Chapter 9

The Spatio-Temporal Analysis of the Use and Usability Problems of EV Workplace Charging Facilities

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Additional information is available at the end of the chapter

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Abstract

With the worldwide calls to meet greenhouse gas targets and policy objectives by 2030, finding an electric vehicle (EV) on the way to work every day has become less surprising. Adapting to owning an EV is challenging to all potential users. Current users tend to rely on domestic charging for a more certain and less hassle charging opportunity. The demand is shifting towards workplace charging (WPC) as a cheap and convenient solution due to the relatively long time the car is parked there. WPC fills a critical gap in EV charging infrastructure needs by extending electric miles and building range confidence. This chapter reports on the social practice of using one of the WPC facilities in the UK. It investigates the use and usability problems that are faced (n = 12) by EV users at workplace environment in one of the UK public sector employer.

Keywords: workplace charging, electric vehicles, charging pattern, behaviour change, shared resources

1. Introduction

Transport represents one of the fastest growing sectors of the economy in terms of energy use and environmental impact. The car has become ubiquitous in late modern society; it is the spine of communities, and the leading object of mobility. Electric vehicles (EVs) show the potential to reduce the energy cost of driving [1] and the environmental burdens of the transport sector and it is seen as the core of future mobility pattern [2]. They are emerging as a zero carbon alternative to conventional internal combustion engine (ICE) vehicles. The transport sector currently supports a wide range of ubiquitous technologies [3]. Research on intelligent transport systems (ITS) covers a wide field, as it comprises combinations of communication, computer, and control technology developed and applied in transport to improve efficiency and system performance and facilitate mobility. Innovative technologies can be applied to vehicles as well as transport infrastructure and are used by stakeholders embracing transport organisation, information technology (real time information, tracking and vehicle-to-vehicle communication) and passengers to improve service quality and transport management.

A multitude of new worldwide policy objectives and measures is caused by the increasing demand for energy and electricity in particular, decrease fossil energy source stocks and the necessity to act against climate change [4]. In recent years, the environmental burden of urban road traffic has been of concern to governments and authorities of developed countries [8, 9] with an increasing interest in mitigating this [10, 11] as well as to develop and (re-) design cities to make them greener [9]. Electric mobility (E-mobility) offers considerable potential to make progress in a variety of wider environmental, societal, and economic objectives [10], which accelerates the development of smarter and sustainable cities [5, 6, 24]. Even though EVs have existed for some decades, the term is still thought of as a new technology [14]. The EV market is dynamic and has unanticipated market changes, the overall market share has grown steadily since 2011 [15], yet it is less than 1% as of 2014 [16] and in Germany and most of the other countries below 1% January 2015. The Electric Vehicle Industry Association (EVIA) forecasts varied wildly ever since and could have been affected by incentives and fuel costs, the projection was raised to 2.4% of total new vehicle sales by 2022 [15, 16]. The reasons behind the slow growth of the EV market are multifaceted. Many factors are responsible, which vary between socio-technical, economical, and psycho-temporal. In order to increase the market penetration and reach 2030 and 2050 EU and UK targets and policy objectives environmental targets [22, 14], the stakeholders particularly R&D, planning authorities and policy makers should develop deployment and operation plans. These plans should take into account the user experience and user interface, where the power of end-user feedback, design requirements and social influence are considered.

Individuals and families struggle with the decision of owning an EV, this is tied directly to the different issues related to limited range [20] and the known anxiety of not having access to a charging point (CP) [18, 19]. Research by Grahm-Rohe et al. 2012 showed that EV Drivers in England Drivers' fear that their EV will not have sufficient power to reach their next destination represents one of the main barriers to the acceptance to this emerging technology [23, 14, 16]. In England, the EV drivers reported that their experience recharging their cars is perceived simpler than anticipated [25]. Despite major technological developments in various EV areas of research, there is a list of issues that needs to be addressed. Among these, the need for a reliable and diverse charging infrastructure, which meets different user needs, is placed at the forefront [26]. Perceptions of EV-resources and, in particular, the limited range and infrastructure shifts over time differ between individuals [27].

1.1. Research importance

The chapter focuses on the emerging social behaviour of EV workplace charging facility (WPC). From literature, the WPC is gaining more attention within the EV community. Employers started to install CPs at their premises in a way to show commitment and environmental concerns, and reduce travel-to-work journeys' carbon emissions. Users started to change their patterns to include WPC within their daily schedules. However, the problem of shared resources remains especially in small-scale institutions where supply and demand problem arises (the number of the CPs is not sufficient for the current EV employees).

To be able to fully understand the nature of the EV charging at workplace environment, an in-depth study of a particular WPC scheme is presented and the emerging social practice around the sharing of CPs among staff is discussed. We derive empirical EV charging pattern and communication between users with access to the same charging network and show how they are affected by charging management as well as charging power. We started this research in early 2015, and have been reporting on some insights of the WPC practice ever since [28]. EV drivers face four particular challenges compared to drivers using the established fossil fuel infrastructure: (i) current battery technology limits range, so depending on the commuted distance drivers may be required to recharge while at work in order to get home without stopping; (ii) re-charging takes significantly longer time than conventional fossil fuel refuelling; (iii) the infrastructure for charging is poorly developed compared to the traditional infrastructure, and (iv) EV drivers may have to compete for the charge points that are available. In order to overcome these hurdles, the planning of non-domestic charging infrastructure needs to be addressed with the associated different factors.

1.2. The emerging questions

The uncertainty of having access to away from home charging facility has slowed the growing trend of smart ecosystems [18, 31, 39]. Recently, it has been claimed that WPC adds flexibility to work day, expand their comfort zone, and shall double the daily range of individuals [29, 28]. However, with the emerging need to have access to the WPC, in some cases the supply surpluses the demand, which creates sort of a competition spirit between the users, so each of them meets their mobility demand. In order to analyse the charging patterns and the importance of the WPC, research has to be backed up with evidence and empirical data that can analytically collaborate the preposition. With the lack of actual data about charging patterns [32] and user preferences, the demand of best practices and showcases is becoming an urgent matter for future development and strategic planning. This study investigates WPC systems by taking a case study approach to a functioning WPC scheme operational at a university. For this study, we had access to all possible data needed to analyse the social practice of the shared charging resources. Unlike the use of public charging, the workplace has unique characteristics:

1. Population: closed population with identified EVs usually stationary for the entire work day;
2. Equality: each EV driver has access to the same number of CPs everyone has;
3. Reachability: users can reach each other as they are working in the same place;
4. Environment: Peer pressure, human aspect, self-regulation, community collaboration, social and anti-social qualities may arise.

This chapter illuminates two research questions: Can we categorise the charging patterns of WPC users? and What are the WPC design requirements that would overcome the use and usability problems?

1.3. EV recharging alternatives

At home charging, which is referred to as the "main charging" [33], allows most EV drivers to fully charge from empty within 3–7 hours (e.g. current Nissan LEAF battery 24–30 kWh capacity, which will charge in about 3 hours at 32A or 7 hours at 16A). The time taken for an EV battery to be charged depends (charging time) on the initial state of charge (at arrival), the battery capacity, age of the battery, type, and level of CP.

Charging at home using a standard 13A outlet or dedicated 16–32A unit has positive values: (i) quiet operation, (ii) zero tail-pipe emissions, (iii) possible green energy in case of solar panel, (iv) ease of use, and (v) the car typically spends most of its idle time at this location (especially at night). However, the current limited range of many EVs means that even a full overnight charge may not meet the daily mileage demand [34]. The recharging time takes several hours, which is considered as a limitation that severely hinders the usability of EVs [35]. Moreover, domestic charging is not an option in the case of 'garage orphans'. A 'garage orphan' is defined as a resident, who has no off-street parking at their residence, or who has off-street parking, but no access to electricity supply close enough to the parking location [36].

1.4. Non-domestic charging

Besides charging at home, EV users can also make use of public CPs with more of these appearing as a facility offered by larger stores, in city centres or located at petrol stations. In the UK, CPs are usually IEC 62196 (Mennekes) sockets with a maximum of 32A (6.6 kW), although some standard 3 pin 13A CPs remain, so they are compatible with all EVs. There are four main EV charging types: slow (up to 3.3 kW), which is best suited for 6–8 hours overnight; Fast (7–22 kW), which can fully recharge some models in 3–4 hours; and Rapid AC and DC (43–50 kW), which are able to provide an 80% charge in around 30 minutes. Service providers are expanding their rapid charging networks in order to alleviate this gap in the system and to meet the end user charging demand and preference especially with the current EV market penetration. There are national charging network websites (www.Zipmap,.ac.uk), Twitter hash tag (#UKCharge) and blogs (unofficial Nissan Leaf forum (www.leaftalk.co.uk) that show updates for all CPs across the UK. In addition, each service provider [e.g. Charge Your Car (CYC) in the North East of England] and Chargemaster Plc. covering mainly Midlands and South of England have their own websites and live maps to show the charging network updates, see **Figure 1**. In addition to other countrywide open source applications, see **Figure 2**.

1.5. Workplace charging

WPC has often been considered in third place in terms of priority behind domestic and public charging infrastructure, and has not been given broad attention. WPC refers to EV charging facility that is provided at or near the user's place of employment [37]. Users only decide to charge away from home for specific reasons due to extra required planning and extra costs (Jabeen et al., 2013). On the other hand, the availability of WPC eases the pressure of electricity peak demand on the grid [38, 31]. Although not all users need to charge at work in order to return home, the ability to charge increases flexibility [33] and fills a critical gap in the EV

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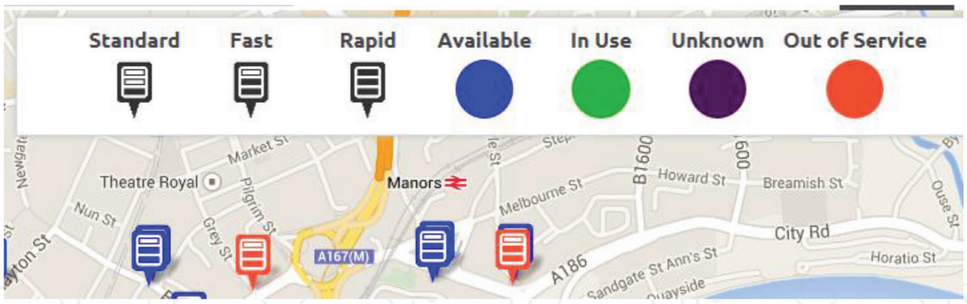

Figure 1. Print screen of CYC network real-time update.

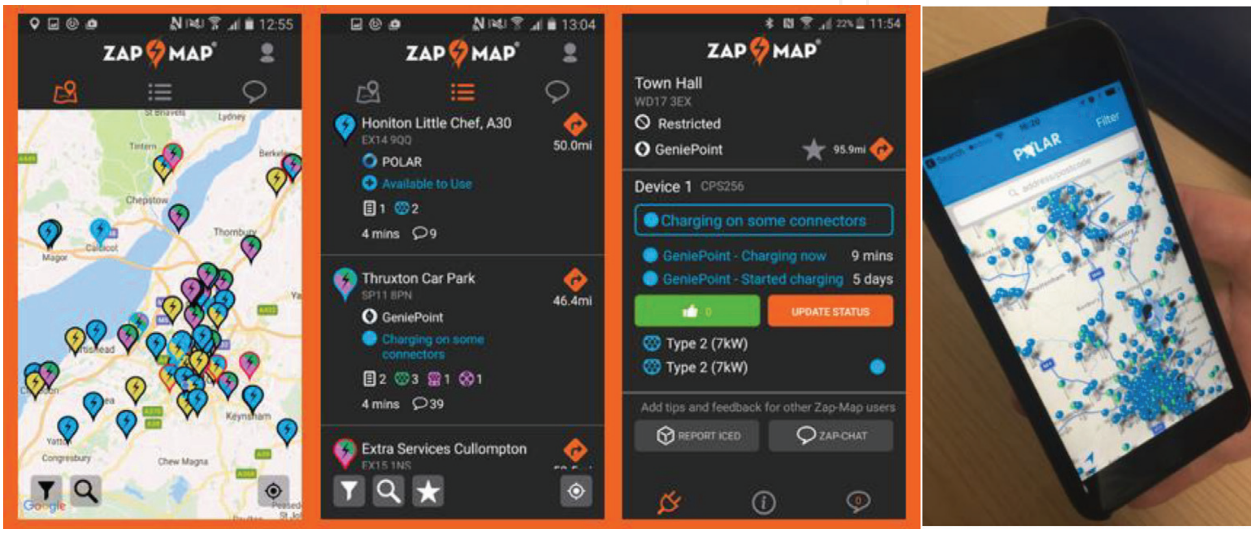

Figure 2. ZAP map and polar, smart phone applications for EV charging network real-time updates.

charging infrastructure [19]. In return, EV might be more spread out and peak problems could be reduced [39–41]. It increases the certainty of having access to charge apart from the domestic one, which in turn decreases EV range anxiety. Because EVs are parked at workplaces for substantial periods over the weekdays, WPC is a promising option only if practical ways can be found to provide the needed infrastructure.

1.6. E-mobility from an end user perspective

Inside many EVs, there is a built in telematics service that allows the driver to interact with the car's energy management systems, as in Nissan Leaf telematics system, NissanConnect EV (Carwings before) mobile application and car display (**Figure 3**). In addition to the user interface, the user can access the car remotely from their smartphone or computer by downloading the application or logging in with their credentials. To check the public charging network, there are various smartphone applications that can be downloaded.

EV owners often create their own collection of applications that cover their mobility demand (e.g., users who do not charge non-domestically, are not keen to install various charging-related applications). Based on the charging network memberships and the open access maps

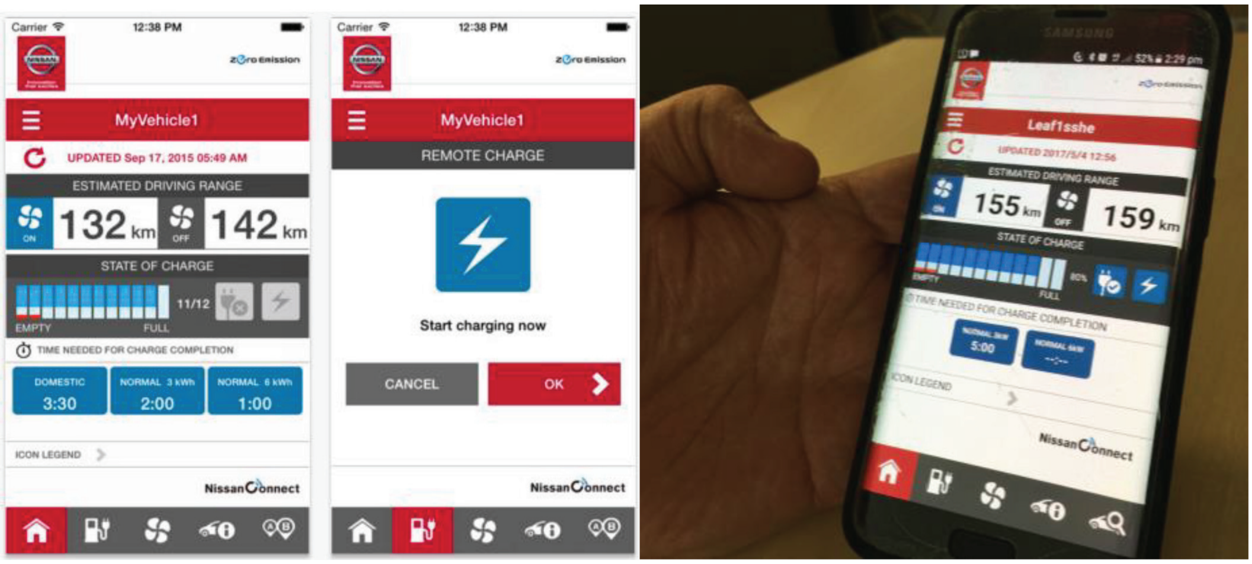

Figure 3. Nissan leaf telematics–NISSANCONNECT EV user interface-UI.

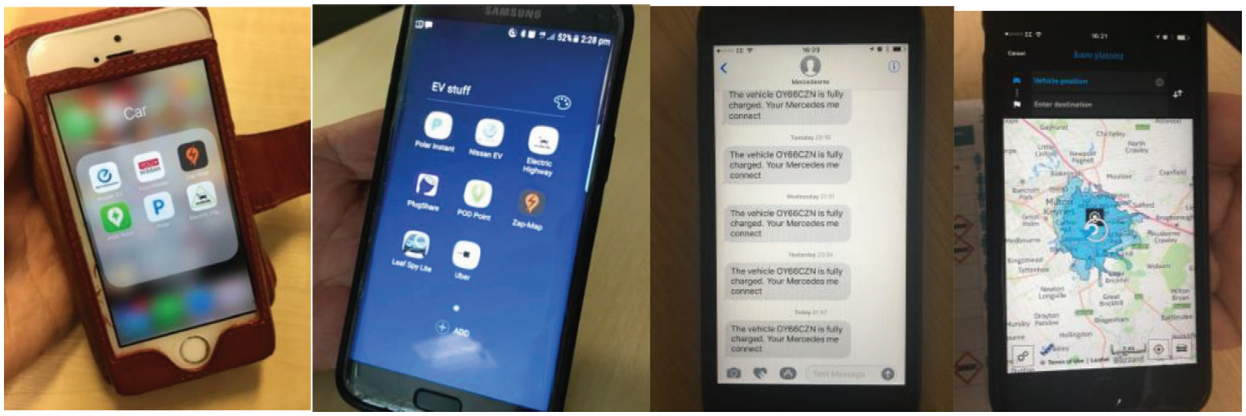

Figure 4. Various collections of smartphone applications EV users have.

each EV driver is using, they each create a list of applications; **Figure 4** gives examples for different sets of applications 4 EV users have on their smart phones.

There are national charging network websites (www.Zipmap,.ac.uk), Twitter hash tag (#UKCharge) and blogs (unofficial Nissan Leaf forum (www.leaftalk.co.uk)) that show updates for all CPs across the UK. The social media and the service providers' applications do not cover the privately owned recharging network, which includes the CPs allocated for particular community, company staff members or customers only. This takes us to the definition of available CPs the EV driver may find in their journeys. An available CP means:

1. It is working and does not report any fault;
2. It is free, not occupied by other drivers or no queuing;
3. It has a compatible power socket;

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4. The driver can access it (e.g. finding a CYC charging point and the driver is not registered with CYC);
5. It is physically located and the driver is aware of its existence. The awareness and the certainty of having a CP is the main issue of WPC, which is the third alternative.

WPC refers to an EV charging facility that is provided at or near the user's place of employment [31]. Because EVs are parked at workplaces for substantial periods of time during weekdays, WPC is a promising option. Although not all users need to charge at work in order to return home, it is another chance to have access to away from home charging, which in turn increases flexibility [4, 19] and decreases EV range anxiety.

2. Literature and related work

Since 2012, studies and research projects have tackled EV adoption [10], range issues, infrastructure [15], charging loads on electricity grid [19, 41] and the use of renewable energy to charge the battery [40]. WPC practices are published as business cases or corporate reports [42] by service providers or a summary of a governmental initiative or grant or scheme announcements [20, 19, 26, 28]. These reports provide data regarding the number of CPs, locations, power capacity, service provider, billing policy, and the number of users. They lack information about operation and management, as there are no examples or practices of usability and utilisation of resources.

2.1. In the UK

In 2013, the Secretary of State for Transport announced a series of grant schemes for plug-in vehicle charge points via the Office for Low Emission Vehicles (OLEV). The grant schemes would provide up to 75% towards the cost of installing new CPs for public sector bodies to install WPC on their estate. In total, 43 public bodies were successful and were granted various amounts (£3200.00 up to £237,000.00) in 2013 and 2014 to install CPs [28]. In the case of councils, the grant covers public CPs across the city. For example in The Open University, two CPs were installed for use by eight EV fleets. In the city of Milton Keynes, 10 staff members leased a Nissan Leaf for 18 months and were given access to three dual WPC for free. The council reported 1500 charging events for the first year with a positive EV user feedback accessing WPC. A further five CPs were installed on three sites of a major health care trust. In another part of the country, 49 fast chargers were installed and in a major city in the south, 20 dual CPs across the city were installed with different service providers in order to deal with the memberships and billing policies.

2.2. In the USA

The emissions from commuters are the main driver giving workplace charging facilities a higher priority. According to [35] in Las Anglos, average employees commute over 24 miles to work generating three times the emissions of the county fleet operation (428,000 MTCO2).

For that, the county requires employers with 250 employees at a site to provide charging facilities for alternative means of transport. Some studies reported some statistics on anticipated use of the network based on surveys. In one California survey, 37% of EV drivers had access to WPC [31]. California is an active region in installing WPC. In 2011, 20 case studies were released [29]. The case studies are all in California and they vary between small-scale companies. Seven companies are intermediate and four large-scale firms reaching 500 EV users. Same as in the UK, these case studies were presented in various business reports showing the installation cost and the service provider with no details on the operation and the charging practice.

In 2013, a workplace challenge was launched by the U.S. Department of Energy covering 40 states. The partners were committed to assess their employee's demand of EV charging at the workplace and to develop and execute a plan to provide charging access. In total, 150 employers joined the challenge and some of them were providing green energy to top up the cars (charging point powered by solar energy).

From 20 case studies that were reported, the majority (80%) provides the charging for free. The billing policy was designed based on the number of the EV users commuting to the workplace. It is free of charge for companies with the capacity of (1–67 EV users) otherwise it is fee-based charging (per kWh or per hour). The common themes of these studies are the billing policy and the ratio between the number of the CPs and the EV users. The companies compete with each other to get a better environmental corporate image. Firms and public bodies install CPs at their premises to promote to carbon emissions of their employees. The UX dealing with the WPC is not a priority.

2.3. WPC trials and showcase

2.3.1. Shell technology centre

In 2010, an EV trial was carried out and reported. The study was to investigate the social influence regarding consumer perceptions and preferences in a technology-based workplace, Shell Technology Centre in Thornton, England. A total of 57 staff members out of 500 (medium-sized workplace) were involved in the trial and 21 out of which were interviewed. The aim of this trial was not to investigate the WPC practice; it was to examine the anticipated social influence and consumer preference for alternative means of transport. Two EVs were offered to the participants to try driving and sharing the experience with their co-workers [2]. The workplace environment was selected, as was the exposure of a limited number of staff to an actual EV served to stimulate conversations with co-workers who did not participate in the trial. It also helped exploring the social influence, peer pressure and the effect of word-of-mouth on the end user perception and preference of driving an EV.

2.3.2. Future transport system

In 2013, Future Transport Systems Ltd. launched a trial (as part of the SwitchEV project) in Northumbria University. In total, (n = 12) staff members participated in the EV trial to drive an EV for 2 months, which aimed at depicting the charging patterns of the participants having access to two onsite CPs [28]. Each user was given an EV (Nissan Leaf) to personally use with free access to charging on campuses. In Northumbria University, the 12 staff members joined based on the voluntarily-based selection process. The users signed a consent form to allow the research team accessing their car's telematics service (Carwings). The study aimed at raising awareness and informing people about EVs and available charging facilities around the two campuses. The trial was followed by a survey capturing respondents' feedback and their EV perception before and after the trial [34].

Nevertheless the trials recruited a good number of participants and the responses were positive, the trials are not an indicator of a successful real practice. The trials can show potentials and forecasted performance or behaviour. Due to the short term of the trial and with the less exposure to driving an EV on a daily basis, understanding the WPC practice remains a non-disclosed matter. With the lack of actual data about charging patterns and user preferences, the demand of best practices and showcases is becoming an urgent matter for WPC future development and strategic planning.

2.3.3. A WPC showcase in the USA

Unlike the case studies reported in California by [6, 29], Connor, 2014 [8] talked about the lesson learned of having a WPC for 6 years in the company he works for in Oregon, USA. Connor is a solar and electric vehicle blogger; he shared the missteps of having WPC. This practice was reported informally in a blog with an EV advocate, who was keen to share their experience with WPC. In 2008, the second trial of installing and operating a WPC took place (after the first trial in late 90's). Four 3.3 kw chargers were installed and eight employees were having EVs. Charging was for free and the slots were 50% of the time utilised. In 2011, more users joined the EV market and the charging became more difficult. The employer ran a pilot study to analyse the system and see the best strategic management approach to operate the WPC. The existing CPs were removed and new six 6.6 kW chargers and the employer applied a charging fee, $1 per hour. This shift badly affected the utilisation of the WPC dropping to 50% use and the CPs became available. Charging the employees for using the CPs added an element of discipline to the WPC system. Users were keen to go and unplug their EVs once they are done with charging allowing others to use the bay. By 2012, the pilot was over and the charging data was collected and analysed. The employer released the new scheme, which is: Payment is per kWh (8 cent per kWh) not by hour, charging using WPC was 20% cheaper than domestic charging and four CPs were added to have in total 11 WPC serving 60 EVs.

With the new scheme, there was no incentive to move the car once done with charging, and the users were back to bay blocking. By time, and since it is a workplace and as it is a closed population with known working hours, the EV users started to know each other. They decided to have a dashboard cards so they can contact each other and they started a company-wide forum to discuss issues. This WPC is an example of a self-regulated AM/PM shifts for charging events. The community started to grow, with some occasions of spotting an EV plugged in but not charging (using the bay to park only). With the peer pressure, these occasions became rare. With some technical problems, a software glitch was responsible to set 5 of the 11 CPs free, and the users were back to bay blocking.

2.4. Gap in the literature

The WPC context provides several unique opportunities for innovative research on social influence and preferences formation. There is a clear gap in the literature due to the lack of information about the WPC practices, access to charging data, and meeting WPC users. Assessing real world use and monitoring of a WPC system will allow the communities (user and provider) design requirements to emerge. Ethnographic studies and spatio-temporal data analytics that explore and identify the behaviour of EV users rather than their perceptions or attitude will allow actual relevant insights to emerge. Relying on anticipated behaviour or probabilistic scenarios of WPC environment would be misleading due to the special nature of this system compared to the public shared charging network and to conventional refuelling infrastructure. EV users do not have pre-existing preferences for novel attributes that they have not previously experienced [1]. Thus, some behaviours are spontaneous and constructed in the process of facing new technology [7] and allow users to examine technology affordances [38].

The latter case study illustrated the mechanism of the WPC as it was seen by one of the EV users. An insider EV user critiqued the missteps and drawbacks of the system. With a bottom up approach, an informal scheme was formed regulating the WPC system. One of the issues the EV users experienced was a practice called bay blocking. It is the phenomenon of someone, who has finished charging but has not moved their vehicle so that another user can use the CP. This phenomenon rarely occurs in publicly available CPs as the service provider charges the EV driver as long as the car is occupying the bay (as long as it is plugged in). This phenomenon influentially affects the use of WPC. The present study will be analysed and compared to this showcase interrogating any similarities between the two systems.

3. Methodology

The present study applies an observational research method; it is a longitudinal study in which a case study was identified and the data was gathered over a period of time [43]. This study takes a data-driven approach. Following a multi method approach, we elicited details about EV users' perceptions, social practice, interactions and charging patterns sharing the WPC at a UK research institute. The methodology was phased, spanning 12 months (March 2015–March 2016), see **Figure 5**. Due to the nature of the longitudinal study, it was expected that new employees join the WPC scheme while others opt out. The availability of all users throughout the phased study was not guaranteed.

Table 1 summarises the methods used and the involved participants in each stage. The first stage of the study was a structured interview [44] (Interview I), which was carried out in March 2015. In total, 4:07 hours were spent interviewing the (n = 10) participants. Qualitative and quantitative data was collected through open-ended questions. **Table 2** summarises the EV users' profiles and relevant data. In 2015, there were 12 users registered in the WPC scheme; however, only 10 were regularly using it. In 2016, three users joined the system and one opted out to have in total 13 EV owners.

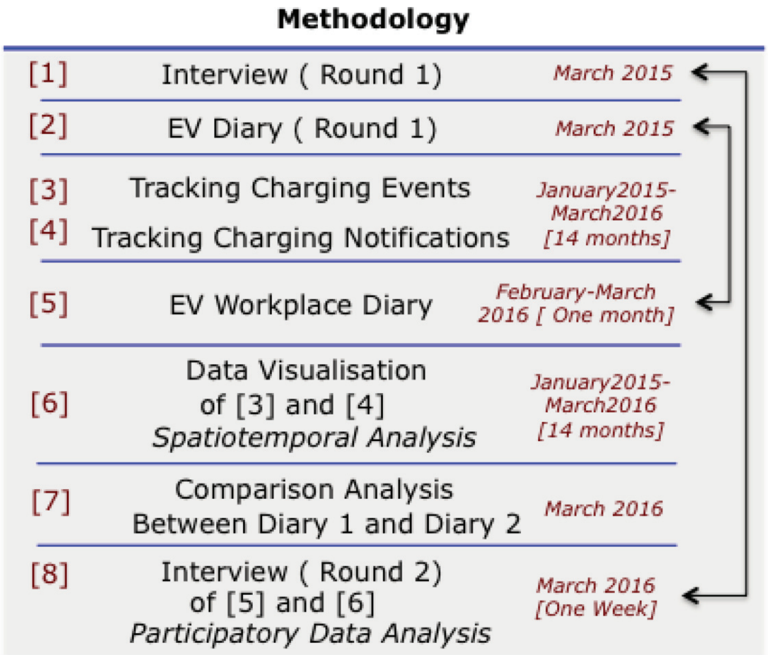

Figure 5. Methodology diagram showing the study timeframe.

Method	Participants
[1] Interview 1	EV01, EV02, EV03, EV04, EV05, EV06, EV07, EV08, EV09, EV10
[2] EV diary 1	EV01, EV02, EV03, EV05, EV07, EV08, EV09
[3, 4]	All users
[5] EV diary 2	EV01, EV02, EV05, EV07, EV08, EV09, EV10
[6] Data visualisation	EV01, EV05, EV07, EV08, EV09, EV10, EV11,EV12,EV13
[8] Interview 2	EV01, EV05, EV07, EV08, EV09, EV10, EV11,EV12,EV13

Table 1. Study phased methods and the involved participants.

In order to get factual figures about the state of the battery and the use of the WPC, participants were also asked to fill in a diary with details of date of the charging event, SOC on arrival, start and end times, and the SOC after charging. The EV diary took place in March 2015 for three consecutive weeks, where (n = 7) filled it in and returned it. In order to interrogate the charging practice, data analytics were conducted accessing the database with charging events provided by the service provider. The database included the (CP identification code, data of the charging event, starting time within the day, end time within the day and the overall kW consumed). In addition to monitoring the notifications, the EV users send charging updates to each other.

In February–March 2016, another EV dairy was designed to report individuals WPC charging pattern. The responses of the two dairies were compared to investigate the changes in user charging patterns during 1 year of use. To have clear insights and justification of users' behaviour, a data visualisation technique was deployed showing each charging event and the

User	EV model	Gender	Purchase date	Distance to work
EV1	Nissan leaf	Male	54 month	3 mile
EV2	Nissan leaf 2nd hand	Male	26 month	6 mile
EV3	LEAF	Female	55 month	8 mile
EV4	LEAF	Male	30 month	4 mile
EV5	LEAF	Male	19 month	5 mile
EV6	LEAF	Male	15 month	6 mile
EV7	LEAF	Male	18 month	30 mile
EV8	LEAF	Female	16 month	27 mile
EV9	Zoe	Female	18 month	8.5 mile
EV10	Zoe	Female	13 month	3 mile
EV11	Zoe	Female	3 month	3 mile
EV12	Nissan leaf	Male	6 month	5 mile
EV13	Hybrid	Male	4 month	60 mile

Table 2. Participants personal and EV-related information (The first user – EV01) joined in August 2014 and the newest joined in December 2014 (EV10). Some of the participants are sharing their car with their spouses (EV01, EV04 and EV11).

corresponding notifications sent by the user. The visualisation was used over the second interview (March 2016) as a Participatory Data Analysis (PDA) approach [45]. PDA aims to understand the human behaviour by conducting interviews in which participants interpret, justify and reflect on their own data. Devereux was the first to highlight that reflection on such personal ways of reacting can be used as a source of knowledge [46]. Interview II was semi-structured and recorded, 7:08 hours in total were spent interviewing (n = 9). As a qualitative research method, a thematic analysis was carried out of each interview to identify and report patterns (themes) within the data collected and helps interpreting various aspects of the research questions [47].

3.1. Case study

The present case study covers a UK university as a one of the WPC grant successful bids. In August 2014, two CPs were installed, see **Figure 6**. Each CP has two ports and each port has a capacity of 32 A, in two different locations on campus. One CP is in the visitor car park near main reception to accommodate visitors and staff (site 1) while the other is in a staff car park (site 2). Since installation, a utility management company was contracted to monitor the WPC. The billing policy is that visitors, as per request, could use the system free of charge (they are loaned an RFID card). As for the staff, providing free electricity (fuel) would be considered a taxable benefit. To avoid this, an annual membership fee was charged for their cards. Users need an RFID card, which is free for visitors but costs GBP 30 per year for staff. Once the car is plugged in, the green light flashes showing that the CP is "charging", and once the charging is over, the CP keeps flashing, "charged". If the CP is not in used, it will have blue colour. **Figure 6a–e** shows the other side of the cable while being plugged in the car, which is controlled by the EV users.

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Figure 6. (a)–(e). On-site WPC facilities and charging compatibility.

The WPC is operated on a de-facto first-come, first-serve (FCFS) scheduling protocol [48]. Those who come later have to wait for the charging service in a queue [49]. However, in this case, EV users do not have a system to register and queue; they have to wait for undefined period of time when someone is done with charging so they can swap. Weeks after establishing the charging network and having more users joining the EV scheme, the users realised that the lack of communication between all the users was a barrier to efficient sharing of the charging facilities. They created a simple mean of communication to facilitate the charging process on campus. They agreed among themselves that when anyone started or stopped charging, they would send a notification message to the mailing list that indicated the estimated time for charging, see **Figure 7**.

It all started with an email with a subject line: EV – On charge. When, we, the employer added another charging bay, the users started to indicate this in their notifications, free spaces. In 2016, the waiting bay was added in each site and users started to send notification if they are waiting, see **Figure 8**.

By the time, an EV community was informally formed, and a friendly atmosphere began to appear. Not long after, more users joined the scheme, and the demand superseded the supply,

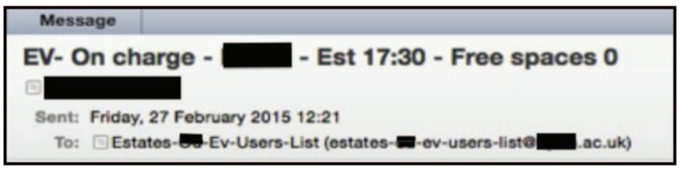


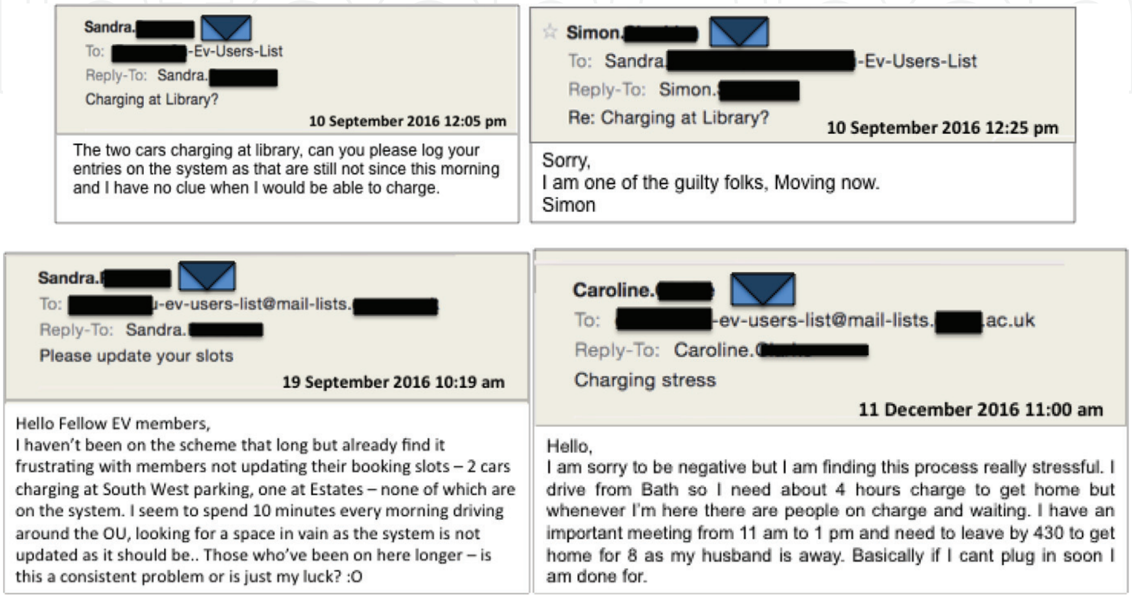
Figure 7. Printscreen of CYC network real-time update.

EV waiting - Berrill - Free spaces 0 + 0
[redacted]
Sent: Thursday, 3 December 2015 09:12
To: Estates[redacted]-Ev-Users-List

EV waiting Estates - 0 spaces free
[redacted]
Sent: Tuesday, 22 March 2016 08:47
To: Estates-Ou-Ev-Users-List

FW: EV waiting - Berrill - Free spaces 1 + 1 - Nothing working!
Panna.Ladwa
Sent: Friday, 12 February 2016 09:16
To: Estates-Ou-Ev-Users-List
Does anyone know when the 2 points on Berrill will be fixed or what is happening with them?

Figure 8. Printscreens of EV user notifications.



Sandra.[redacted]
To: [redacted]-Ev-Users-List
Reply-To: Sandra.[redacted]
Charging at Library?
10 September 2016 12:05 pm
The two cars charging at library, can you please log your entries on the system as that are still not since this morning and I have no clue when I would be able to charge.

Simon.[redacted]
To: Sandra[redacted]-Ev-Users-List
Reply-To: Simon.[redacted]
Re: Charging at Library?
10 September 2016 12:25 pm
Sorry,
I am one of the guilty folks, Moving now.
Simon

Sandra.[redacted]
To: [redacted]-ev-users-list@mail-lists.[redacted]
Reply-To: Sandra.[redacted]
Please update your slots
19 September 2016 10:19 am
Hello Fellow EV members,
I haven't been on the scheme that long but already find it frustrating with members not updating their booking slots – 2 cars charging at South West parking, one at Estates – none of which are on the system. I seem to spend 10 minutes every morning driving around the OU, looking for a space in vain as the system is not updated as it should be.. Those who've been on here longer – is this a consistent problem or is just my luck? :O

Caroline.[redacted]
To: [redacted]-ev-users-list@mail-lists.[redacted].ac.uk
Reply-To: Caroline.[redacted]
Charging stress
11 December 2016 11:00 am
Hello,
I am sorry to be negative but I am finding this process really stressful. I drive from Bath so I need about 4 hours charge to get home but whenever I'm here there are people on charge and waiting. I have an important meeting from 11 am to 1 pm and need to leave by 430 to get home for 8 as my husband is away. Basically if I cant plug in soon I am done for.

Figure 9. (a)–(d). Various notifications sent by EV users.

adding stress and competitive behaviour to the recharging process. Users started to send polite reminders asking others, who are bay blocking, to remove their EVs. Taking a community centric approach, the users created a Google-shared document, where they can log in their charging sessions. Initiatives and suggestions were brought up by the users trying to find solutions to release some of the recharging stress, **Figures 9a–d**.

3.2. 2015 interview (round 1)

Through Interview I, the users (n = 10) were asked 24 questions classified into 5 categories: (i) EV profile, (ii) driving profile, (iii) workplace insights, (iv) HCI in EV context and (v) usability. The questions varied between qualitative and quantitative addressing questions related to their motivations of purchasing an EV, charging and driving patterns for work-based trips, WPC practice, use feedback, communication system and design recommendations. Attention was given to their insights and feedback on the use of the WPC. The questions that addressed the perceptions of shared resources were:

- Does the current system allow you to meet your mobility demand?
- Is anyone taking a priority to charge? And if any, do you see this as a fair protocol of managing the WPC?

- Do you see any shortcomings in the service provided? Any recommendation for an improvement?

The social influence plays a main role in the adoption and usability of EVs [29, 28]. The motivations varied between environmental concerns, the habit of being a technology geek, long-term based financial calculations, the self-satisfaction of being an early adopters or a risk taker. The interviews showed the two main predictors of the purchase decision: domestic and WPC access. With no hesitation, the users said:

"Having access to domestic charging is compulsory; otherwise, owing an EV would not have been possible." [EV07]

"I am waiting for my domestic charger to be installed next month, I only rely on the WPC for now." [EV10]

"Some EV users rely mainly on workplaces, yet domestic charging is essential for non-work, weekends, and long journeys." [EV04]

WPC is a cheaper, more accessible (closed population) and convenient (vehicles are parked typically for at least 8 hours during the day) option compared to public charging. Through interviews, the EV users commented on the ad-hoc email list solution they had created.

"It is a good temporal mean of communication. Surely, it will break down with more users and CPs, it does not scale." [EV04]

"Driving an EV is a joy; however, the system is associated with socio-technical, behavioural needs. The communication between the CPs and us deemed fundamental." [E0V2]

"It opens a channel of communication; however, it is not a platform with real-time updates." [EV10]

"I do not have a smart phone, I come early after I drop off my kids at school, and charge almost everyday morning." [EV05]

As for the shared resources, the responses were different.

"The current practice now is based on first come first served. I am ok with that, as I have to be at work at 8 AM everyday. Wondering what others think!" [E0V9]

"Honestly, 90% of my charging events are opportunistic!. I don't have to charge to secure my home journey" [EV01]

"last week I was going to the Heathrow and I was in need to charge at the workplace, I had to send notification 2 days before asking if the Estate Department can secure a bay for me, but I didn't get a response!.. Luckily, I found a bay on the day but I was there at 7 AM!!!." [EV03]

3.3. Data analytics (stage I)

Studying the various degrees of exposure to EV driving and technology, and the social network structure created by the community, sheds light on the WPC system dynamics and the emerging social practice. The first round of the interviews provided useful and meaningful insights. Visualising users' mobility patterns helped with understanding the daily patterns, types of the journeys, denoting the daily locations of individuals (mobility demand). The EV is the second household car to all participants apart from one participant, EV10.

The interviews showed user perceptions and personal preferences; however, there was a need of actual figures that reflect how people rely on the WPC. The spatio-temporal analysis explored the charging patterns, shifts, usability and users' behaviour. Data retrieved from the CPs do not indicate the real need of charging, as it does not reflect the urgency of charging event. The data does not show if the charging event was opportunistic (the EV owner plugged in their car as the bay was available) or it was urgent to have a secured journey back home.

3.3.1. Diaries

The first diary study was carried out asking the participants (n = 7) to report their state of charge (SoC) for 3 weeks. The users reported the charging sessions' timing, which was compared to the CP database for validation. In April 2015, the dairies were collected and responses were tabulated showing minimum and maximum SOC on arrival: EV02 scored the least SOC of 9%.

The second diary study was more detailed as it was asking the users about their arrival time on campus and if they needed charging everyday they are in. The users filled the diary; some of them did this manually, while others preferred to fill it in a spread sheet. Among the two diaries, there were five users in common, EV01, EV02, EV07, EV09 and EV10. The responses were compared to interrogate if there was any difference in the SOC **Figure 10**.

3.3.2. Participatory data analysis

We conducted interviews with each participating EV user, in which we used the visualisations to help participants reflect on their previous charging patterns (2015 and 2016 diary studies). It

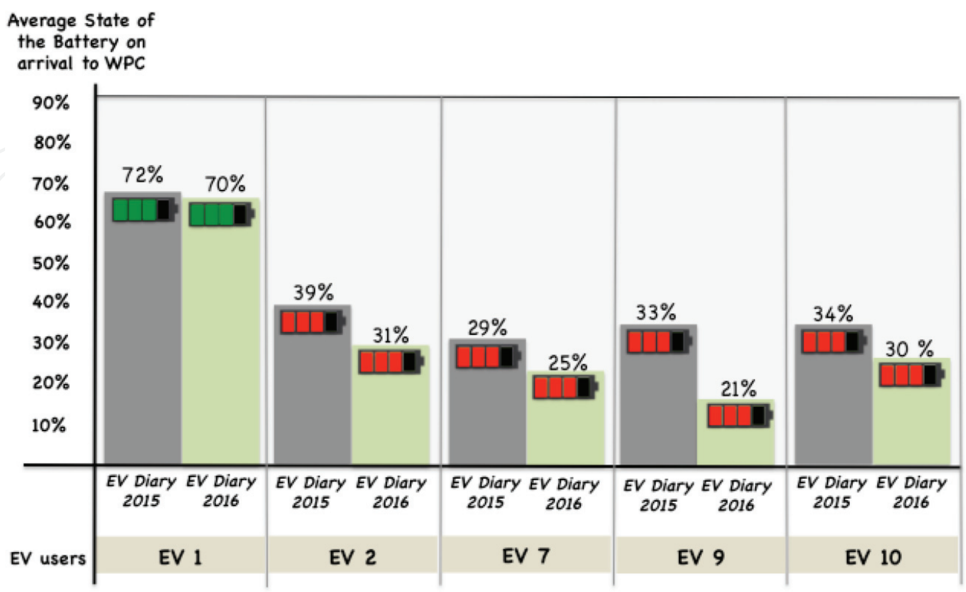


Figure 10. The average of SOC on arrival (2015/2016).

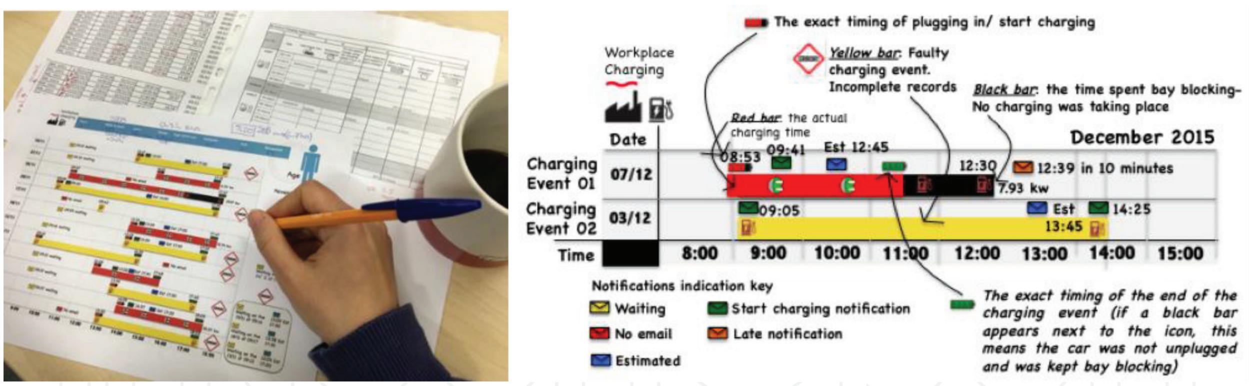


Figure 11. (a), (b). Visualising of charging even and showing it to the participants over Interview I.

was not necessary for participants to recall each day we presented, the main aim of the discussion was to observe the EV users' justification for the collective behaviour being denoted in the visualisation. Some charging events were striking and the participants were able to figure why such behaviour was made by checking their personal diaries or remembering a particular event that happened on that day.

> *"Only once, suddenly it didn't charge...only 50%." [EV07]*

Each interview lasted about 50–60 minutes and took place at the participants' workplace. Each session was voice recorded and transcribed. We briefly introduced the visualisation to the participants through an enlarged and linear bar chart representing the charging events with all needed data, see **Figure 11a** and **b**.

The interviews were conducted using 2 A4 paper sheets with their 4th quarter of 2015 charging events and a separate sheet representing the last month (15 February–15th March) of driving and charging behaviour before the interview date.

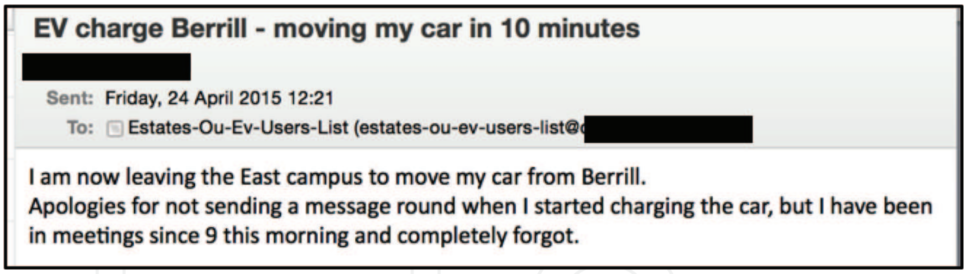
3.4. Data participatory approach

3.4.1. Community action

The participants were asked: (1) when they send notifications to other users and (2) what kind of information they are sending over. The questions were asked over the visualisation of each user, see **Figure 7**. Some participants were very keen to send notifications to others; however, there was always a delay and in some occasions they forget to send at all. Only one participant accesses work email from their smartphones. As a result, there is a delay, as they have to return to their desks to send email after they plug or unplug their cars. On some occasions, this causes an inconvenience as the case of EV09. EV09 has to walk around 15-minute to reach site 1 and 20 minutes to reach site 2, see **Figure 12**.

3.4.2. Confidence level and use of WPC

The users were asked about the importance of WPC in their daily charging demand after another year of having access to it. They were asked whether they rely more now on WPC or



EV charge Berrill - moving my car in 10 minutes

[redacted]

Sent: Friday, 24 April 2015 12:21

To: Estates-Ou-Ev-Users-List (estates-ou-ev-users-list@[redacted]

I am now leaving the East campus to move my car from Berrill.
Apologies for not sending a message round when I started charging the car, but I have been in meetings since 9 this morning and completely forgot.

Figure 12. EV09 message sent to the EV users.

they plan to opt out the scheme and rely on domestic charging. The question was asked, as by looking into the charging data retrieved from the CPs, there was variance in the total kWs used by each EV user. For the charging records of 2015, EV01, EV09 and EV10 charged equivalent to <30 GBP; whereas, EV02 charged equivalent to 60 GBP and EV05, EV07 and EV08 used kW worth over 120 GBP. The participants were asked to report their car mileage since they have joined the EV scheme.

3.4.3. Charging patterns

The participants were asked about their visualised charging events and whether there is a routine, they have to stick to or they change their working hours to accommodate charging. Some users cannot make it to the workplace before 9:15 AM as they drop their kids at school. Some of those users live 30 miles away from work or the school is 20 miles away. Those users are aware that by the time they arrive, they will hardly find an available charging bay. From the charging records, those people target Noontime charging sessions. EV05 was saying:

> *"I do not look for a charging bay now when I arrive, I go straight to my office. Once I am on my desk, I login and keep an eye on the nearest estimated time. I mark the email with a 10 minute late reminder…I go to plug it in." [EV05]*

Other users give up if they could not find a morning slot as they will be too busy to go over the day to plug it in and unplug it.

> *"I usually have enough in my battery to go home. So if I miss the morning session, I don't bother charging." [EV05]*

Other users charge only twice a week, on Tuesdays and Fridays and with the FCFS protocol, it is becoming a hassle.

> *"Now realising how the charging affects my day and considering one of the charging bay wasn't working… it costs me a lot of effort to charge here."![EV09] "I don't live very far from work; however, the way we use the car is: you take the car, you do the school run." [EV10]*

While most of the users are competing to charge their EVs, some users gave up their slots for those who in need to charge.

"At work, I used to charge it more often, but I know there's a queue and because I can charge it at home. In fact I did charge it yesterday and it is on charge at the moment. Only because I had to go out lunchtime, so I come back and there was a free space…" [EV12]

3.4.4. Bay blocking

Bay blocking (black bar in visualisations) appeared for all participants. Some participants had short bars indicating that they were stuck in a meeting or the time it took them to go to their car. In other cases, the black bars were almost the same length of the red bars (charging), which means 50% of the time the car was plugged in, and was not charging.

"I was in a meeting so I couldn't unplug it earlier." [EV10] "We are here to work not to charge the car. I am not supposed to shift a meeting to charge the car." [EV05] "I look on the dashboard how many hours for a full charge. I walk to my office, I check my calendar, and based on it, I send the estimated time. And if there is a! meeting, I will definitely extend the time and go afterwards."[EV09]

3.4.5. System reflection

The participants were asked about their opinion about the system as some of them have been using it for more than a year and others just joined early this year. The users' attitude towards the system is different and a few of them felt unwelcomed because they have hybrid cars or live close to the university.

"If decided to have an exact charging session, lets say…a 3 hour session from (8,30-11,30), I will use it lesser." [EV09]

"I try to be early to charge before others." [EV07]

"Sixty miles away from here. Without any traffic, travelling at 70 miles an hour, it takes me one hour to get here on the M25 and M1. I have to leave home with a full battery. I get here, in winter, with about 15% left. In winter I need a good five hours. If I don't get the five hours I can't get home." [EV13]

Throughout the interviews, the users found a chance to freely discuss and reflect on the current system. Some practical solutions were suggested.

"Yes. It was my idea especially when we were down to one post that we limited to an hour and a half a week per person– people said, "No, I need to charge three hours a day." [EV12]

"The charging here is a big stress, a major stress…I need 3 hrs to charge my battery!" [EV13]

3.5. Data analytics (stage II)

Throughout the study, certain personality traits emerged, which can identify the individuals using a WPC, some of which are social (sending on-time notifications), whereas other traits are anti-social (bay blocking). Via interpreting the records reported in the dairies and the critical analysis of the interviews' responses, a WPC user will have at least three qualities of the following seven, as one quality in each criterion: mentality, priority and requirements. A WPC user maybe a considerate person, who cares about other EV owners sharing the limited resources with them or a selfish user, who cares about his convenience and charging needs. Each WPC user would also set a priority; whether they will put their work as a priority (e.g. they will not change anything in their work habit to accommodate shared charging), they will not shift a meeting or reschedule it to avoid bay blocking; however, they will try to avoid this as much as they can and they will show remorse for doing so. The third trait is that they will not stay in the system if it adds more pressure to their daily life and will leave the WPC scheme and go back to rely mainly on domestic charging. The last criterion is the requirements. Each WPC user would have a vision in mind for the ideal fair and efficient WPC system. These requirements vary; some users demand advanced ubiquitous computing, looking for interactive mobile applications that bring ease to their charging process; whereas, others still prefer an intuitive WPC system that requires less computer involvement.

3.6. Observations and discussion(s)

When studying WPC for emerging vehicle technology, neglecting social influence processes will ignore or underestimate the potential for consumer perceptions to develop and shift. Analysing WPC systems shows cases of variant consumer personas, charging behaviour, and the need of the WPC as part of the daily routine. Charging behaviour is the collective behaviour, the EV user performs. It is the charging session they try to get, the arrival time, the time they send updates to others, the state of charge, the state of the charging point, and the time they are plugged in versus the actual charging time. It is the emergent behaviour of sharing WPC. Thus, based on this study, we cannot confidently approve the preposition of "WPC adds flexibility to work day and shall double the daily range". The WPC infrastructure is intrinsic to certain EV users, who are ready to deal with the social dynamics associated with it. A WPC system is not a prototype of a public charging network at a smaller scale, and it is a subset of an e-mobility system that has its own unique paradigms, policies and conditions.

3.6.1. A. RQ1: The four WPC user personas

In a previous study that was carried out covering different sample sizes of EV users [50], three personas were created: the old school, the risk taker and the opportunistic. The old school is the EV user, who is still afraid to have a flat battery so they are over protective and very conservative in their charging pattern. The risk taker is the EV user, who extends their driving range by exploring irregular road trips relying on public CPs. The opportunistic are the EV driver, who does not own an EV but drive fleet EV and promote car sharing as a way to be environmentally aware. These personas fit typical EV users; however, the WPC users have different personas due to various factors: shared resources protocol, peer pressure, selfishness, competition mode, priorities of individuals and work-related arrangements, which are associated with the charging process. The human aspect and the social interactions created different personas that can identity different WPC users. Four personas are generated from exploring the WPC social practice, see **Figure 13**.

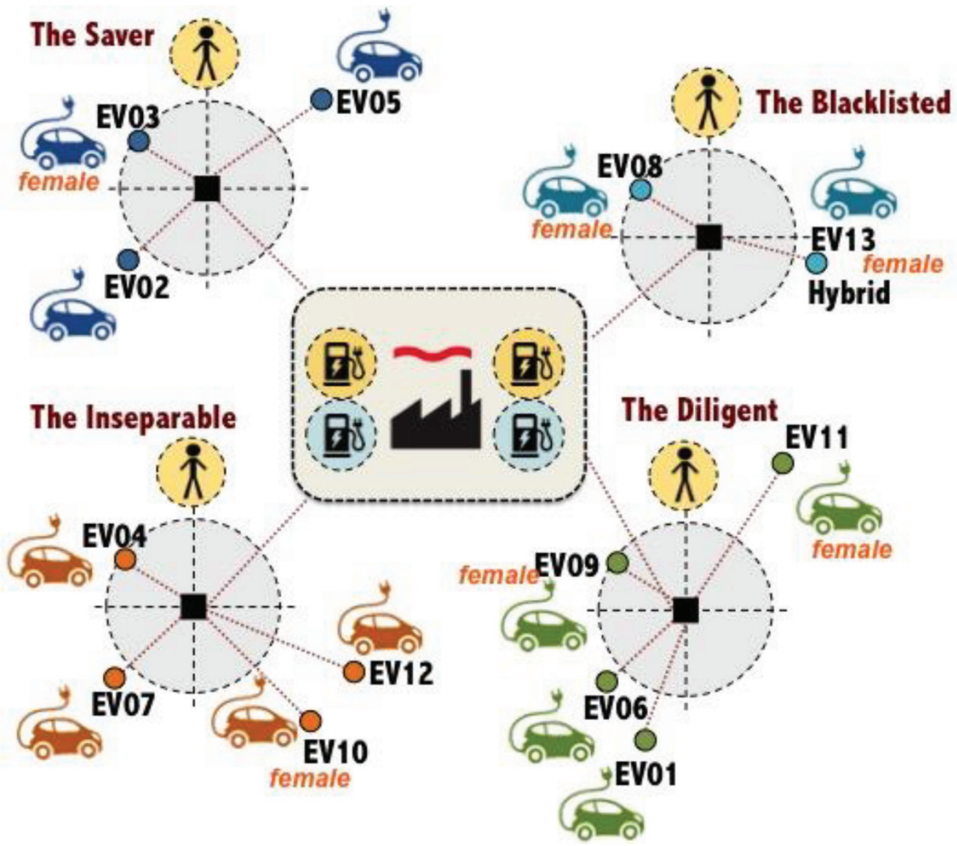
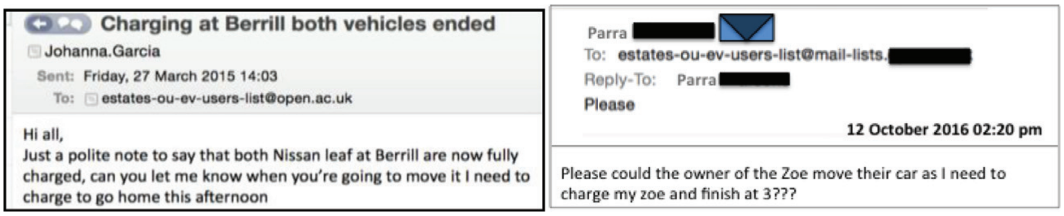


Figure 13. EV WPC personas.

3.6.1.1. The inseparable

This persona describes the EV users (EV04, EV07, EV10 and EV12), who are very considerate to other users, who are sharing the WPC. They demand daily or at least three times a week WPC. They usually arrive at work with a relative low battery (10–20%). Due to their high demand, they make sure they deserve a secured access to WPC. Even though, the system is managed with a FCFS protocol, they manage to schedule their day to make sure they charge. They abide themselves with the communication system giving a chance to whom in demand. They notify others once they are plugged in/unplugged and may bay block in late occasions. This persona is not likable within the EV community, as they believe they take advantage due to their flexible time schedule or that they live locally, so that recharging their batteries is not as stressful to them as to others (**Figure 14**).



Charging at Berrill both vehicles ended
Johanna.Garcia
Sent: Friday, 27 March 2015 14:03
To: estates-ou-ev-users-list@open.ac.uk

Hi all,
Just a polite note to say that both Nissan leaf at Berrill are now fully charged, can you let me know when you're going to move it I need to charge to go home this afternoon

Parra [redacted]
To: estates-ou-ev-users-list@mail-lists.[redacted]
Reply-To: Parra [redacted]
Please
12 October 2016 02:20 pm

Please could the owner of the Zoe move their car as I need to charge my zoe and finish at 3???

Figure 14. EV09 message sent to the EV users.

3.6.1.2. The diligent

The diligent persona is the EV user, who would try to charge at the WPC if the charging would fit within their work routine (EV01, EV06, EV09 and EV11). They are not going to change their daily routine. They arrive to the workplace with an average of (40–50%) as their charging demand is not as high as the *Decent persona*. Those users tend to be more active in the EV forum and open channels with the employer to discuss solutions and alternatives. They keep reminding other users not to bay block or to update their charging records. They are considered as system administrators.

3.6.1.3. The saver

This persona includes EV owners (EV02, EV03 and EV05), who are very close to being opportunistic users. They may not need to charge at all at the WPC. However, this persona includes risk takers, who can extend their comfort zone reaching a very low SoC. Their confidence level has increased by the time they use the car. They are confident enough to reach the workplace with one cell or even zero cells left in their batteries. Due to their local commute, they are familiar with the work journey to an extent that they can confidently leave home with only 5 miles left in their battery knowing that they will charge at the WPC. They are more flexible compared to the *Diligent persona* as they can slightly shift their work patterns to accommodate charging. They charge at their ease, they do not pay attention to the communication pool, they check if they miss morning shift.

3.6.1.4. The blacklisted

This persona includes EV owners (EV08 and EV13) whom their charging matter is not seen as urgent as others. This persona includes those who have hybrid, so relying on petrol is an option. Although they have the same right as other users, the community may stigmatised them as their case is not as critical as full electric users. Also this persona includes those who are against the suggestions for limiting the charging sessions, as this does not fit their mobility demand. They do not commute to work five times a week and live relatively far from their workplace. They do not bay block, yet they make good use of the system and charge at work very frequently. (EV08 used kW worth over 120 GBP). This persona is the least flexible compared to other personas due to mobility demand.

3.6.2. B. RQ2: Usability and related issues: recommendations for assessment and design of new WPC system

There is no definite theory that controls the use of WPC, analysing the current WPC-formulated lesson learned informing the design of future technologies that can improve the away from home charging experience:

- WPC management: sophisticated infrastructure to communicate between the users and the management is not compulsory. Simple communication pool can work. However, it has to have a way to deter bay blocking;
- Billing policy: Annual fees with unlimited charging does not serve applying self-regulated based systems;

- System assessment: Relying on the WPC retrieved data is misleading especially in the kW calculations. Interviewing EV users justifies unexplained behaviour.
- Peer pressure: may only reduce anti-social incidences.

4. Conclusion

Ev is still in an early technology adoption stage; it has not yet taken the role of main stream of major daily transportation option [51]. We cannot confidently approve the preposition of "WPC adds flexibility to work day and shall double the daily range" [9]. The WPC infrastructure is intrinsic to certain EV users, who are ready to deal with the social dynamics associated with it. A WPC system is not a prototype of a public charging network at a smaller scale, and it is a subset of an e-mobility system that has its own unique paradigms, policies and conditions. This is an ongoing research; the next step is to analyse the social practice with more users joining the scheme and testing different simulation scenarios for the scheduling protocol.

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