), users showing off either through demonstration rides (Woodjack et al., 2012) or boasting of cost savings and seeing others' reactions (Caperello et al., 2014), and dispelling negative preconceptions about, for example, electric vehicles not being 'normal' or 'proper' vehicles (Burgess et al., 2013, Friis and Gram-Hanssen, 2013); negative, mockery and ridicule (Burgess et al., 2013, Hutchins et al., 2013) . Interestingly, although Graham-Rowe et al. (2012) also presented a wide spectrum of imagined judgements from others, other people's responses in reality were mostly quite mild, centred on curiosity on how the car worked, although some were nonetheless harshly negative, including "complete and utter ridicule" and harassment for driving slowly. Social interactions strongly influenced how drivers viewed PEVs (Axsen and Kurani, 2011): budding prosocial interpretations need peer support, without which they may fail to develop (Axsen and Kurani, 2012, Axsen and Kurani, 2013). Axsen and Kurani (2014) also propose the Reflexive Layers of Influence model as a framework for understanding how social influence affects how users respond to an innovation. Social influence occurs at three layers: awareness, assessment and alignment with self-concept; these are concerned with: basic knowledge of the innovation and its attributes; translating these attributes into specific benefits or disbenefits; and framing this translation relative users' self-concepts. The social influence processes occurring at these layers are: diffusion (unidirectional flow of awareness knowledge); translation (other people influencing how a user assesses the innovation) and reflexivity (social interactions that directly or indirectly address the user's self-concept). Amongst PEV users themselves, other sub-themes emerged: community and competition. Community was not universally important: some liked ‘belonging to a clan’ (Ryghaug and Toftaker, 2014) but others disdained the idea (Caperello et al., 2014). Family members enjoyed competing against each other to maximise fuel economy (Caperello and Kurani, 2012, Friis and Gram-Hanssen, 2013) but users were not particularly enthusiastic or responsive to seeing their fuel economy figures relative to their peers’ percentiles (Stillwater and Kurani, 2013). Gender-based responses also featured – women tended to frame their discussions of PEVs in practical, present-oriented terms; men, in more future-oriented ways, discussing topics such R&D (Caperello et al., 2014). However, men also mocked and felt threatened by PEVs, the latter possibly due to links between masculinity and the internal combustion engine (Burgess et al., 2013).

4.3.3 User feedback for future PEVs

Apart from finding how users evaluated PEVs’ various features, some studies obtained user feedback for future PEVs.

As previously discussed, range was experienced as a limitation: even users who were mostly satisfied wanted more (Franke et al., 2012b). It is hard to generalise across international markets but Trommer et al. (2015) found that both PHEV and BEV owners in Germany not only wanted more range but were willing to pay for it. Seventy percent would have had a greater range given the choice, around sixty percent wanted electric-only ranges of over 100km and 200km respectively and as a whole they were willing to pay over 2,000€, on average, for their desired range. Neumann et al. (2010) observe that participants find a range of 100 km insufficient, 200 km and above sufficient and 250 km optimal in a BEV. Mainstream buyers would only consider a BEV with a 100-mile range as a second car; with a range of 150 miles some might consider it as a main car (Skippon and Garwood, 2011, Skippon et al., 2016).

Substantial and specific feedback was given on the vehicle instrumentation. Users wanted new information. They particularly wanted a detailed breakdown of all energy loads while driving, not only including the motors but the auxiliary features (Franke et al., 2015, Neumann and Krems, 2016, Rauh et al., 2015b). They also wanted to see displayed longer-term fuel economy goals such as ‘per-tank of fuel’ (Stillwater and Kurani, 2013), ‘points-of-no-return’, and the ‘true’ remaining range after the battery was ‘officially’ depleted (Franke et al., 2015). Information should be displayed clearly and simply so easily understood (Neumann and Krems, 2016), and possibly on a head-up-display to obviate looking up and down (Rauh et al., 2015b).

Users also wanted customisable and ‘intelligent’ instrumentation. They wished to be able to adjust how the range estimator worked; for example, by adjusting reference periods (Franke et al., 2015). They also felt that the range estimator should not just be historic but predictive, using information on terrain and weather conditions (Franke et al., 2015, Rauh et al., 2015b). It should also be able to distinguish between inter- and intra- individual variations in driving style, even at the day-to-day level of variation (Franke et al., 2015). One user suggested being able to make the car aware of upcoming events automatically, to make forecasting more accurate and make planning easier (Bourgeois et al., 2015).

Regarding other attributes, very few users wanted artificial noises (Cocron and Krems, 2013, Graham-Rowe et al., 2012), although Cottrell and Barton (2012) found adding automatic artificial sounds to warn PEV users not much more stressful than having none. Users favouring artificial noises suggested activating them at lower speeds (Cocron et al., 2010). Electric vehicle branding could have been improved by making it clearer that the car was electric (Burgess et al., 2013) or by catering to mainstream tastes with a broader line-up (Graham-Rowe et al., 2012). Some found the regenerative brake too strong and wished either to be able to adjust it or to turn it off completely (Schmitz et al., 2013, Turrentine et al., 2011).

5. Discussion

To improve understanding of users, this research aimed to synthesize user experiences of the PEV innovation through a systematic review. It searched a comprehensive range of sources. Through a narrative synthesis, it identified a set of themes relevant to users' experiences. A series of insights relevant to informing the transition to low-carbon mobility and avenues for future research emerged and are discussed in this section.

One of the key themes related to how users actually use PEVs – their journey-making, or their patterns of usage or mobility. As regards their role in the transition to low-carbon mobility, these patterns are important, for two reasons. The first is that, as Cocron et al. (2011) argue, mobility patterns relate to 'acceptance', that PEVs are "usable and satisfying in their present form." Acceptance, however defined or understood, is vital for any innovation to become widespread, as PEVs must do to in displacing ICEVs. The second is that the greenhouse gas emissions that either type of PEVs can reduce is a direct function of the mileage they substitute from ICEVs. Life-cycle analyses show that this must be significant for PEVs to meaningfully reduce emissions, because their manufacturing process is relatively more energy-intensive, owing, significantly, to their batteries (Hawkins et al., 2013).

From an 'acceptance' perspective, the evidence from users suggests that they can incorporate PEVs, and BEVs in particular, into their daily routines in a relatively unproblematic way, although gaps were also identified for future research. This is consistent with studies which assess how well BEVs can be matched to existing travel patterns (e.g. Element Energy (2009)) and shows that they can meet users' needs both in practice and in theory. It may not be fully advisable, however, to generalise from these findings. This is because many of the users were not representative of the broader population, being better-characterized as early adopters or innovators. Additionally, they were self-selected in many cases. They could have been more willing to tolerate limitations because of their greater enthusiasm and desire for the innovation, or because their travel patterns were more conducive to vehicles with limited range in the first place. The evidence relevant to the mainstream users in the included studies (none of whom actually owned the vehicles) suggests that mainstream users would not be willing to tolerate or adapt to these limitations, particularly at the relatively premium currently commanded by PEVs. Nonetheless, the behaviour of Tesla users, briefly touched on, does offer additional insight for the future. The Model S is marketed as a premium vehicle and is not a realistic financial prospect for most households. However, BEVs are becoming much more competitive, both from a range and price perspective. Tesla itself now offers the Model 3, with a 300-mile range and priced at $35,000 (Tesla, 2018) and the Chinese PEV market is booming (Hertzke et al., 2017). The evidence from current Tesla users suggests that future PEVs (and BEVs in particular) with capabilities superior to current models should satisfy future users better. Any studies of future users, however, should not ignore the identified evidence gaps pertaining both to mainstream owners and potential users in developing or emerging societies (including, possibly, the most important of all from a PEV perspective – China).

From a mileage perspective, BEVs were found to dominate both vehicle and total mileage shares, being used as a ‘first’ car in the household, although this was not unambiguously positive environmentally. In some cases, total vehicle mileage increased, while usage of travel modes more environmentally-friendly than PEVs – namely walking, cycling, and public transport – was found to decrease after users gained access to plug-in electric vehicles. Users were comfortable admitting their motives, which included feeling less guilty and enjoying the extra car's convenience. It is unclear whether these findings can be used to robustly or precisely estimate greenhouse gas emissions reductions; for example, none of the included studies examined counterfactual behaviour (i.e. how total vehicle mileage would have changed had the household not accessed a PEV). Still, if it is assumed that vehicle travel patterns in 'business-as-usual' counterfactuals do not differ greatly from those with the PEVs, the magnitude of PEV mileage shares by actual users suggests that it is reasonable to assume that vehicle-miles are meaningfully substituted from ICEVs. This has implications for energy modelling studies (Anable et al., 2012, Brand et al., 2012, Linton et al., 2015) and, more importantly, suggests that, conditional on becoming widespread, PEVs will not be ineffective in reducing greenhouse gas emissions in the usage phase of their lives.

Another theme, closely related to usage and mobility patterns, related to the limited all-electric range (in BEVs), arguably the most important difference from ICEVs. This was not found to be debilitating, but was far from perfect for users. Similar caveats apply to this aspect of the innovation as to journey-making, in that early adopters were more willing to adapt than mainstream users. Another important point is that many of the studied users belonged to two-car households. This is consistent with studies that associate electric vehicles with two-car households (Karlsson, 2017, Jakobsson et al., 2016) or 'hybrid households' (Kurani et al., 1994, Kurani et al., 1996, Turrentine and Kurani, 2001) who are more adaptable because they can use an ICEV for long trips. However, a significant fraction of users belong to single-car households and would lack recourse to this option (Department for Transport, 2017). Clearly, how they might adapt to BEVs is another important future avenue of research. Also relevant to this are the findings on PHEV electric-only range. Although it was not as significant as either BEV range or PHEV fossil-fuel range, users valued it greatly, in many cases going out of their way to drive on electricity alone. This suggests manufacturers should prioritise increasing the electric-only range in future PHEVs, and researchers should specifically understand how PHEVs can be targeted to single-car users who would like to maximise electric-only driving but cannot access an alternative car for long trips. A relevant but unexamined theme would have pertained to users' responses to replacing batteries after long-term usage, as well as reliability records of very long-term ownership. These could be done as long-term experience becomes more common.

Other themes related to specific aspects of the innovation, such as instrumentation, regenerative braking, and low noise. The instrumentation was somewhat negatively received, although users offered very detailed feedback for further improvement. Manufacturers could incorporate this feedback relatively easily to improve user experiences. Users reacted to low noise and regenerative braking very positively and adapted very rapidly. Relating to these aspects, PEVs were observed to have fairly surprising and unexpected spill-over effects. These related to user welfare (enjoyment, pleasure and relaxation) and user behaviour (driving more safely, attentively and economically, both in the PEV and the ICEV). There may also have been spill-over effects beyond those captured here. It would be interesting to research their hypothetical effects in the aggregate and whether their valuation or social benefit might justify support for PEVs in addition to that currently offered on low-carbon grounds. Further examination could lead policy-makers to reassess the support for PEVs.

Finally, various subjective responses were observed, both symbolic and social. Although the environmental benefits of PEVs are widely touted, they are neither unambiguously positive nor supremely important for users. Negative perceptions were also observed, particularly among mainstream users in trials. Nonetheless, many of the vehicles in those particular trials were non-production prototypes, and their weaknesses are not likely to be applicable either to current and future PEVs. Two social aspects of PEVs emerged as important: social influence and gender-distinct responses. It was shown that social influence from peers affects how users regard PEVs; and that men and women respond differently to PEVs. With regard to the latter point, for early UK adopters, most of the buyers are men and the men play the dominant role in the purchase decision (Hutchins et al., 2013). However, for mainstream households who might want to buy a PEV as a single car, and particularly in those where both male and female household heads have equal input into the purchase decision, it is important that future electric vehicles are designed to meet both of their needs. Clearly, these factors should be taken into account when designing and marketing future PEVs. Research-wise, there is increasing research that emphasises the need to market PEVs in a targeted or segmented way to users (Morton, 2013, Morton et al., 2016b, Sovacool et al., 2018a). Future research could incorporate these factors to understand their role not only for different segments of future users, but future vehicles themselves.

In conclusion, a systematic review attempted to review user experiences of the plug-in electric vehicle innovation. Understanding these user experiences is important because innovations generally embody a degree of uncertainty and the particular innovation that is the PEV is a direct ‘end-user product’. Many aspects of user experience, both positive and negative, emerged from the empirical evidence of users. The evidence from users was that PEV experiences were mostly positive, satisfactory or acceptable, but this has to be qualified with regard to the ratio of early adopters to mainstream users. Users such as mainstream owners, single-car households, and potential users in developing and emerging societies, were not at all represented.

Nonetheless, given this evidence, policy-makers and other stakeholders might be more confident that some uncertainty around this innovation has been dispelled. While there were less than fully satisfactory aspects of experience, improvements in future PEVs are likely to mitigate against these disbenefits. Policy-makers should help maintain an environment in which these improvements can be realised. It is concluded that, based on the existing evidence from users, PEVs can play an effective role in the transition to low-carbon mobility.

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