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

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## 14 **A systematic review of the evidence on plug-in electric vehicle user** 15 **experience**

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

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

40

## 41       **1. Introduction**

42       Compared to conventional vehicles, plug-in electric vehicles (PEVs) are innovations  
43       because they can transport their users exclusively using electricity from the grid;  
44       potentially, from zero-CO<sub>2</sub> renewables (Kurani et al., 2009). They are therefore central  
45       to the low-carbon mobility transition, which is itself important because transportation  
46       contributes significantly towards global greenhouse gas emissions (Anable et al., 2012).  
47       PEVs encompass battery electric vehicles (BEVs), which rely solely on batteries, and  
48       plug-in hybrid electric vehicles (PHEVs), which combine batteries with the drivetrain of  
49       a conventionally-fuelled internal-combustion-engine vehicle (ICEV).

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

64             An increasing number of PEV trials have been conducted and more people are  
65       becoming PEV owners, but there has not been a synthesis of the accumulated evidence

66 from these users. Reviews of the relevant literature have tended to focus on the uptake  
67 decision rather than user experiences *per se*. Rezvani et al. (2015) review factors  
68 affecting the adoption decision; Liao et al. (2017) build on this by considering factors  
69 beyond psychological constructs (see also Anable et al. (2014). Also, many of the  
70 included studies in those reviews evaluate PEVs' likely success based on users who  
71 have not experienced them (e.g. stated preference studies, surveys).

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

## 83 **2. Method**

### 84 ***2.1 Search Strategy***

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

91 Science Direct. A combination of four sets of keywords was used, respectively  
92 pertaining to electric vehicles, users, individuals, and some exclusionary keywords. The  
93 third set of keywords was used to omit studies that might have investigated usage, but  
94 from a modelling or simulation perspective, as the focus of this review was on first-  
95 hand, personal, or lived experience with the vehicles, whether in a trial situation or real-  
96 world uptake. The fourth set of exclusionary keywords was comparatively large and  
97 was used to exclude studies from unrelated disciplines, such as engineering and  
98 computer science. It was developed iteratively after a series of scoping searches. For the  
99 first set of keywords, the use of the proximity operator was important to exclude studies  
100 in which elements of each subset appeared anywhere in the title, abstract or keywords,  
101 rather than directly next to each other. Ovid Transport Database enabled the use of the  
102 “PRE/0” operator, ensuring the element of the first subset (including e.g. “alternative  
103 fuel”) directly preceded the element of the second subset (containing e.g.  
104 “automobile\*”); Web of Science only enabled “NEAR/0”, meaning that elements in the  
105 two subsets could come in any order. Table 1 contains the sets of keywords that were  
106 used in searching academic databases. We supplemented references from these searches  
107 with existing library references, results from a grey literature search (Google), and  
108 expert recommendations.  
109

110 Table 1: Keyword combinations used for searching academic databases.

<b>Keywords for electric vehicle</b>	<b>Keywords for usage</b>	<b>Keywords for individuals who have experienced the electric vehicle</b>	<b>Exclusionary keywords</b>
"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*

111

112 In the context of a systematic review, we did not use quality assessment criteria.

113 Located studies had differing methodologies and were not easily comparable. Where

114 appropriate, we have included assessment of the implications on our findings of  
115 different approaches and sampling used in the studies reviewed. In addition, answering  
116 the research question involved ‘inductively’ discovering relevant themes, and  
117 discarding studies could have meant losing distinctive thematic material. Relevant to the  
118 latter point, there was not initially a clear-cut selection criterion for including studies  
119 that had passed the full-text scan phase. This was because it could not have been  
120 definitively known *a priori* what set of relevant concepts or themes existed.

## 121 ***2.2 Study inclusion and data analysis***

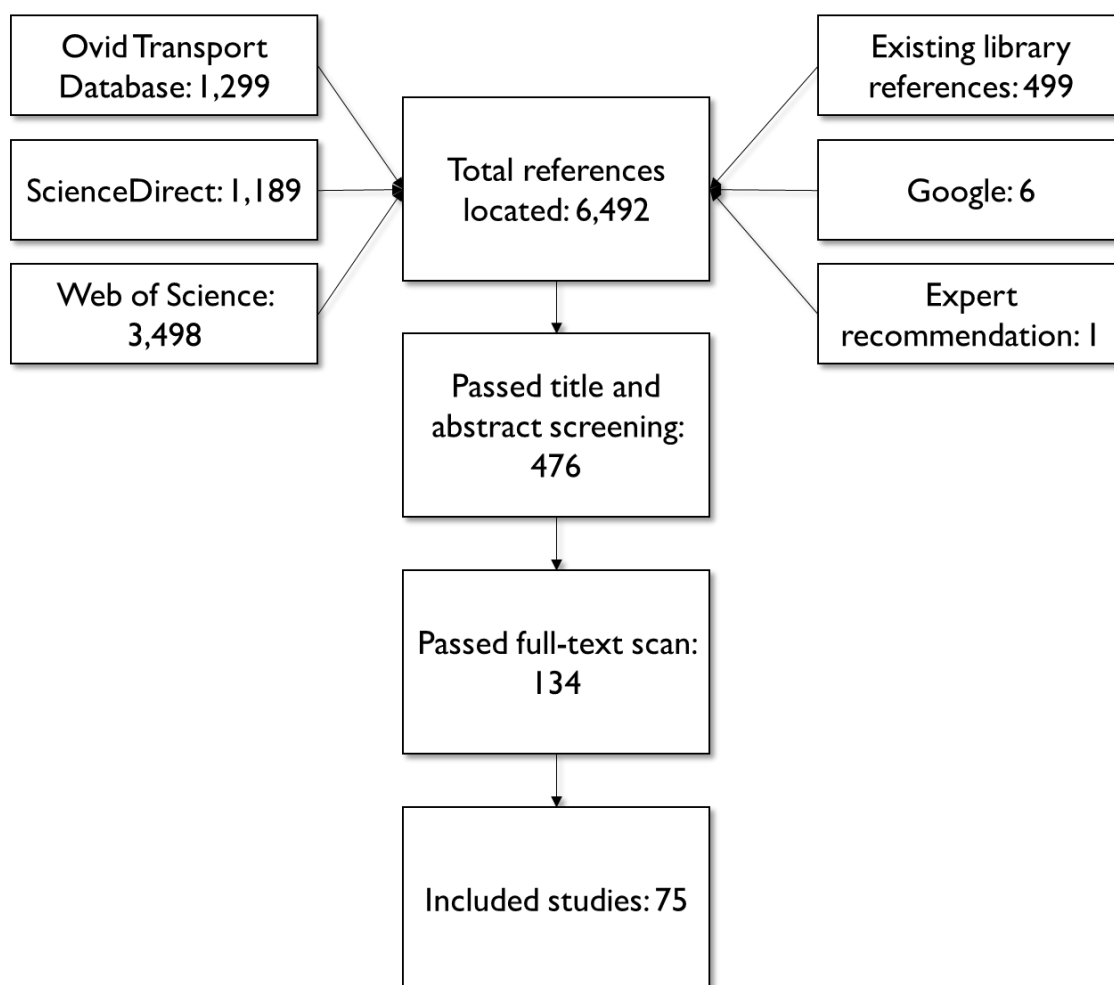
122 This review aimed to synthesize user experiences; to be included, a study needed to  
123 offer valuable insight into PEV user experiences. We excluded evidence on charging  
124 behaviour, with a focus on user experiences related the vehicle itself. Although charging  
125 behaviour is certainly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

128 The data extraction and analysis approach involved the use of narrative synthesis  
129 and thematic saturation. Narrative synthesis is defined as an approach that relies on  
130 words and texts to organise data in the form of a ‘narrative’ or a ‘story’ (Popay et al.,  
131 2006). Thematic saturation means that data is collected until “additional data do not  
132 lead to any new emergent themes” (Saunders et al., 2018). We implemented the  
133 approach as follows. In the title and abstract screening stage, we selected studies that  
134 were judged to meet the criterion of offering valuable insight into PEV user  
135 experiences. In the full-text-scan stage, we exported these studies to a spreadsheet table  
136 and coded them using a set of open keywords, as part of an iterative process. At the  
137 start, we read the studies once, and coded them on subsequent re-readings. The set of  
138 codes to use was not decided beforehand but emerged from reading the studies. Then,

139 we extracted data from references and deposited them by theme into a set of word  
140 processing documents, which was based on the previously used codes. We also coded  
141 sub-themes and iteratively organised the data until we judged that a coherent and  
142 meaningful framework had emerged.

### 143 3. Nature of the evidence found

144 We located a total of 6,492 references: 5,986 references from academic databases and  
145 506 from additional sources. After title and abstract screening, 476 references were left.  
146 After full-text scanning we found 134 references that met the inclusion criterion. Of  
147 these, we extracted content from 75 studies. Figure 1 displays the flow of references  
148 that were processed during the review.



149

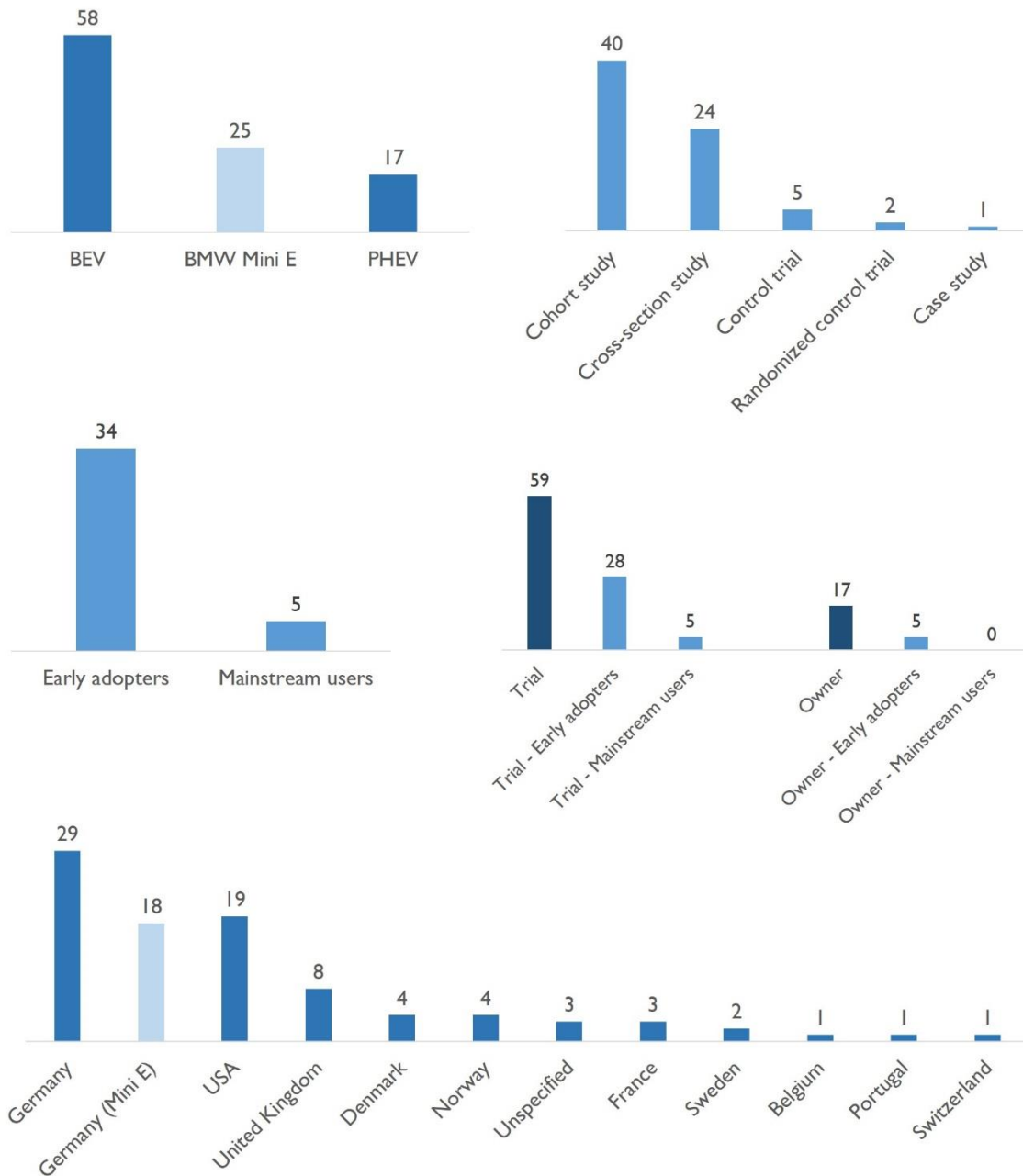
150 Figure 1: Flow of references processed during systematic review.

151 The features of the selected references are henceforth described (Figure 2 shows  
152 detailed specifics of the references found). The evidence was dominated by BEVs,  
153 featuring in 58 studies against 17 for PHEVs. Studies featuring trials and owners were  
154 split almost identically (59 vs. 17). Studies of the earliest adopters (innovators or  
155 enthusiasts according to Rogers (1962) Diffusion of Innovation Theory; herewith  
156 referred to as 'early adopters') were much more common than those of mainstream users  
157 (34 vs. 6). Notably, no references were found which included mainstream owners. It  
158 should also be noted that other studies did not explicitly designate their sample type (i.e.  
159 using those terms) and we did not judge that we could make any robust inferences about  
160 their samples, thence leaving their samples undescribed. Nonetheless, the predominance  
161 of early adopters in the evidence potentially raises issues of early adopter or  
162 'enthusiast/innovator' bias (Rogers, 1962, Morton et al., 2016a, Axsen et al., 2016).  
163 That is, evidence from these types of users and their reactions may not be fully  
164 generalizable to the population of desired PEV users: early adopters (innovators) have  
165 greater resources (both financial and social) and have more innovative dispositions,  
166 making them more tolerant of an innovation's shortcomings or limitations; people  
167 further along the adoption curve may be more sceptical and less tolerant and accepting  
168 (Rogers, 1962). Most references pertained to Germany (29), with the USA second (19).  
169 All studies took place in developed nations; no studies were found relevant to  
170 developing or emerging societies.

171 Incidentally, the international BMW Mini E trial, the largest of its type in the  
172 world (Vilimek et al., 2013), contributed significantly towards the evidence. Twenty-  
173 five of the studies featured the BMW Mini E, which is more than the number of studies  
174 which included PHEVs. The Mini E study was focussed on Germany; there were almost  
175 as many German Mini E studies as there were of studies for the entire USA. The trial

176 also focussed on early adopters as a deliberate feature of the study design (Vilimek et  
177 al., 2013, Turrentine et al., 2011), and participation was conditional on successful  
178 application and on paying a monthly lease, raising possible questions of self-selection.

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



184

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

191

192

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

197 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)
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198

199 **4. Results: systematic review**

200 **4.1 Driving and travel behaviours**

201 *4.1.1 Range satisfaction in BEVs*

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

207 In this review, with respect to post adoption or user experience, mixed results  
 208 were found regarding users’ satisfaction with the range. Studies from the international  
 209 Mini E trial found that users, who were ‘early adopter’ or ‘innovator’ types who  
 210 voluntarily participated in the trial, were not hindered by the limited range. Rather, they  
 211 felt that BEVs were suitable for their daily use, were willing to adapt and did not feel a  
 212 loss of mobility. They mostly saw limited range as a problem to be solved, rather than  
 213 as a cause for stress, with limited seating and storage (due to the battery) experienced as  
 214 a greater inhibitor on usability than limited range (Franke and Krems, 2013a, Turrentine  
 215 et al., 2011, Woodjack et al., 2012). These users become more satisfied with range with

216 experience and more willing to accept a lower range, finding that having to plan was  
217 less difficult than initially expected (Franke et al., 2012b, Franke and Krems, 2013b).  
218 Other studies had similar findings (Bühler et al., 2014b, Schmalfuß et al., 2017,  
219 Ryghaug and Toftaker, 2014); elsewhere, a timeframe of up to two weeks was indicated  
220 for people to adapt to the range. Users referred to it as mere ‘mental blocking’ they  
221 needed to get over (Agerskov and Høj, 2013), and Labeye et al. (2016) found that 10%  
222 could adapt immediately. Range satisfaction was also higher with more regular and  
223 predictable daily mobility patterns (Franke et al., 2017).

224         Some studies, however, found dissatisfaction amongst users. Early adopter  
225 owners found that only of third of them were satisfied with their range (Trommer et al.,  
226 2015), and that they were concerned about disparities between the range as advertised  
227 and as achieved in real life (Hutchins et al., 2013). Some trials, some of which included  
228 mainstream users, also discovered concerns of being unable to meet mobility needs  
229 (Jensen et al., 2014, Graham-Rowe et al., 2012) and that not only was range the main  
230 barrier to acceptance but it became a barrier to more people over time (Bühler et al.,  
231 2014a). Other trials found that hands-on experience of range reduced range satisfaction  
232 amongst users (Carroll et al., 2013, Heyvaert et al., 2013) or made them less willing to  
233 accept a BEV, either as a first or second car (Skippon et al., 2016). And even users  
234 satisfied with vehicle range tended to regret its limitations (Magali and Fulda, 2015) and  
235 wanted it to be higher (Franke et al., 2012b).

#### 236         4.1.2 *Range anxiety in BEVs*

237         Range anxiety is distinct from range satisfaction in referring to how users feel  
238 when they sense that their range is either not enough or only marginally enough to  
239 complete their trip – a ‘critical range situation’ (Rauh et al., 2017a); range satisfaction  
240 might refer to the general evaluation of the range as such. Someone who is broadly

241 satisfied with the overall range of their BEV might experience range anxiety when, for  
242 example, they are stressed or afraid because they don't think they will be able to  
243 complete their journey; conversely, someone not satisfied with their range (feeling it is  
244 not enough and greatly wanting more) might never experience range anxiety simply  
245 because they never go anywhere near the limits of the BEV, or because they just do not  
246 get that stressed when the range is nearly depleted. Range anxiety was not found a  
247 hugely debilitating problem, principally because situations that evoked it only rarely  
248 occurred. Franke et al. (2012c) found that only 12% of drivers worried about range  
249 while driving. On average, drivers averaged one 'range-related stressful situation' per  
250 month and most drivers (75%) only experienced this once per month at most.

251         Range was not a particularly positive feature from an emotional perspective;  
252 contrasting responses were observed. Early adopters in a trial were at worst annoyed  
253 when in a critical range situation, and very few mentioned being so (Franke et al.,  
254 2012c). In a study of mainstream users, however, they reported a high level of anxiety,  
255 with "alarm bells" due to concern about having enough range and charging points en-  
256 route, although BEVs were mostly prototypes with a range of only 75 miles (Graham-  
257 Rowe et al., 2012). Interestingly, Nilsson (2011) found that users who actually did run  
258 out of range were frustrated with and reproachful towards themselves rather than the  
259 vehicle. Unsurprisingly, higher range anxiety in critical range situations was associated  
260 with greater dissatisfaction and lower acceptance of the vehicle (Franke et al., 2016).

261         Two factors linked to variations in range anxiety were experience and perceived  
262 certainty. Range anxiety was found to decrease with experience (Franke et al., 2016,  
263 Rauh et al., 2015a) due to higher subjective range competence and understanding of  
264 range dynamics (Rauh et al., 2017b). Interestingly, while Franke et al. (2016) found that  
265 having fewer range-stressful encounters reduces range anxiety, Rauh et al. (2017a)

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

#### 287 *4.1.3 Range utilisation in BEVs*

288 Evidence suggests that while users preferred not to use the maximum capacity of the  
289 range, they were not overly conservative. Users were generally comfortable using  
290 between 75 to 80 percent of the vehicle range for trips, preferring to reserve a fairly

291 substantial safety buffer (Franke et al., 2012a, Franke and Krems, 2013a, Franke et al.,  
292 2012c). Elsewhere, Walsh et al. (2010) found that only 7% of trips were taken when  
293 half or less of the range remained. But Franke et al. (2012b) found that participants’  
294 comfortable range limit fell slightly after experiencing a car for three months.  
295 Pichelmann et al. (2013) found that on average, users reached their maximum available  
296 estimated range without recharging after just under 100 days. Risk-taking was found in  
297 Mini E users, who enjoyed testing the range, describing it as exploratory and as  
298 providing a sense of adventure, using discourses of discovering territory (Turrentine et  
299 al., 2011, Woodjack et al., 2012). Other studies also found between 30% and 50% of  
300 users deliberately trying to exhaust range to see how far they could go (Carroll et al.,  
301 2013, Labeye et al., 2016). Some users even claimed to have driven BEVs beyond their  
302 stated electric-only range (Bourgeois et al., 2015).

#### 303 *4.1.4 Electric range in PHEVs*

304 As previously noted, PHEVs do not suffer from the same range issues as BEVs, but  
305 their users still engaged meaningfully with the electric-only range. Indeed, Graham-  
306 Rowe et al. (2012) found that PHEV users did not raise concerns about range in the  
307 same way as BEV users. Rather, users wanted to maximise the distance covered using  
308 electricity alone. Figenbaum and Kolbenstvedt (2016) found ‘doing short trips on  
309 electricity’ as the most important adoption factor, consistent with Carlson (2014) who  
310 found trips under thirty miles mostly powered by electricity, and trips over that by fossil  
311 fuels. Trial participants in the UK were found to deliberately stay in electric-only mode  
312 to save money (Graham-Rowe et al., 2012). Some owners went to extreme lengths to  
313 stay in electric-only mode (Heffner et al., 2009); one user was frustrated when the  
314 engine came on, even during short trips (Kurani et al., 2009). Despite its importance  
315 with respect to overall emissions, there is limited information on the overall proportion

316 of mileage undertaken in PHEVs are carried out on the electric-only mode reduction.  
317 One study in Germany found owners run their vehicles for approximately 70% of miles  
318 in on the battery (Trommer et al., 2015). Smart (2013) also found a similar average  
319 statistic for a trial; most users were above this average (positive skew). A very large  
320 study found the share of all-electric driving (or utility factor) increasing non-linearly  
321 with the all-electric range. The lowest utility factor was with a range of 20km (12%);  
322 PHEVs with 40km and 120km ranges had utility factors of 50% and 80% respectively  
323 (Plötz et al., 2017).

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

#### 330 *4.1.5 Cognitive and behavioural driving adaptations*

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

341 shopping).

342           The limited range made users much more aware of their energy use (Bourgeois  
343 et al., 2015, Friis and Gram-Hanssen, 2013, Magali and Fulda, 2015). They became  
344 aware how their actions impacted performance and fuel efficiency and in some cases  
345 monitored their own driving behaviour on a near-constant basis (Caperello and Kurani,  
346 2012). The heightened sense of awareness resulted in chiefly two behavioural  
347 adaptations to minimise energy use: a changed driving style and a reduced use of  
348 auxiliary features (e.g. air conditioning, heating, radio). More people became aware of  
349 these strategies after experiencing an EV (Neumann et al., 2010).

350           Behaviourally, two-thirds of BEV owners reported changing their driving style  
351 after adoption: three quarters drove more slowly and under a quarter drove less  
352 aggressively and more efficiently (Rolim et al., 2014). Users apply a smoother and more  
353 fluid driving style (Magali and Fulda, 2015). Strategies included anticipatory driving  
354 styles, using decelerating to recover energy from the regenerative brake and driving as  
355 economically as possible to improve the range of driving (Freund, 2007, Friis and  
356 Gram-Hanssen, 2013). Both the heightened awareness and the changed driving  
357 behaviour spilled over to when they drove their ICEVs, and they felt better drivers  
358 generally (Friis and Gram-Hanssen, 2013, Ryghaug and Toftaker, 2014, Helmbrecht et  
359 al., 2014). Changes in driving style indeed reduced energy consumption significantly  
360 compared to when drivers drove normally (Neumann et al., 2015). A study at the  
361 Millbrook Proving Ground in the UK which used telemetric data to monitor BEV  
362 driving found that drivers drove more efficiently as the remaining range fell (Walsh et  
363 al., 2010). A simulation study also found that drivers with a lower initial state of charge  
364 drove more efficiently, and actually took very slightly less time to complete the  
365 simulated course (Beloufa et al., 2014). Some drivers who changed their acceleration,

366 speed, and use of coasting, specifically attributed this to being able to see the  
367 instantaneous fuel consumption rate on the display. They also engaged in experimental  
368 behaviour, seeing how various actions affected the economy display, such as ‘flooring  
369 it’ and changing auxiliary features such as air conditioning (Caperello and Kurani,  
370 2012). One study found that after five months, drivers accelerated more smoothly and  
371 were better at driving at more consistent speeds than drivers of ICEVs, although no  
372 differences were found in average speeds (Helmbrecht et al., 2014). The curtailed use of  
373 auxiliary features was in some cases a deliberate and voluntary economising measure  
374 (Friis and Gram-Hanssen, 2013) but also a response to range anxiety, reducing driving  
375 pleasure (Graham-Rowe et al., 2012). PHEVs also were found to change driving  
376 behaviour (Kurani et al., 2009).

#### 377 *4.1.6 Journey making*

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

388 Examining snapshots of travel patterns, PEVs, and BEVs in particular, appear to  
389 fulfil users’ needs. Haugneland and Hauge (2015) found that households used them for  
390 mandatory and maintenance trips, such as commuting, education escort trips and small

391 errands, and that all owners used them every day, as did Klockner et al. (2013) and  
392 Rolim et al. (2014). Hutchins et al. (2013) found that the trip purpose distribution (the  
393 share of all household trips by trip type) was not statistically significant from the UK  
394 National Travel Survey's. Figenbaum and Kolbenstvedt (2016) found BEVs were used  
395 more often than ICEVs and PHEVs for all trips types except vacations. Magali and  
396 Fulda (2015) further found that BEVs were not only used for short trips but also  
397 'medium range' extra-urban trips on a regular basis, being the most frequently used  
398 transport mode. Families with young children also felt their PHEVs met their practical  
399 daily needs (Caperello and Kurani, 2012).

400         Examining modal shares, a pattern emerges of the BEV coming to a place of  
401 dominance. Many studies assess what happens after a household accesses a BEV in  
402 addition to an existing ICEV, and found the BEV becoming the primary car in multi-car  
403 households (Bourgeois et al., 2015, Nicholas et al., 2017), despite initial expectations of  
404 its being used as a 'secondary car' (Magali and Fulda, 2015). Users explicitly sought to  
405 maximise its use (Turrentine et al., 2011) and reserved the ICEV as a 'backup' for  
406 weekend trips and holidays (Agerskov and Høj, 2013, Ryghaug and Toftaker, 2014).  
407 Studies quantifying modal shares found the BEV covering 60-70% of both overall and  
408 vehicle mileages travelled, with no significant changes over the trial period (Bühler et  
409 al., 2010, Franke et al., 2012a). Cellina et al. (2016) found similar figures for  
410 mainstream households, and this did not differ greatly from a comparative sub-sample  
411 of early adopters. Jensen and Mabit (2017) however found that while the BEV  
412 constituted a majority of vehicle miles travelled, the decrease in ICEV miles after the  
413 BEV was acquired was very small. Mileage shares ended up similar across vehicles and  
414 overall vehicle mileage increased significantly. Studies also observed a significant  
415 decrease in travel using active travel and public transport (Franke et al., 2012a, Labeye

416 et al., 2016). Friis and Gram-Hanssen (2013) provided an interesting perspective: once  
417 single-car households experience the freedom and convenience of an additional car,  
418 they become habituated to it and still retain a desire for it after returning it. Increases in  
419 total vehicle mileage at the apparent expense of environmentally-friendlier travel were  
420 also observed when a BEV replaced an existing ICEV instead of joining it in the  
421 household fleet (Figenbaum and Kolbenstvedt, 2016), although a smaller study which  
422 also examined changes after a BEV replaced an ICEV did not find any clear direction of  
423 change; ‘first’ cars remained first cars and ‘second’ cars mostly remained second cars  
424 (Jakobsson, 2016).

425         Other adaptations occurred over the course of people’s daily lives. It was found  
426 that people were mostly willing to adapt and did not feel seriously inconvenienced,  
427 although there were exceptions, particularly among mainstream users. These  
428 adaptations included: trip chaining, trip elimination, avoiding trips, learning distances  
429 between key locations and sometimes finding alternatives, planning trips, using  
430 convenience charger at work/other destinations and charging frequently and/or during  
431 trips, and multimodal travel (Franke et al., 2012c, Woodjack et al., 2012, Turrentine et  
432 al., 2011). The most common adaptation, however, is simply to use a conventional  
433 vehicle for long trips (Caperello et al., 2014, Magali and Fulda, 2015, Woodjack et al.,  
434 2012, Figenbaum and Kolbenstvedt, 2016) and households are often able to access one  
435 even when not owned (Magali and Fulda, 2015). As with range anxiety, the need to  
436 adapt in this way happened only occasionally (Caperello et al., 2014). For example,  
437 while over 80% of drivers couldn’t take their cars to some places they had wanted to,  
438 these were only visited on a monthly basis or less frequently (Woodjack et al., 2012).  
439 Households did not express an overall feeling of losing mobility (Turrentine et al.,  
440 2011) and did not begrudge the need for extra planning (Agerskov and Høj, 2013). One

441 early adopter household commented that while they were more than willing to adapt,  
442 other people would not have the patience to perform all the planning needed (Turrentine  
443 et al., 2011). And even some early adopter owners did not regard planning positively,  
444 viewing it as ‘restrictive’; others were unwilling to compromise on functionality  
445 (Hutchins et al., 2013, Kurani et al., 2009). Mainstream users also felt it unacceptable to  
446 be unable to use a car for all household trips, particularly at a relatively high price  
447 (Cellina et al., 2016).

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

#### 459         ***4.2 Interaction with the vehicle***

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

465       4.2.1 *Instrumentation*

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

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

478               Three specific responses to the instrumentation were found: goal-directed  
479       behaviour, confusion, and distraction. Goal-directed behaviour was mostly engaged in  
480       enthusiastically. PHEV drivers were spurred by the psychological target of seeing  
481       triple-digit fuel economy figures (100 mpg+), treating it as a game or test (Caperello  
482       and Kurani, 2012, Kurani et al., 2009). Stillwater and Kurani (2013) made the power  
483       display shine bright blue under low energy consumption which was enthusiastically  
484       received, but some were frustrated by being set an implied goal of all-electric driving  
485       they couldn't always meet. Displaying cost information didn't motivate energy savings.  
486       Confusion arose for various reasons. One was the complexity of the design and layout  
487       (Graham-Rowe et al., 2012). PHEV users felt that fairly basic variables, such as the  
488       state of charge and remaining range, were not clearly displayed, and had difficulty  
489       telling when the battery was charged or not. Likewise, the fluctuating fuel economy

490 display was confusing and even overwhelming, (Caperello and Kurani, 2012, Kurani et  
491 al., 2009) making it hard to get a sense of overall fuel economy (Kurani et al., 2009). A  
492 power meter was divisive: people either found it very useful or not useful at all  
493 (Turrentine et al., 2011). Certain variables were also difficult to interpret, such as  
494 energy consumption displayed in electrical units (Neumann and Krems, 2016) and  
495 people found it hard to make sense of CO<sub>2</sub> emissions for want of a reference frame  
496 (Stillwater and Kurani, 2013). Finally, a number of people found the instrumentation  
497 distracting (Graham-Rowe et al., 2012), and adapted by watching elsewhere when they  
498 felt it to be so (Stillwater and Kurani, 2013).

#### 499 *4.2.2 Regenerative braking*

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

503 Cocron et al. (2013) found that users learnt quickly, switching rapidly from the  
504 conventional brake towards regenerative braking within the first 10km of driving; by 50  
505 km, no more adaptation occurred. Helmbrecht et al. (2014) observed that by only the  
506 first trip, 95% of drivers positively evaluated the single-pedal accelerator and brake.  
507 Cocron et al. (2013) also found that users with the chance to experience regenerative  
508 braking were more trusting and appreciative of it. The regenerative brake changed  
509 driving styles: users drove more smoothly (Turrentine et al., 2011) and nearly a fifth  
510 reported driving more safely (Labeye et al., 2016). Günther et al. (2017) found  
511 regenerative braking the most commonly-used eco-driving strategy in a critical range  
512 scenario. However, Schmitz et al. (2013), in a simulation study, observed that people  
513 much preferred a stronger regenerative braking force and to have the regenerative brake  
514 integrated into the accelerator rather than the conventional brake pedal. With a one-

515 pedal solution, they enjoyed not needing to brake separately, but sometimes found the  
516 ‘coasting’ region hard to find.

#### 517 4.2.3 *Noise*

518 Silence is another experiential aspect specific to current PEVs and thus requires some  
519 behavioural and cognitive adjustments. The lack of noise is generally very  
520 enthusiastically received, but not without qualification. Bühler et al. (2014a) in fact  
521 found it the most important experiential advantage of BEVs, and users became  
522 significantly more enthusiastic about it with experience (Carroll et al., 2013). Users  
523 enjoyed the new driving sensations (Magali and Fulda, 2015), highlighting the  
524 ‘relaxation’ and ‘mindfulness’ of the silence and peace, the sense of a rare escape or  
525 moment of solitude and its pacifying effect on children (Friis and Gram-Hanssen, 2013,  
526 Agerskov and Høj, 2013). Swart et al. (2018) simulated augmented BEV noises and  
527 found them slightly preferred to the ‘natural’ sounds. However, Graham-Rowe et al.  
528 (2012) found that many mainstream drivers had used the engine noise in an ICE vehicle  
529 to be ‘in tune’ with the car and found it hard to adapt to its absence.

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

540 patient and experienced insecurity when they felt other road users couldn't hear them  
541 (Friis and Gram-Hanssen, 2013).

### 542 ***4.3 Subjective aspects of usage experiences***

#### 543 *4.3.1 Symbolic aspects*

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

566       4.3.2 *Social aspects*

567       As with status/identity, a spectrum of social interactions was recorded. Positive  
568 interactions included receiving enthusiastic attention from others (Ryghaug and  
569 Toftaker, 2014, Burgess et al., 2013), users showing off either through demonstration  
570 rides (Woodjack et al., 2012) or boasting of cost savings and seeing others' reactions  
571 (Caperello et al., 2014), and dispelling negative preconceptions about, for example,  
572 electric vehicles not being 'normal' or 'proper' vehicles (Burgess et al., 2013, Friis and  
573 Gram-Hanssen, 2013); negative, mockery and ridicule (Burgess et al., 2013, Hutchins et  
574 al., 2013) . Interestingly, although Graham-Rowe et al. (2012) also presented a wide  
575 spectrum of imagined judgements from others, other people's responses in reality were  
576 mostly quite mild, centred on curiosity on how the car worked, although some were  
577 nonetheless harshly negative, including "complete and utter ridicule" and harassment  
578 for driving slowly. Social interactions strongly influenced how drivers viewed PEVs  
579 (Axsen and Kurani, 2011): budding prosocial interpretations need peer support, without  
580 which they may fail to develop (Axsen and Kurani, 2012, Axsen and Kurani, 2013).  
581 Axsen and Kurani (2014) also propose the Reflexive Layers of Influence model as a  
582 framework for understanding how social influence affects how users respond to an  
583 innovation. Social influence occurs at three layers: awareness, assessment and  
584 alignment with self-concept; these are concerned with: basic knowledge of the  
585 innovation and its attributes; translating these attributes into specific benefits or  
586 disbenefits; and framing this translation relative users' self-concepts. The social  
587 influence processes occurring at these layers are: diffusion (unidirectional flow of  
588 awareness knowledge); translation (other people influencing how a user assesses the  
589 innovation) and reflexivity (social interactions that directly or indirectly address the  
590 user's self-concept). Amongst PEV users themselves, other sub-themes emerged:  
591 community and competition. Community was not universally important: some liked

592 'belonging to a clan' (Ryghaug and Toftaker, 2014) but others disdained the idea  
593 (Caperello et al., 2014). Family members enjoyed competing against each other to  
594 maximise fuel economy (Caperello and Kurani, 2012, Friis and Gram-Hanssen, 2013)  
595 but users were not particularly enthusiastic or responsive to seeing their fuel economy  
596 figures relative to their peers' percentiles (Stillwater and Kurani, 2013). Gender-based  
597 responses also featured – women tended to frame their discussions of PEVs in practical,  
598 present-oriented terms; men, in more future-oriented ways, discussing topics such R&D  
599 (Caperello et al., 2014). However, men also mocked and felt threatened by PEVs, the  
600 latter possibly due to links between masculinity and the internal combustion engine  
601 (Burgess et al., 2013).

#### 602 *4.3.3 User feedback for future PEVs*

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

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

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

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

634           Regarding other attributes, very few users wanted artificial noises (Cocron and  
635   Krems, 2013, Graham-Rowe et al., 2012), although Cottrell and Barton (2012) found  
636   adding automatic artificial sounds to warn PEV users not much more stressful than  
637   having none. Users favouring artificial noises suggested activating them at lower speeds  
638   (Cocron et al., 2010). Electric vehicle branding could have been improved by making it  
639   clearer that the car was electric (Burgess et al., 2013) or by catering to mainstream  
640   tastes with a broader line-up (Graham-Rowe et al., 2012). Some found the regenerative

641 brake too strong and wished either to be able to adjust it or to turn it off completely  
642 (Schmitz et al., 2013, Turrentine et al., 2011).

## 643 **5. Discussion**

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

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

660 From an 'acceptance' perspective, the evidence from users suggests that they  
661 can incorporate PEVs, and BEVs in particular, into their daily routines in a relatively  
662 unproblematic way, although gaps were also identified for future research. This is  
663 consistent with studies which assess how well BEVs can be matched to existing travel  
664 patterns (e.g. Element Energy (2009)) and shows that they can meet users' needs both in  
665 practice and in theory. It may not be fully advisable, however, to generalise from these

666 findings. This is because many of the users were not representative of the broader  
667 population, being better-characterized as early adopters or innovators. Additionally,  
668 they were self-selected in many cases. They could have been more willing to tolerate  
669 limitations because of their greater enthusiasm and desire for the innovation, or because  
670 their travel patterns were more conducive to vehicles with limited range in the first  
671 place. The evidence relevant to the mainstream users in the included studies (none of  
672 whom actually owned the vehicles) suggests that mainstream users would not be willing  
673 to tolerate or adapt to these limitations, particularly at the relatively premium currently  
674 commanded by PEVs. Nonetheless, the behaviour of Tesla users, briefly touched on,  
675 does offer additional insight for the future. The Model S is marketed as a premium  
676 vehicle and is not a realistic financial prospect for most households. However, BEVs are  
677 becoming much more competitive, both from a range and price perspective. Tesla itself  
678 now offers the Model 3, with a 300-mile range and priced at \$35,000 (Tesla, 2018) and  
679 the Chinese PEV market is booming (Hertzke et al., 2017). The evidence from current  
680 Tesla users suggests that future PEVs (and BEVs in particular) with capabilities  
681 superior to current models should satisfy future users better. Any studies of future users,  
682 however, should not ignore the identified evidence gaps pertaining both to mainstream  
683 owners and potential users in developing or emerging societies (including, possibly, the  
684 most important of all from a PEV perspective – China).

685         From a mileage perspective, BEVs were found to dominate both vehicle and  
686 total mileage shares, being used as a ‘first’ car in the household, although this was not  
687 unambiguously positive environmentally. In some cases, total vehicle mileage  
688 increased, while usage of travel modes more environmentally-friendly than PEVs –  
689 namely walking, cycling, and public transport – was found to decrease after users  
690 gained access to plug-in electric vehicles. Users were comfortable admitting their

691 motives, which included feeling less guilty and enjoying the extra car's convenience. It  
692 is unclear whether these findings can be used to robustly or precisely estimate  
693 greenhouse gas emissions reductions; for example, none of the included studies  
694 examined counterfactual behaviour (i.e. how total vehicle mileage would have changed  
695 had the household not accessed a PEV). Still, if it is assumed that vehicle travel patterns  
696 in 'business-as-usual' counterfactuals do not differ greatly from those with the PEVs,  
697 the magnitude of PEV mileage shares by actual users suggests that it is reasonable to  
698 assume that vehicle-miles are meaningfully substituted from ICEVs. This has  
699 implications for energy modelling studies (Anable et al., 2012, Brand et al., 2012,  
700 Linton et al., 2015) and, more importantly, suggests that, conditional on becoming  
701 widespread, PEVs will not be ineffective in reducing greenhouse gas emissions in the  
702 usage phase of their lives.

703 Another theme, closely related to usage and mobility patterns, related to the  
704 limited all-electric range (in BEVs), arguably the most important difference from  
705 ICEVs. This was not found to be debilitating, but was far from perfect for users. Similar  
706 caveats apply to this aspect of the innovation as to journey-making, in that early  
707 adopters were more willing to adapt than mainstream users. Another important point is  
708 that many of the studied users belonged to two-car households. This is consistent with  
709 studies that associate electric vehicles with two-car households (Karlsson, 2017,  
710 Jakobsson et al., 2016) or 'hybrid households' (Kurani et al., 1994, Kurani et al., 1996,  
711 Turrentine and Kurani, 2001) who are more adaptable because they can use an ICEV for  
712 long trips. However, a significant fraction of users belong to single-car households and  
713 would lack recourse to this option (Department for Transport, 2017). Clearly, how they  
714 might adapt to BEVs is another important future avenue of research. Also relevant to  
715 this are the findings on PHEV electric-only range. Although it was not as significant as

716 either BEV range or PHEV fossil-fuel range, users valued it greatly, in many cases  
717 going out of their way to drive on electricity alone. This suggests manufacturers should  
718 prioritise increasing the electric-only range in future PHEVs, and researchers should  
719 specifically understand how PHEVs can be targeted to single-car users who would like  
720 to maximise electric-only driving but cannot access an alternative car for long trips. A  
721 relevant but unexamined theme would have pertained to users' responses to replacing  
722 batteries after long-term usage, as well as reliability records of very long-term  
723 ownership. These could be done as long-term experience becomes more common.

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

738         Finally, various subjective responses were observed, both symbolic and social.  
739 Although the environmental benefits of PEVs are widely touted, they are neither  
740 unambiguously positive nor supremely important for users. Negative perceptions were

741 also observed, particularly among mainstream users in trials. Nonetheless, many of the  
742 vehicles in those particular trials were non-production prototypes, and their weaknesses  
743 are not likely to be applicable either to current and future PEVs. Two social aspects of  
744 PEVs emerged as important: social influence and gender-distinct responses. It was  
745 shown that social influence from peers affects how users regard PEVs; and that men and  
746 women respond differently to PEVs. With regard to the latter point, for early UK  
747 adopters, most of the buyers are men and the men play the dominant role in the  
748 purchase decision (Hutchins et al., 2013). However, for mainstream households who  
749 might want to buy a PEV as a single car, and particularly in those where both male and  
750 female household heads have equal input into the purchase decision, it is important that  
751 future electric vehicles are designed to meet both of their needs. Clearly, these factors  
752 should be taken into account when designing and marketing future PEVs. Research-  
753 wise, there is increasing research that emphasises the need to market PEVs in a targeted  
754 or segmented way to users (Morton, 2013, Morton et al., 2016b, Sovacool et al., 2018a).  
755 Future research could incorporate these factors to understand their role not only for  
756 different segments of future users, but future vehicles themselves.

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

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

773

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781

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