IOP Conf. Series: Earth and Environmental Science 1176 (2023) 012024 doi:10.1088/1755-1315/1176/1/012024

Sustainable Electric Vehicle charging scheme: User requirements in designing energy trading algorithm

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Abstract. Promoting Electrical Vehicles (EVs) as a cleaner alternative to traditional Internal Combustion Engine (ICE) vehicles is an important step towards transformation to a sustainable world. However, usage of grid electricity in charging EVs hinders achieving zero carbon emissions, hence, necessitates developing a renewable energy-based model for EV charging. On the other hand, encouraging renewable energy (RE) usage contributes to United Nations 2030 agenda for sustainable development. An energy trading algorithm which facilitates trading excess renewable energy generation of households to charge EVs is a key component in such renewable energy-based EV charging model. However, to design an algorithm beneficial for both stakeholders, i.e., EV users and households with solar power systems, user requirements of both stakeholders should be taken into consideration. This paper investigates the user requirements and specifications for an improved energy trading algorithm from both stakeholders' point of view. Semi-structured interviews were conducted with 20 EV users and 16 household solar users in the United Kingdom (UK) to explore the above. According to the findings of the interviews, both participant categories highlight renewable energy utilisation as a key requirement, whereas EV users highlight non- financial user- experience related requirements such as improving convenience and selection of preferred charging speed and household solar panel users highlight trading with less time and effort as their requirements. Additionally, households also expect higher returns to cover capital costs of solar panel installations. These findings can be used by practitioners from the industry in developing effective energy trading solutions for end users.

1. Introduction

The field of energy trading (ET) has evolved throughout the past few decades due to number of environmental and economic reasons. In particular, the conventional unidirectional energy markets dominated by large scale thermal and hydro generators have reformed with the wide adoption of Distributed Energy Resources (DERs) like Renewable Energy Sources (RESs) and Energy Storage systems (ESSs) by households becoming prosumers who can both produce and consume energy [1-3]. Paris Agreement 2015 highlights the requirement of maintaining the global temperature increase below 2°C in comparison to preindustrial level, by reducing Greenhouse Gas (GHG) emissions, with the measure of replacing conventional fuels with RESs. Electrification of transportation sector with the growth of EV usage has received significant attention given that the transportation sector accounts for a larger proportion of CO2 emissions in Europe [4, 5].

An explosion in demand for EVs is expected globally [6] and in particular, in the UK, due to the government ban on the sale of new ICE vehicles by 2030 [7]. Hence, the insufficiency of current charging infrastructure in fulfilling the charging requirements of upcoming mass penetration of EVs urges the requirement of new energy trading models (ETMs) for EV users to acquire energy [8, 9]. In light of that many authors have presented Grid-to-Vehicle (G2V) models [10, 11], Vehicle-to-Vehicle (V2V) models [5, 12-14] and peer-to-peer (P2P) models which are becoming popular due to their proven advantages; economic incentives [3, 15, 16], reduced consumer costs and improved grid resilience [17].

However, with most of the currently proposed models, electricity for charging EVs is eventually drawn from utility grid. Although this reduces the direct tailpipe emissions of CO_2 in EVs, it indirectly causes a significant amount of CO_2 emissions caused by using grid electricity [18-20]. Hence, RESs should be exploited to charge EVs to procure the most environmental and economical benefits of EVs [18, 21, 22].

There is an insufficient number of works that discuss the requirement of utilizing RE to charge EVs. Within the few available, majority have explored the strategy of providing solar Photovoltaic (PV) to charge EVs at public charging stations[9, 18, 19, 22] or solar-powered parking lots [23]. The work [24] propose an ETM between a commercial prosumer with a solar PV system and a group of electric vehicles in a charging station which eventually promotes solar energy utilization. However, in the current context, little attention has been paid in designing an ETM between the domestic prosumers (e.g., with solar PV systems) and EV users for EV charging. Such model can benefit EVs as well as household prosumers given their struggle to be financially viable in the post-subsidy environment. An improved ET algorithm which optimizes the benefits of both consumers and prosumers while facilitating the energy trade is a key component in such model.

In light of that, this paper investigates current ET related practices, behavior, expectations of participants to identify the user requirements and specifications to be incorporated in designing the improved algorithm. The UK is used as a case study and households with solar PV systems are selected as domestic prosumers in this research. Firstly, we investigated current ET related practices, behavior and expectations of users through interviews and secondly, building on the interview findings we identified the specifications to be incorporated to the algorithm.

2. Related work

Different algorithms satisfying different ET objectives have been presented so far. These objectives and the requirements in the algorithms can be categorized based on different criteria. In particular, different literature have identified the objectives/requirements from different perspectives. For instance, some researchers have focused on the requirements of individual participants[25, 26], whereas some have focused on the overall system (entire market) requirements [27, 28] or both individual and overall system requirements [14]. However, irrespective of the perspective and the participant category (EV user or household with solar PV systems), many authors have attempted addressing the economic requirements in trading mentioning that ‘most profitable and long-term sustainable local energy market business models should focus on financial benefits as their main value proposition’.

In relation to EVs, [5], [19] and [29] have considered cost minimization whereas [14],[25] and [30] have considered utility maximization in algorithm designing. However, authors have discussed other service-related requirements such as reliability [26, 31], availability[8], distance minimization [10] and privacy preservation [32] less frequently. Similarly, in household prosumer research, authors have widely considered financial requirements of revenue improvement [33], and utility improvement [26, 34] and barely considered user experience related requirements such as reliability and privacy and security of data[31].

Interestingly, some studies have presented RE based ET mechanisms for EVs and household prosumers which optimizes RE penetration[35], promotes RE utilization [24] and encourages EVs to be green by experiencing lower prices [18].

Despite all the studies which have considered the requirements of one participant category or the entire system, there are a smaller number of studies which consider and address the requirements of both energy consumers and prosumers. It is important to find solutions that deliver value for both participant categories in ET to encourage user adoption of such solutions [36, 37]. In light of that [38] exploited motivational psychology-based models to identify the key motivators for peers. The results suggest that economic benefits like 'monetary cost' and 'revenue' and environmental concerns like 'environmentally friendly behavior of a person' affect the users decisions. Similarly, [31] presented a four-level basic energy objective model incorporating the basic requirements of consumers and producers. Apart from financial requirements, it have identified user experience related objectives like availability, fairness in trading, reliability, privacy and security of data and freedom of supply source selection for consumers and opportunity to sell, fairness in trading, privacy and security of data and freedom of buyer selection for producers although it does not include environmental sustainability as an objective. However, requirements mentioned in both these studies are relating to household participants and based on theoretical facts, not actual user perceptions.

Therefore, this research aims to address that by investigating current ET related practices, behavior and expectations of participants through interviews to identify the user requirements to be incorporated in designing the improved algorithm. The work [39] has followed a nearly similar approach to find key factors important to integrate blockchain into ET, but their study considers designing a platform for domestic and business participants. In light of that, to the best of our knowledge this work becomes the first study which explores user behavior and perceptions to identify the user requirements to be incorporated in designing an improved ET algorithm.

3. Methodology

To gather and explore uncovered knowledge that is not reflected in existing research and to identify requirements from user perspective we conducted in-depth interviews with the stakeholders (EV users and household prosumers). These interviews aimed to evaluate the current ET models in practice as perceived by the users to identify user requirements in developing an improved ET algorithm (model).

3.1. Interview design

Since identifying user evaluations and requirements is explorative in nature, semi-structured interviews [2, 15, 37] which allow generating as much as information from interviews were selected. Rather than structured interviews [39] which limits the speakers only to a limited set of responses and unstructured interviews which can lead the conversation into unexpected directions [40] resulting the interviewer losing control over the interview, semi-structured interviews which provide more flexibility[41] in responding within the focused areas of the discussion are well suited.

Interview guide containing a list of questions and prompts comprising the key topics to be discussed were used to guide the semi-structured interviews. In this study, two separate interview guides were developed for EV users and household prosumers incorporating the research questions and the existing research on the overarching topic [41]. The questions in the guide were open ended and designed in a logical order where less challenging introductory questions were ordered at the beginning (of the interview) to help establishing a rapport with the interviewee. However, for each interview these questions were adjusted according to experience and technologies of the interviewee[42]. The questions were designed to address four topics as depicted in figures 1 and 2 below.

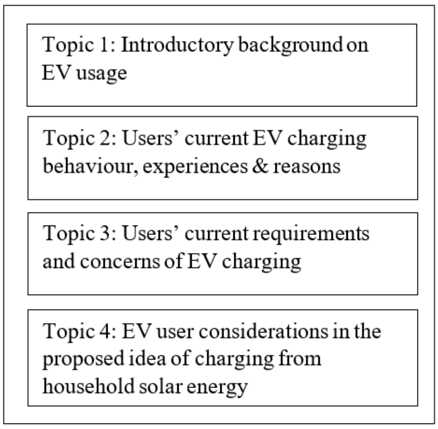

Figure 1. Topics of the questions for EV users in the interview guide.

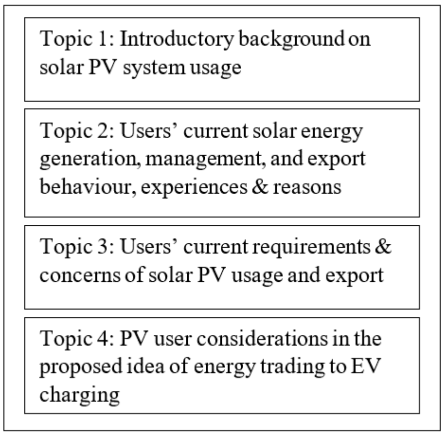

Figure 2. Topics of the questions for households with solar PV systems in the interview guide.

After developing the initial interview guide, the validity and the effectiveness of the initial questions were reviewed by the supervisory team experts. Further, to ensure the clarity of the questions and the sensitivity to participants' language, preliminary (pilot) interviews were conducted with one participant from each group. Some interview questions were rephrased and reordered according to the pilot interview experiences. The modifications made are shown in table 1 below.

Table 1. Modifications to the interview questions after pilot interviews.

	Pilot question	Modified question	Modification
EV	Imagine that you can switch to a supplier who supply electricity generated from renewable energy. Based on which factors will you decide whether to switch?	Imagine that you can switch to buy energy to charge your vehicle from a household with solar energy. Based on which factors will you decide whether to switch?	Rephrased
PV	I know that you have solar panels at home. So, do you have any storage technologies available? How long have you had solar panels at your place?	I know you have solar panels at your home. Give me an explanation about their capacity, how long have you had it? Do you have any storage technologies available as well?	Rephrased and reordered

3.2. Participant selection

The populations for interviews are inferred as all the EV users and all households with solar PV systems in the UK. Therefore, participants for the interviews were selected from these two groups. To ensure the quality of data, more experienced participants in the field of ET who fulfilled the criteria for years of experience were selected. According to that the EV users should be at least one year experienced on using and charging an EV. However, no such criteria were applied on household PV users because, if did, it could exclude the participants who are experiencing the latest ET practices introduced for households by the policy changes in 2020.

Initial sample sets were recruited using gatekeepers' email circulars and online advertising via UK wide networks, groups, and forums. Since the initial number of participants were insufficient, snowball sampling approach was used to identify further participants by asking the first set of interviewees to recommend new participants. The interviewees identified through this method were linked to a trusted person and hence improved the openness [39].

Considering the high time consumption of the in-depth interviews and the researcher's time for the field work, smaller number of participants were selected for the interviews [39] allowing more time with each participant. The number of participants in each category was not initially fixed but was determined by information gathered from each interview. When no new patterns were identified, no more interviewees were selected. 20 EV user and 16 households with solar PV systems were recruited as participants for the interviews. Adhering to participant selection criteria, the selected EV users were 1-10 years experienced in EV charging except the two users 12 and 19 who were still included due to the information richness of their responses. For example, EV user 19 was the only participant without home charging facilities and hence his inclusion in the sample was crucial. Further, the selected household PV users were 1-10 years experienced in solar energy generation and export.

3.3. Conducting interviews

The interviews were conducted with participants from September-October 2021. Due to the social restrictions, they took place online via MS Teams or Zoom which also eliminated the time and cost of travelling to meet participants face-to-face. The interviews were conducted following the University of Central Lancashire ethics procedures where participant's informed consent was obtained beforehand to conduct the interview, audio recording, data processing and the data arising from interviews were pseudonymized. The interviews took between 21 min-38 min for EV users and 18 min-55 min for household solar PV users depending on the speaker's willingness to share information, level of understanding on the questions and the general talkativeness.

3.4. Interview analysis

All the interviews were audio recorded, and the recordings were transcribed word for word in MS Word with the support of MS Teams auto transcriptions. The process of transcribing itself was helpful to familiarize with the data and identify codes/ key ideas. Then the transcripts were analyzed by the first author using QSR NVivo, a Computer-Assisted Qualitative Data Analysis Software (CAQDAS) which aids analysis of qualitative data timely and efficiently. Before analysis for the ease of referencing and categorizing, each speaker was assigned to a case in NVivo, namely, EV user 1,..., EV user 20 and PV user 1,..., etc.) Qualitative Content analysis method which distils a large amount of text data into fewer content-related categories was selected for analyzing the interview data. This method was selected because the interviews were conducted using the guide designed based on the existing research and the purpose of analyzing the interviews were to validate and extend the existing research and theory by using adding practical perspective. Phrase segment was selected as the unit of analysis and the data was coded using open coding and axial coding to identify emerging themes and make connections between themes emerged, respectively.

4. Findings/ Results

This section presents findings from interview analysis for the two separate participant categories. The summaries of interview responses to the key areas of questioning are presented under subheadings.

4.1. EV users

4.1.1. Current energy trading practices and evaluations. Out of all home charging is the most popular among participants followed by motorway services, destination charging and workplace charging due to convenience in terms of 'not having to travel anywhere' and low cost of home charging. However, home charging is limited by lower charging speeds and unavailability to some EV users due to not having a driveway or access to off-street parking (EV user 8,12). As highlighted by EV user 19 workplace charging provides an opportunity for such users by providing nearly the same benefits of home charging but the availability of workplace charging is yet to be improved.

Despite the higher charging prices, public charging is used by all the participants occasionally to extend the range of their vehicles during a journey. Eight EV users appreciate the convenience offered by public chargers by providing higher charging speeds and do not see their higher costs as a barrier given that their usage is occasional (EV user 7, 12) and being still cheaper compared to petrol/ diesel:

"But it's a bit more expensive to do that (public charging) and, I mean not hugely. Compared to petrol it's basically nothing. I'm not really worried about the cost of charging when we're out." (EV user 13)

However, higher charging speeds of public charging were interpreted as a cause for faster battery degradation and hence the importance of minimizing the number of fast/ rapid charging while using public chargers were highlighted by some users (EV user 4, 13).

4.1.2. Reasons for selecting suppliers, charging network operators (CNOs) and chargers. As mentioned by three users (user 2, 9,18) supplier selection reasoning for home charging was not solely based on car charging but all the home electricity usage. However, ten of the users have selected suppliers who offer 'cheap overnight tariffs' or 'good deal' to charge their EVs. Apart from users who selected supplier purely based on price, some have switched suppliers after experiencing a price increase hoping for a 'cheaper tariff' (EV user 3, 14, 17). The only difference was EV user 11 who believed that there was not much difference between prices among companies and trusted a friend's recommendation.

Six EV users (user 2, 4, 7, 10, 13, 16) deliberately selected their suppliers due to their 'sustainability', i.e., RE based electricity generation profile 'as a matter of principle even though they are not the cheapest in the market'. Among them, the two users EV user 2 and 7 have shifted the suppliers due to both environmental reasons and costs.

Like supplier selection, most users didn't deliberately select a particular CNO. Instead, they used 'whatever operator' at that location depending on their convenience of 'not having to go too far off the route' (EV user 3, 4, 7, 9, 14, 15), facilities availability where they 'can spend time in a nice environment' (EV user 1, 8, 11, 12, 17) and ease of payment with 'not having to use different apps' and 'using contactless cards' (EV user 2, 7, 16). Further, the 'type of charger' (EV user 3,6, 10, 12, 19) relating to the waiting time for charging, availability (EV user 6, 20) and reliability (EV user 6, 12, 14, 19) of chargers identified as 'always working' are the other factors considered by the users. Furthermore, cost was not mentioned as a deciding factor given that the prices are 'not prohibitively expensive' (EV user 7, 15) and there are no multiple chargers at the same location (EV user 18) to select.

4.1.3. User requirements and considerations on switching to household renewable energy generator (seller) to charge EVs. All requirements extracted from EV user responses are presented in Table 2.

Regarding user requirements in switching to household based RE to charge EVs, some interviewees (EV user 3, 8, 10, 11, 20) liked the idea since 'it is the right direction to go to promote renewables' stating their decisions to adopt/ switch depend on few other factors. All except two (EV user 5, 18) highlighted that they like the environmental friendliness of RE by 'reducing carbon and fumes emissions' (EV user 1, 17) while passionately talking about CNO's and supplier's projects on RE based EV charging (EV user 1 and 19). Further, few users expressed their interest of paying a bit more (EV user 3,4,9,11,13) for RE. However, they stated that there should be a balance between RE and affordability (EV user 20):*"I think it's worth paying a slight premium for renewable to try to encourage the grid to become greener. I guess it's partially selfish, but I don't also want to double my bills to do that." (EV user 03)*

Further, some users mentioned cost as one of the factors to be considered whereas some (user 16, 17) stated cost as the only consideration highlighting price could be the only concern given the 'homogeneous' nature of electricity as a product (EV user 08).

Similar to supplier and CNO selection section, most interviewees have mentioned about the importance of convenience in accessing electricity and making payment with less effort (user 4, 7, 9, 11, 15), 'less time taken' (EV user 19) and by 'having unified payment method' (12). In addition, ease of method with 'less administratively complicatedness' (user 2, 9, 11, 12 ,15) was mentioned highlighting the benefits of automatically matching trades(EV user 2). Further, reliability of a new scheme by 'having an uninterrupted supply' (EV user 14) or 'not going out of business' (EV user 1, 5) and the value that the idea of trading household based RE to charge EVs brings to the society by 'evenly distributing wealth' (EV user 14) and 'helping each other' (EV user 4) were highlighted as important.

Table 2. User requirements extracted from EV users.

Interviewee code (EV user xx)	Availability	Battery degradation	Required charging speed	Cost of charging	Convenience	Environmental sustainability	Privacy and information security	Reliability	Social concerns
01			x	x	x	x		x	
02			x	x	x	x		x	
03			x	x	x	x			
04		x	x	x	x	x			x
05	x		x	x	x			x	
06	x		x	x		x		x	
07			x	x	x	x		x	
08				x	x	x		x	
09	x			x	x	x			
10	x		x			x		x	
11	x		x	x	x	x	x		
12			x	x	x	x		x	
13	x	x	x	x	x	x		x	x
14			x	x	x	x	x	x	x
15	x		x	x	x	x			
16			x	x	x	x		x	
17			x	x	x	x	x		
18	x		x	x	x			x	
19	x		x		x	x		x	
20	x		x	x	x	x		x	
No of participants	10	2	18	18	18	18	3	14	3
% of participants mentioned	50	10	90	90	90	90	15	70	15

4.2. Households with solar PV systems

4.2.1. Current energy trading practices and evaluations. Out of all methods, energy export is the most popular energy-related practice among users followed by self-utilisation and energy storage. Some users were interested in self- utilisation and energy storage due to 'minimising imports' (PV user 6), 'feeling of self-sufficiency' (PV user 7, 8, 13, 14) and 'bill reduction' (PV user 7, 14) despite the higher cost of storage systems highlighted by some users.

Among all the above, energy export is the only practice that actually involves ET, where the excess amount of energy generated is traded to the utility grid. As suggested by the findings interviewees export their excess solar energy under two different schemes; Feed-In-Tariff (FIT) which accounts for 75% of the sample and Smart Export Guarantee (SEG) which accounts for 19% of the sample where one user (PV user 5) exports without any scheme. Irrespective of the scheme, users prefer energy export due to the simplicity of the process which doesn't require any additional effort (PV user 9, 12) and convenience (PV user 8):*"I had a system that put in. That just feeds in and there I don't do anything with it at all. I don't manage it at all. It was a very simple process." (PV user 9).*

FIT scheme was adopted by users who started before 2019. It offered a payment for both generation and export which was appreciated by the interviewees for the 'financial benefit' (PV user 2,7,10,13) and 'paying for the cost of panels' (PV user 6, 12). However, users mentioned that the removal/ reduction of this incentive as an inhibition that challenges the uptake of domestic RE systems. Further, users had mixed opinions on the fact that the export tariff of FIT assumed 'deemed export,' i.e., 50% of generation being exported. However, the SEG which is the scheme currently available for new small-scale RE systems, pays export rate based on actual amount of export. But it's seen as 'lot less money' which is 'not economic' by the users.

4.2.2. Reasons for selecting suppliers for solar power export administration. As identified from the user responses, the prices offered for FIT by all suppliers were nearly 'all the same' (PV user 3,4, 9,

16) since the prices are governed by the government/ Ofgem policy. Similarly, under the SEG scheme users identified 'prices not any different' (PV user 8) among the suppliers. Therefore, the users selected the suppliers based on the convenience (PV user 4, 12, 16), suppliers' professionalism (PV user 8, 14), financial stability (PV user 9) and interest and activeness towards RE (PV user 1, 7, 11) in conjunction with price (PV user 1): *"And so, for me, it's generally just about being green and moving towards correct future that we're looking to live in…So, it's because they're good in that space and that in a combination of price." (PV user 1)*

4.2.3. User requirements and considerations on trading of excess energy to charge EVs. All requirements extracted from PV user responses are presented in Table 3.

Table 3. User requirements extracted from PV users.

Interviewee code (PV user xx)	Financial requirements			Infrastructure requirements		Environmental requirements	Other requirements	
	Higher revenues	Bill reduction	Covering initial costs	Accurate measuring equipment	Communication	Environmental sustainability	Less time and effort needed	Privacy
01	x	x				x		
02						x	x	
03	x		x				x	
04		x				x		x
05			x			x		
06			x			x		
07		x	x			x	x	
08	x	x				x	x	
09	x	x	x			x	x	
10	x		x	x		x	x	
11		x				x	x	
12	x	x	x			x	x	
13	x							
14	x	x			x			
15		x	x		x	x	x	
16			x				x	
No of participants	8	9	9	1	2	12	10	1
% of mentioned participants	50	56.25	56.25	6.25	12.5	75	62.5	6.25

When asked about the idea of selling excess solar energy to charge EVs, interviewees had mixed responses. Some speakers mentioned that the trading system/tool should be simple and less complicated with no extra workload (PV user 2, 7, 9, 10), automatic matching, trading and bill calculation (PV user 3, 11, 14). Importantly, majority of interviewees highlighted the importance of economic considerations mentioning 'attractive rates' (PV user 13), 'guarantee at least current rate' (PV user 3, 8, 9), 'massive financial incentive' (PV user 12) and 'return on investment' (PV user 5,12) given that they have invested a lot of money in buying solar panels.

Further, majority of speakers have already taken steps and are interested in supporting RE (PV user 15) and 'help saving environment' (PV user 1,2) by 'reducing carbon footprint' (PV user 4, 6, 8) and 'living a green life' (PV user 9, 10,11). Interestingly PV user 7 mentions helping the grid to being greener might be more important than making extra money: *"Making additional money or whatever. It might even be just choosing to use your assets to help the grid be greener. For example, that might be more important to somebody than just making a few extra quid". (PV user 7)*

Furthermore, only a few users have mentioned about other requirements of having necessary metering and communication equipment (PV user 10, 14, 15) and security concerns (PV user 4, 15).

5. Discussions and limitations

In this section, we particularly reflect on what the above findings highlight as key requirements in ET which later could be incorporated in designing ET models and algorithms and the limitations of the study.

5.1. EV users

Based on the user perceptions related to current practices and user expectations the following four emerged as the key requirements/ specifications for EV users.

Improving convenience was a key requirement for the group of EVs. Convenience was referred to as the locational convenience of not having to travel too far off the route [10] and ease of use relating to reducing the need of conscious involvement in buying and paying [39] by EV users. However, on some occasions charging quickly and being located near to facilities were interpreted as convenience. In that case, the charging speed is considered as a separate requirement in this research whereas the closeness to facilities is noted as something which cannot be incorporated to the algorithm and can only be considered in practical implementation. Therefore, this finding of convenience can be applied to the algorithm by matching the EVs and households such that the distance travelled by the EVs are optimized and by automating the trade matching process.

The second key requirement for the group was improving environmental sustainability. The need of environmental sustainability [38] of the group was evident from their supplier selection decisions and conscious expression of interest in paying higher for RE, although they used phrases like 'slight,' 'a little bit' to hint that the prices shouldn't be too high. However, this user interest of paying higher for renewables contradicts with the finding of [39] which highlighted that the consumers select the cheapest supplier irrespective of the energy source.

The third key requirement for the group was reducing charging costs. It was clear that cost was an influential factor given that almost all the users have talked about cost. However, among the group cost was not a major or deciding factor for most users except for a very few influenced from the cost benefit of charging EVs in comparison to the refueling of ICE vehicles. However, a balance between the cost and convenience or cost and environmental benefits were valued in the group. This disagrees the study findings of [39]and[37] which highlighted cost as the main priority and value proposition for consumers. However, cost being one of the influential factors implies that cost should be taken into consideration in designing the algorithm.

The final key requirement for the group was selection of user preferred charging speed. It was evident that the charging speed requirement of users was dependent on the circumstance and the charging purpose. Faster charging was not always the favourite in the group due to its impact on the battery degradation [24]. Therefore, providing user the choice of selecting a charging speed which suits his requirements can be incorporated to the algorithm by allowing the user to select the preferred charging speed.

5.2. Households with solar PV systems

Based on the user perceptions and expectations the following emerged as the key requirements/ specifications for the household prosumers with solar PV systems.

Improving environmental sustainability was a key requirement for the group of household prosumers. It was clearly evident that the group valued environmental sustainability from their actions of reducing carbon footprints and living green lifestyles. This was further highlighted by some in the group consciously expressing their positive feeling on doing something for the environment irrespective of the money they receive or the payback period.

The second key requirement for the group was ease of trading. Given that user willingness in adopting a new scheme depends on the simplicity, less complexity of the process which requires minimal/ no user interaction [39] and the time and effort taken to make decisions in trading and administration, considering ease of use is important. Therefore, it can be applied to the algorithm by automatically price setting and matching buyers for household prosumers. However, these automated prices should comply with the financial requirements [24].

The final key requirement for the group was improving revenues. It was clearly stated throughout the group that the economic requirements are important in light of reducing FIT schemes in the UK. This was identical to the findings of [2, 15] who highlighted economic benefits and new revenue models are essential for the post- subsidy prosumer phenomenon in the UK. Given the fact that users have already made investment on solar panel installation, higher price than export tariff [15]should be paid to the users as highlighted by the majority of users except only one who valued environmental sustainability over making additional money. This implies that improving revenues is a key requirement to be fulfilled in the algorithm and can be used in price calculation by setting the lower margin of trading price.

Despite our efforts, we note that there are limitations of the interviews given that opt-in recruitment strategy was used. Therefore, the findings may be subjected to volunteer selection bias, which might lead to distort the external validity of the findings. Further, due to the time intensiveness of interviews, a relatively small sample was recruited for the interviews which might raises the question to what extent the findings can be generalised to the broader population.

6. Conclusions

This study aimed to investigate the current energy trading related practices, behavior and perceptions of EV users and households with solar PV systems with the intention of identifying the user requirements and specifications for designing an improved energy trading algorithm which could encourage the user adoption of renewable energy technologies. This also contributes to knowledge on energy trading algorithms by being one of the few works that have attempted to extract user defined specifications in designing an algorithm. This provides evidence that novel approaches like peer-to-peer trading and vehicle-to-vehicle trading are still not generally in use in the UK in household and EV energy trading.

Further, based on users' evaluations and perceptions four and three user experience related specifications were derived related to EV users and households respectively. In particular, improving renewable energy utilization was derived as a key requirement for both categories whereas, improving convenience, selection of preferred charging speed and charging cost reduction were identified as significant specifications for EV users. In terms of household PV user's financial requirement of having a higher revenue to cover the cost of solar panel installation and trading with less time and effort were identified as key requirements. All the other user requirements relating to reliability, infrastructure, privacy, and information security can be incorporated in further research in practically implementing the system and by practitioners from the industry in developing effective solutions. These findings would be relevant to locations beyond the UK with similar electricity and EV sectors given that the findings are accordant with the results from other studies [15, 37].

Acknowledgements

The authors acknowledge this project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No 801604.

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