The Charging Personas of the E-Mobility Users of Newcastle-Gateshead Urban Area

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Abstract. From a planning and policy making standpoint, the location allocation of electric vehicle (EV) refueling stations is intrinsic problem. The preposition is that the more the charging points are installed, the higher the possibility of potential users gaining confidence in driving their EVs. However, the unplanned deployment of infrastructure may cause a waste of investment. Previous research focused on the domestic charging events and the connection to the grid, slim literature covered the non-domestic charging events and patterns of EV owners. This article develops and identifies the charging personas of EV owners using non-domestic charging points. Spatiotemporal analysis was conducted based on the usage data provided by Charge Your Car (CYC) Ltd. Company, the service provider in Tyne and Wear County. This paper reports on the e-mobility system of a metropolitan area in the North East of England, Newcastle-Gateshead Area. It proposes a methodological approach to analyse current EV users' patterns and assists planning authorities and policy makers in understanding the mobility system hence strategically plan for future EV users.

Keywords: Electric vehicles · Charging network · Charging preference · Comfort zone · User charging personas

1 E-Mobility System

Alternative means of transport have obtained attention in the last decade due to the environmental burden of the transport sector. In the context of urgent challenges presented by carbon reduction targets and air quality goals, Electric vehicle (EV) industry is seen by developed countries to be a viable solution [1]. EVs are currently being discussed intensively around the world especially in European and North-American countries but also emerging economies such as China and India [2]. It is perceived that the electrification of mobility is the most efficient mean of transport compared with Internal Combustion Engine (ICE) vehicles with the smallest CO2 footprint [3–5]. Regardless of the insignificant market share today, automotive companies predict that EVs will progressively gain popularity due to environmental and social-economic factors [12, 13]. In the next 20 years the number of EV, will exponentially increase [8]. The diffusion of purely EVs is on the forefront of the non-conventional power-train technology developments [9]. Stakeholders and EV advocates claim that EVs are winning broader consumer acceptance and the options are

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growing for potential users to join the market. Nissan reported rising demand for its Leaf from a broader range of consumers [10]. Nissan claims that they are currently beyond the early adopters phase and they are selling for practically minded consumers who are looking at the monthly economic savings of mobility. The opportunities and issues that e-mobility brings will have lifestyle implications for large parts of the population [11]. The wide-scale adoption of privately owned low carbon emission vehicles certainly would provide an improvement [14, 15].

There are many ways and advanced technologies to recharge EVs' batteries: plugged in (domestic/ public), electrified roads, wireless charging stations, wireless charging under the roads [14], and battery swapping [15]. There is a rising demand for Charging Points (CPs) to support the e-mobility system in its urban context. Studies have showed that investments in publically available CPs would better support the EV market. Having an integrated reliable network should promote the EV market as this should slow the rapid increase of the upfront cost of the EV due to the marginal cost of expanding the car range and increasing EV battery capacity [16]. Automotive manufacturers are working on extending the range to 250 miles or more in the EVs. Planners and policy makers have to economically design integrated CPs that can support the demand and secure the way for potential users to join the market.

The non-domestic charging service can be on street or off street CPs. This embraces all publically available CPs, including the shopping centre and workplace car park. The on street one can be like the CP outside the side door of a restaurant and may refer to as "opportunity charge" [17]. This type continues to be rolled out across the UK whether using a pay as you go scheme or the membership scheme [18]. In the North East of England, the charging network is mainly managed and maintained by Charge Your Car Ltd. Company (CYC). Through CYC website and cellphone application, the current state of the CPs can be checked, see Fig. 1.

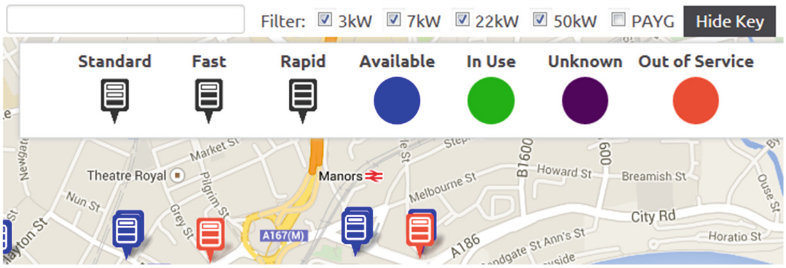

Fig. 1. CP status updates (Color figure online)

CPs are usually 7 kW or 3 kW both with 13 Amp and 32 Amp sockets so they are compatible with all EVs. Drivers can plug in their cars in for approximately 3.5 h if they want to have a full charge as per their battery capacity (Nissan Leaf battery is 21 kW capacity) using a 7 kW charge. The actual charging time will depend upon the on-board type of charger, type and the level of CP including the initial State of Charge (SoC), at arrival.

2 The Consumers and the Myth of the Limited Range

Analysing the behavioural element of an existing EV system and the level of interaction with the infrastructure, will assist in designing for future EV users [19]. Before reviewing the previous work of the social practice, there are some socio-technical common phrases in the context of EVs that need to be highlighted.

Comfort zone concept is derived from the proxemics approach and it is widely applied in the field of psychology. The proxemics approach is the scenario to social science, which evolves around the spatial behaviour of individuals [20]. The comfort zone of an EV driver is about the individual's psychological boundaries they draw to themselves. [21] explained this zone from a psychological point of view as the comfortable range and [22] defined it as:

> *"the zone (metric, time or defined destinations), within which the driver will not worry about the battery."*

The range of these boundaries is a product of technical awareness, confidence level, mental comfort, analytical thinking, road network layout, and quality of charging services' locations and size. This definition needs to be more precise, as the driver may gain access to non- domestic CP, hence the zone will be expanded.

The definition is to be modified as: the zone (metric, time or defined destinations), within which the EV driver will not worry about the battery with no access to any nearby CP. Figure 2 illustrates the home in the centre (Origin), and the destinations (multiple: school, work, leisure, etc.) are the randomly spotted dots. The EV driver tends to tolerate short trips, which vary from one to another. The origin is the last place that has access to a CP. The first circle from inside is the comfort zone of the users. The road trip can be directed to any of the directions, as the destinations are denoted as black, green, and red circles. The comfort zone is relatively small compared to

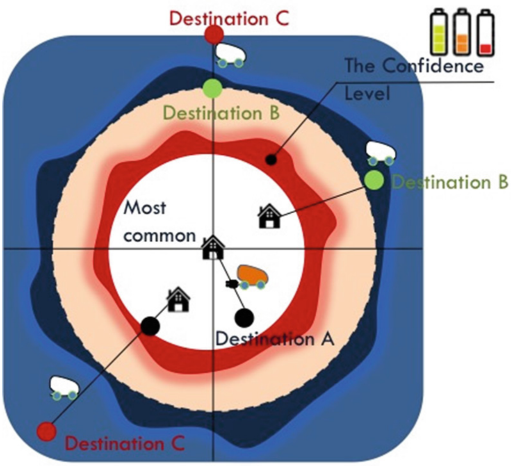

Fig. 2. EV comfort zone (Color figure online)

conventional means of transport. Will remain smaller until the stakeholders and policy makers pick up charging service difficulties.

The comfort zone is coupled with the confidence level of the users, which is the area between the first and the second circle. This area has an irregular curvature shape; it can be extended to cover even beyond the boundaries of the second circle, in which case the confidence level scores the highest levels of certainty. The black circle represents destination A, which is a destination that falls within the comfort zone. The green circle is destination B, which is relatively far compared to destination A, and it might be reached if the comfort zone of the driver is wide enough to reach it. The red circles are the destinations where the EV driver needs to have access to public CPs throughout their road trip. The wider the comfort zone, the less worried the driver would be. To get a wider comfort zone, the routes need to be supported by charging services so as to cover the routes to destination C for instance.

2.1 EV Usability and Technology Affordances

The production of new technology can be divided into a number of periods corresponding to the different social groups [23]. The technology development is a user-centred design based approach, which is driven by the usability, affordances, and difficulties. As per [24], usability refers to:

> *"ensuring that interactive product are easy to learn, effective to use and enjoyable from the user' perspective."*

User experience (UX) is a phrase that reflects how a product behaves and is used by consumers in the real world, which is central to interaction design. All aspects of the end's user' interaction with a system [25]. Collecting information of a user's performance is a key component of usability testing. Applying this in the e-mobility context, carrying out user studies and analysing real information about users provides insights into the charging behaviour and the use and usability of the EV system (car and infrastructure). Affordance as [24] is a term that refers to:

> *"an attribute of an object that allows people to know how to use it."*

As [26] simplified its meaning as "to give a clue". Affordance as a term has been used in the interaction design and is being used to describe how interfaces should make it obvious as to what can be done using them. UI or vehicle dashboard, is conceptualised as a perceived affordance, it is a screen-based interface, which is different than real affordance of physical objects. The variety of technological solutions and the link between them and socio-political choices lead to the emergence of the design interventions [23]. In the context of EV use, the overall system is complex with different protocols and interactions between the users themselves and the built environment.

2.2 The User Interface and Mobile Applications

There is basic information about the battery, charging types and rates which the driver should be aware of. Each EV model has its own designed user interface (UI). UIs of

EVs show the charging information, see example of Nissan Leaf, see Fig. 3. The SoC may be in cells or in percentages, see Fig. 3.

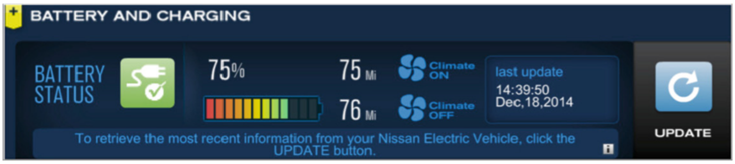

Fig. 3. Nissan Leaf UI showing battery status

This information is fundamental as it justifies the charging patterns and profiles. Starting with the battery, EV battery has 48 modules with 192 cells. An arbitrary display of 12 cells is in the car UI. In case of full charge, the 12 cells will flash in green, the last cell from top displays from 12 % to 15 %, depending on the model. Each following cell displays 8 %–5 % of the charge, depending on the model.

The EV users have different applications on their cell phones to check the charging network, Fig. 4. Each user creates their own collection of applications that covers the mobility demand (e.g., users who do not charge non-domestically, are not keen to install various charging-related applications).

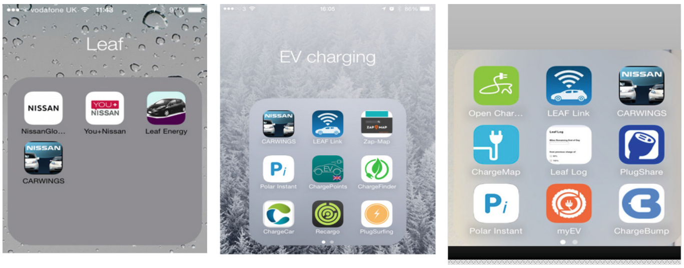

Fig. 4. EV battery arbitrary cells and the percentage display

2.3 The Importance of the Study

Previous studies show that the vast majority of current users rely on domestic charging [27–31]. Even so, in order for EVs to gain widespread consumer adoption, it is critical to have an existing integrated charging infrastructure in urban areas [32]. In order to design an integrated and reliable charging network, a clear understanding of the charging patterns and preferences of privately owned EVs is fundamental. The paper presents the formation of the charging personas based on empirical data (2010–2013). It starts with the relevant work and setting the context for the case study. This is followed by the methodology section introducing the charging preferences and spectra membership and the way the user charging persona (UCP) is developed.

2.4 Related User Studies on Limited Range

Limited range was addressed in 14 studies varied between consumer and EV user, see Fig. 5, highlighting the consumer studies in red and the EV user studies in green. [33] attempted to predict the EV diffusion in the market addressing the range as to evaluate the vehicle attributes. [34] study surveyed the purchase decision and how fundamental is the range to the consumer. For the same objective [35, 36] addressed EV range in their studies investigating the consumer opinions and preferences and what would motivate them to own/lease an EV.

From a different angle, [37] conducted V2G project survey asking the consumers on the minimum acceptable range. [38] asked EV users about the minimum range they accepted or they would have accepted in their EVs. With a different approach, range related questions are addressed in consumer and EV user studies. In the latter, the participants have experienced driving the car and thus the questions relate to the use of EV rather then to predict behaviour. In order to assist Automotive and battery technology providers meet the end user's design needs, [40] surveyed the minimum SoC the users ever reached interrogating the accepted range for their daily use. In brand-perception surveys, the range was addressed to evaluate the user selection criteria as was mentioned by [41] in the USA study. EVREST project [42] surveyed the impact of the EREV on the users acceptance. A further study reported by [43] addressed the range in the Chinese market. The outcomes highlighted it as a barrier to purchase. Finally, the range was surveyed by OFAS [44] when asking the staff members on their individual preferences and how the range and the workplace charging fit within their daily routine.

2.5 The Study Area

Newcastle upon Tyne city is located in the North-East of England. The city is divided into 64 postal districts, see Fig. 6. The inner urban core is mainly the area around the river Tyne, which is defined by the postal district boundaries of NE1 (6 km^2), NE4 (14 km^2), and NE8 (16 km^2). The city has an existing EV charging infrastructure and there are plans to install more CPs around the Newcastle and Gateshead metropolitan

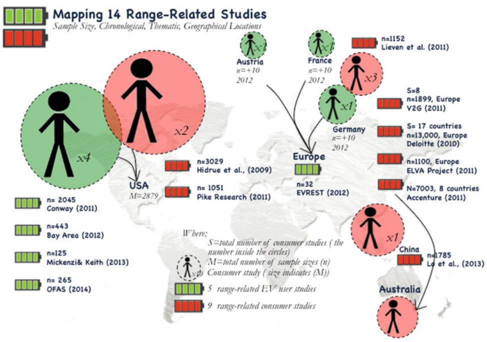

Fig. 5. **(Left)** Mapping of range-related studies (Color figure online)

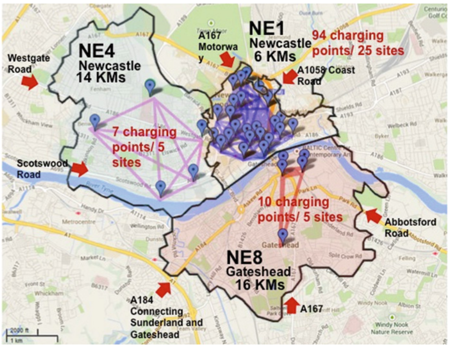

Fig. 6. (Right) CP's distribution Newcastle upon Tyne (CYC) (Source: Google map, 2014)

area over the next two years (2015–2016). According to CYC, 1,500 CPs are installed for the public use [45]. The inner urban core is a hotspot for inhabitants and visitors who are flying or sailing to Newcastle. The majority, 25 CPs are in NE1 and 5 CPs each in NE4 and NE8.

3 Methodology

This study focuses on 395 EV users' records of charging using non-domestic charging points (CPs) between 2010 and 2013. CYC Company retrieves the data from the CPs and generates up to date reports. Based on the data provided, there are four main variables related to charging patterns of individuals, see Fig. 7.

The first behavioural variable measures the time of charging within the day, labelled as Most Frequent Time (M) and it is used to know the busy times of charging (occupation). The Average time spent (A) measures the average time spent by drivers charging their cars using the refueling station (RS). M reflects the peak hour/period where most of the population prefers to replenish their batteries. This is particularly useful when dealing with a big dataset similar to the one used for Newcastle. The first attempt of calculating "M value" is the average time of charging events over a period of time. This is misleading as (M) calculates the most frequent time the users tend to charge their car. To get "M value", the day is to be divided into four time spans, and then the total number of the charging events took place in each period (morning, afternoon, evening and night) is calculated, see Fig. 8 for an example.

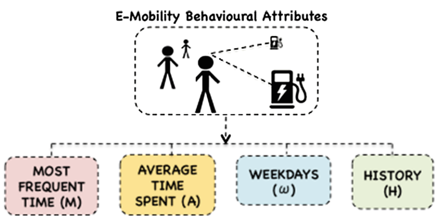

Fig. 7. (Left) E-mobility charging related attributes (measures)

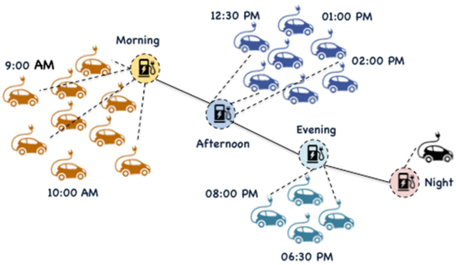

Fig. 8. **(Right)** Most frequent time "M value" visualization. The morning starts from 6 am to 11:59 pm, the afternoon is from 12:00 pm to 5:55 pm, the evening is from 6:00 pm to 11:59 am and the night is from 12:00 am to 5.59 am.

3.1 Charging Personas

[46] created and defined Persona as: a user-centred design method which sets up fictitious characters to represent the different user types within a targeted demographic group that might use a site or product. A persona is a collection of realistic representative information. In this article, the target group is the EV users and the persona as a user-centred design method is employed to characterise the charging spectrums among the group. Charging personas can be defined as:

> *"EV users have non-linear charging patterns that change on weekly and monthly basis. A charging persona is the charging pattern of a user after tracking their charging records (location and timing) for a period of time not less than 6 months. Charging personas are associated with demographic and socio technical elements."*

The charging personas stems from individuals charging preferences. A charging preference can be described as:

> *"Individual's usual charging pattern that is convenient in terms of time, price, and location. The EV user demands an easy way to publically charge their car in addition to the domestic charging. Depends on the individual mobility demand, the EV owner uses the car in a way that it suits their lifestyle."*

To classify the different charging preferences of EV users, CYC dataset (charging sessions of all users for a period of three years and half of operation) is analysed in a way that serves the study objective. From the definition of charging personas, the attributes Most Frequent Time (M) and Average Time Spent (A) are considered.

3.2 Charging Spectra

Prior to integrating the charging measures M and A in an attempt to classify the charging preferences, the charging practice has to be identified. The charging practice can be defined as:

> *"The common practice of EV drivers using non-domestic charging network where the users charge their cars to commute not a matter of opportunity charging. A creation of charging spectrum that has different patterns. Each spectrum stems from: the desired road trip, initial*

SoC (as charging rate differs), confidence level and level of awareness, SoC in relation to the distance to be commuted, charger capacity and the willingness to spend time charging. There are five charging spectra (practices)."

The dataset has been analysed based on the five charging spectra, see Fig. 9.

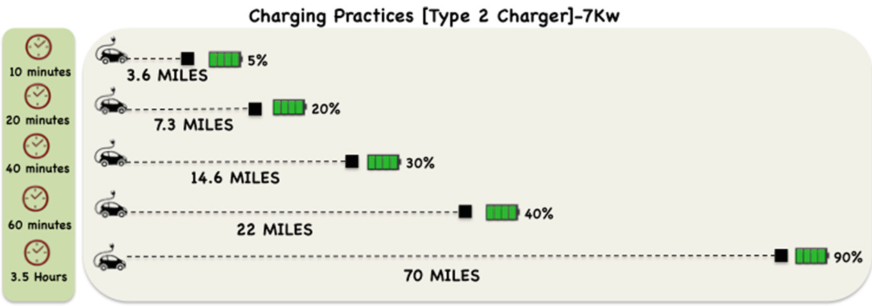

Fig. 9. Charging spectra

The first charging practice is a 10 min-charge, which will top up the battery with enough charge to at least commute around 4 miles in case of using Type 2 charger (in case of Rapid charger, more miles and higher probability to occur in the charging spectrum). Based on the literature and the EV user study, short-distance commuters may stop to charge their car for 10 min.

The second charging practice is a 20 min-charge which would be enough to replenish the battery almost 20 % charge (differs based on the initial SoC before charging. The third charging practice is a 40-min charge, which would allow the commuter to drive another 15 miles. The fourth and the fifth charging practices are for those who are willing to spend time charging (one hour up to three hours and a half). The fifth practice is when the drive gets a full charge or 90 % charge (it is advised by battery technology provider to charge the battery only up to 90 % for a better battery lifestyle).

To interrogate the possible charging preferences, the first step is to look for a charging trend that reflects the EV population. An insufficient group of EV users charging their cars in a discrete pattern does not assist the understanding of the charging patterns of current users. For example, a significant group of EV users tend to charge usually at the afternoon, for 15 min using a particular rapid charger in the city centre, will indicate a emergent behaviour.

4 Method: Forming User Charging Persona

Following this line of thought, the analysis is carried out by designing a matrix of four data arrangements, see Fig. 10, creating five user charging personas. The four data arrangements are: M, A, cumulative value of all monthly charging events, and the percentage of the overall EV population. By applying the matrix to the three and half years of operation charging records, the data is administered in a spatiotemporal data analytics (secondary X axis chart) at these five levels of practices. The personas are based on Nissan Leaf model battery capacity and consumption rate. Equation 1 calculates the charging persona membership based on M and A values.

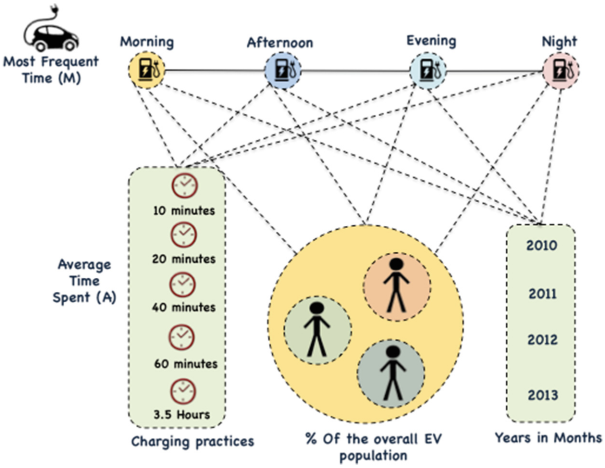

Fig. 10. EV charging personas formation data matrix

$$\begin{aligned} &User\,Charging\,Persona(UCP) \\ &= INDEX\,(\{BeyondCharging, Superb, TheLuckyYou, GoodEnough, TheTop\}, \\ &\qquad MATCH((time\,of\,departure\,(d) \\ &\qquad = -Time\,of\,arrival\,(\delta)), \mathrm{TIME}\,(0, \{600, 180, 60, 40, 20\}0), -1)) \end{aligned}$$

Where the time is in minute.

5 Outcome: User Charging Persona (UCP)

This study presents five user-charging personas of Newcastle-Gateshead area. Personas were generated based on the users data. The first persona is "The Top Up" contains those drivers who are willing to spend up to 20 min charging their cars over the daily road trip, see Fig. 11 as an example. This can be down to 10 min, which is sufficient to replenish their batteries and go home safely. A high percentage, 91 %, of this group charges their car for 10 min only. This reflects the reliance on domestic and workplace options. Almost half of the users charge their cars for 10-min in the evenings, which means after work and probably on their way home. The other half is equally distributed over the mornings and the afternoons.

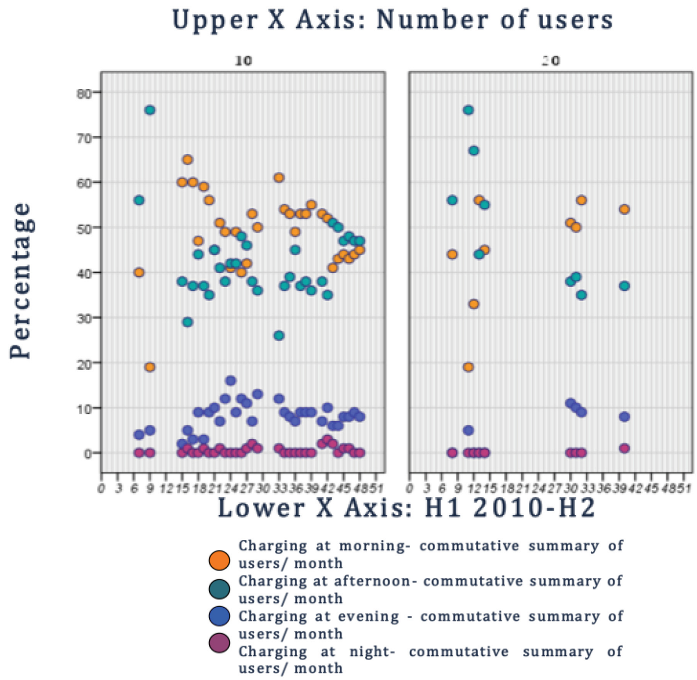

Fig. 11. The Top Up persona visualisation (Color figure online)

The second persona is “The Lucky Charge” and contains those drivers who are willing to spend up to 40 min charging their cars throughout their daily road trips. The analysis showed that the majority of transactions made by this group are ranging between 10 and 19 transactions per month. These records were scored throughout the 3.5 years. This means that this persona barely contributes to the overall charging events. Those users charge their cars in the mornings and the afternoons, in particular in the mornings.

The third persona is “The Good Enough” and contains those drivers who are willing to spend up to almost an hour charging their cars throughout their daily road trips. The analysis showed that the majority of transactions made by this group are ranging between 10 and 19 transactions per month. These records were scored throughout the three years. This means that this group barely contributes to the overall charging events. The EV users with this persona are those who charge their cars at mornings, and afternoons and in particular in the morning.

The fourth persona is “The Superb” which contains those drivers who are willing to fully charge their batteries using RSs. This means that they are so technically oriented and think wisely with respect to electricity. This group does not have a problem with charging. This is due to the high probability of having access to workplace charging (as implied from the charging spectrum), which means that users do not need to worry if they did not charge at home. They save a lot as they probably do not mainly rely on domestic charging, they plan ahead so that they can have full charge which will guarantee a safe daily trip, and also they will ultimately have the longest life time for their batteries. However, in case of having 3 kW CP, this will only replenish 50 percent of the battery capacity. Yet, this is still considered as a high level of dependency and reliance on public charging services. Graphs reflect that the majority of the charging events of this group are more often during the day. Compared to other groups, 50–59 transactions are made monthly. The second highest scores are these charging events that happen between 40–49 times a month and the third ranked scores are over 60 charging events per month.

The fifth persona is “Beyond Charging” and contains those drivers who are using 3 kW chargers and/or have the luxury of fully charging their batteries using it. The charging events of this group are fairly distributed between (20 and 50) charging events monthly. Users tend to charge also in mornings, afternoons while less likely at evenings.

6 Conclusion

This paper described an approach and preliminary observations of EV usage patterns, based on a data collected from EV charging stations in Newcastle-Gateshead Area. Analysing current systems shows cases of variant consumers’ profiles and preferences, charging behaviour, and supply and demand records. It provides insights on prices, technologies, barriers and incentives and standardization. The study classified users into different clusters based on usage behaviors (the 5 personas) starting with *The Top Up* to *Beyond Charging*. The study visualised the collective dynamics underlying the dissimilar confidence level and variant comfort zone of the EV-users. The illustration of the UCP shows the non-linear charging patterns of users and how different the users can be when it comes to non-domestic charging. Coupling charging spectra with identified measures formed the membership of the UCP. We contend that range anxiety barely occurs at particular time during the road journey. The EV-drivers do not experience full electric range and they commute known and planned journeys, which makes the event of a “flat battery”, is almost impossible.

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