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Power to the Electric Car People: The Infrastructuring of Charging

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ABSTRACT

Driving an electric car relies on physical, digital, and human infrastructure. However, the charging infrastructure along with breakdowns and the work that people do to recover, that is, infrastructuring, remain understudied in HCI. In this paper, we present a study of 19 Danish electric car drivers and their infrastructuring to recover from breakdowns they encounter in charging their car in public. We describe the three most reoccurring types of infrastructuring with inherent breakdowns making charging infrastructure visible to the electric car driver: (1) Adjusting to conventions of parking, (2) Navigating the standards of charging services, and (3) Learning through community participation. Drawing upon the extant research, we discuss how our study contributes to a deeper understanding of the use of charging infrastructure and its implications for future research and design.

CCS CONCEPTS

• **Human-centered computing → Empirical studies in HCI**.

KEYWORDS

Electric car charging, infrastructuring, Electric car drivers, Sustainability, User study

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1 INTRODUCTION

Electric cars (also sometimes referred to as electric vehicles) are becoming widespread in many countries around the world and sales are gradually increasing [13]. The growing popularity of electric cars is pushed by technological advancements, such as improved driving range, but also pulled by the strong political focus on introducing electric cars as a solution to environmental problems and pollution (e.g. [1, 8]). As an example, Denmark is aiming at going from roughly 17.000 electric cars today to between 750.000 and 1.000.000 electric cars in 2030 [1]. But such changes in numbers of electric cars does not only involve people buying them, but it also requires investments in physical, digital, and human structures such as chargers, applications, and human resources.

Over the past years, HCI research has also shown an interest in electric cars [4, 17, 18, 26, 28–31, 41, 42]. Research studies have highlighted perceived shortcomings such as limited range [18, 29] and lack of feedback [30], but also designs to help electric car drivers through range prediction [30] or route planning [28]. In particular, HCI research has focused on electric car charging in the home and found challenges of not being able to charge cars because of intervening household practices [4], underdeveloped physical, electrical installations [41], expectations that are different from reality [26], or the lack of digital technology to fully support monitoring and planning activities [17, 41]. Consequently, electric car driving is often facilitated by planning activities using applications that locate chargers to reduce range anxiety and worries about depleting the car's battery [42]. Within this complexity, studies have found that sustaining the activity of driving is often facilitated by drivers themselves, who tinker with technology and create their own solutions through both physical and digital technology to mitigate challenges and facilitate driving their car [17, 41, 42]. However, an important aspect that makes electric car driving possible is the underlying infrastructure. Despite former HCI studies have problematized several aspects of the use of electric car infrastructure, the work that people do to recover from the breakdowns they encounter, that is, infrastructuring, remain understudied in HCI research.

In this paper, we add to the current discourse in HCI research on electric cars. We present an empirical study of 19 Danish electric car drivers' use of charging infrastructure and what they do to make charging work for them when they charge in public. As infrastructure is often invisible and blends into the background, when it works [37], our focus in this paper is on the instances in which it becomes visible to the user, that is, upon breakdown [37]. We further use the term infrastructuring to elicit what individual electric car drivers do to recover from breakdowns and make charging infrastructure work for them. We address the following research

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questions: (1) what kinds of breakdowns in the charging infrastructure of electric cars trigger individual drivers' infrastructuring? and (2) what types of infrastructuring do individual drivers have to conduct?

Our key findings are three types of infrastructuring that electric car drivers regularly conduct to recover from charging infrastructure breakdowns. First, they adjusted to other drivers' conventions of parking, for example, as a result of fossil-fueled cars occupying chargers. Second, they were navigating the standards of charging services, for example, because of the many choices of charging plugs and subscriptions available. Lastly, drivers were learning through electric car community participation, for example, as a result of limited support from professionals. Our contributions to HCI research on electric cars are two-fold. Firstly, we discuss how our work contributes to deepening our understanding of how charging infrastructure is actually used and by whom; Secondly, we discuss, by illustrating two strategies for how our findings on infrastructuring can contribute to future HCI research and design of electric cars.

2 RELATED

In this section, we outline the literature in two areas. Firstly, we outline HCI research on electric cars and describe the research aim. Secondly, we outline the research on infrastructure and infrastructuring.

2.1 HCI Research on Electric Cars

In HCI research, several studies are oriented towards designing interfaces for the electric car [18, 22, 28–31]. Much of this research is design-oriented investigating how to address the perceived shortcomings of electric cars compared to fossil-fueled cars [4]. In the HCI literature, challenges such as range anxiety (i.e. the fear of battery depletion)[29, 31] and route planning [28], or lack of driver feedback [30] have been addressed. Most of the research on design is dealing with interfaces to address these challenges. For example, Jung et al. explore how displayed uncertainty impacts estimates of range [18], Landau et al. demonstrates an app for route planning [22], and Lundstøm et al. [30] investigates interfaces that address the lack of feedback in electric cars, such as using ambient lighting for knowing when the car is ready to drive [30].

A different focus of electric car research is the empirical study of why people own and drive electric cars [4, 17, 26, 41, 42]. This research has mostly been concerned with aspects, such as motivation for ownership and how electric cars are integrated into peoples daily practices. Important aspects in the motivation for owning and driving an electric car includes expectations that meets actual driving experiences [26], feelings of being sustainable [4, 41], owning and using novel technology [42], and pleasurable driving experiences [17]. For example, Bourgeois et al. [4] investigated the feasibility of self-sustaining electrical mobility and provided an understanding of owning and integrating electric cars into household routines. The authors found that utilizing own-produced electricity, and the feeling of being sustainable was a reason for owning and driving an electric car. Further, studies of how people use electric cars have found that although the electric car is potentially able to be charged anywhere with a power outlet, challenges emerge such as having the right plug or planning when and where to charge. For example, Svangren et al. [41] found that for electric car owners, planning an exact route was seen as an important way of ensuring an available charger when going on a long drive. We have also seen research focusing on the connected features of electric cars and how they support daily activities such as planning and remote control [42].

The above HCI studies have shown that driving electric cars and integrating them with daily practices relies on underlying supportive physical, digital, and human infrastructure ([4, 17, 18, 22, 26, 41, 42]). Despite this, HCI research are mostly focused on how it integrates in the home and has only started to explore the use of public infrastructure. Although HCI research has revealed aspects of infrastructure, none has treated it as an object of inquiry in its own right. Given the fragmentation and complexity of this infrastructure, we argue here, that there's a need to understand better the challenges that electric car drivers in their everyday encounters with charging infrastructure.

2.2 Infrastructure and Infrastructuring

An infrastructure is traditionally considered something upon which something else "runs" or "operates", such as a system of railroad tracks on which rail cars run [37]. Challenging this notion, Star [37] brings infrastructure into the foreground as a topic of ethnographic inquiry. She proposes that infrastructure is the often invisible sociotechnical structures that are part of the background for other kinds of work [37]. Building on these notions, Star and Ruhleder [38] propose that infrastructure only becomes infrastructure concerning organized practice. For example, for electric car drivers, public chargers or smart-phone applications that facilitate charging is part of the charging infrastructure. On the other hand, for engineers designing chargers or developers designing smart-phone applications, they are topic.

Although we might think of infrastructure as something physical such as railroads and information networks, it is important to note that infrastructure can have many aspects. Towards this end we need to consider digital infrastructures, which are "a shared, evolving, heterogeneous install base of IT capabilities based on open and standardized interfaces" [11] and human infrastructures, which are "the arrangements of organizations and actors that must be brought into alignment in order for work to be accomplished" [7]. In the work of Star and Ruhleder [38], they outline the following properties of infrastructure as; 1) embedded into other structures, 2) social arrangements, and technologies; 3) Transparent to use in the sense that it invisibly support the task at hand; 4) either spatial or temporal – it has reached beyond a single event or on-site practice; 5) learned as part of membership; 6) links with conventions of practice in the sense that it is shaped and being shaped by communities of practice; 7) embodied into other structures through standards; 8) built into the install base; fixed in modular increments; and 9) becomes visible upon breakdown, which can be used as a flag for examining it.

While infrastructure is a useful term to describe various structures that sustain our activities, it does not describe the effort that people put into recovering from, i.e. breakdowns. As such, it does not describe the variety of effort that goes into its integration and

the ongoing work required to maintain it [3]. Instead, the notion of infrastructuring as a verb (also referred to as infrastructuring work [10]) has been suggested to describe the ongoing work that sustains infrastructures [5, 20, 23]. Pipek and Wulf refer to infrastructuring as the "in-situ design work of tailoring and configuring the infrastructure" [34]. They further argue that infrastructuring can be understood as design and as a "motivated, transformational activity that individuals or groups perform. Motivated means that every design activity has a goal or at least an intention. Transformational means that it induces a change that is intended to have a longer-lasting effect".

We are not the first to use infrastructuring as a lens. Scholars from other fields have used and defined it in different ways e.g. [19, 20, 32, 34]. In HCI, studies have explored infrastructure and infrastructuring in various contexts such as entrepreneurs' infrastructure activities contributing to public service transformation [6], blockchain information infrastructure [14, 15], mobile knowledge workers' infrastructuring practices [9], or individual actors' infrastructuring activities to make health care infrastructure work [10]. These studies indicate that infrastructuring work is being carried out by both professionals and ordinary people to circumvent problems with the infrastructure. As examples, Gui and Chen [10] investigate infrastructuring to explain work in healthcare infrastructure by both patients and caregivers. They found that ongoing labour is being put into making healthcare infrastructure work every day because alternatives do not exist. Similarly, Jabbar and Bjørn [14] focus on infrastructuring activities contributing to sustaining the blockchain infrastructure. They found that in growing the infrastructure, many decisions are taken to purposefully work around constraints that entrepreneurs are wrestling with such as constraints afforded in the install base.

In this paper, we propose infrastucturing it as a lens for studying electric cars as we investigate individual drivers use of charging infrastructure in public. Although there are many definitions of infrastructuring, we will use the term adopted from [34] as the effort that individual electric car drivers engage in to recover from breakdowns and make charging infrastructure work for them. The term is further useful to question individual drivers meanings and experiences around the contemporary design of charging infrastructure [34]. Because infrastructure is invisible when it works, we focus on the instances in which it becomes visible to the individual user, namely upon breakdown [37]. Breakdowns happen when the infrastructure "breaks" in such a way that it is no longer hidden from the user [37].

3 STUDY

In this section, we first unfold the case of electric car charging in Denmark. Second, we describe recruited participants, and last we describe data collection and analysis.

3.1 Electric Car Charging in Denmark

Electric cars in Denmark are still in an early stage of development and adoption. The total number of electric cars on the road in mid-2020 was 16.600, but in 2030, the Danish government aims for 1 million electric cars on the road [39]. Although much of the infrastructure is essentially the same as that for fossil-fueled cars (e.g., roads for driving and spaces for parking), charging infrastructure is emerging in many places covering many different technologies, standards, and conventions of use. It's the Governments plan to expand towards 2025 with more public chargers with more beneficial EV legislation on its way [1].

Electric cars can be charged from a standard electrical outlet using AC (alternating current) charging. AC chargers are found on all-electric car models today, although the plug standard may vary (i.e., Type 1 or Type 2 plugs). Public charging infrastructure serves those who do not have access to a charger at home and those who want to charge while on the road. To serve the current electric car fleet, at the end of 2021, approximately 2.500 publicly available chargers are operated by private companies [35]. Some subscriptions provide unlimited charging at the company's chargers for a monthly subscription fee, while others provide "pay as you charge". Roaming subscriptions for charging across company chargers are also available, but prices typically vary greatly depending on the provider (from $0.50 above $1.00 pr. kWh). Companies also usually provide applications with overviews of chargers and pricing. Chargers and plugs are not standardized. Some chargers only provide the often slower AC (Alternating Current) charging, some only offer the often faster DC (Direct Current) charging, and some provide both. AC charging provide at most 43kW of power, while DC charging (some car models do not have a DC charging option) provide at least 50kW and, in some cases, 100kW or more of power. Depending on the type of charger, plug standards (i.e., Type 1, Type 2, CHAdeMO, CCS) may also vary, which fits into the different car makes and models, which means that not all cars can use all AC charging plugs or DC charging plugs.

Chargers in Denmark are placed both along the highways near rest areas or in urban areas. In the larger cities, charging spots dedicated to electric cars have started to emerge. It is illegal for fossil-fueled cars to park in these spots, while electric cars can park there for free. However, in many cases, charging spots act as just regular parking with a charger placed next to it and with only time limit restrictions for parking.

3.2 Electric Car Drivers

We recruited study participants through a survey advertised through online forums for electric car drivers, e.g., Facebook groups for different fully electric car models (BEV's). As part of the survey, we collected demographic data about drivers and asked them if they were willing to participate in this study. Of the 204 survey answers that were asked if they were willing to participate, 16 families accepted, and 13 were subsequently selected based on diversity regarding (1) car make and models, i.e., different electric cars and/or secondary fossil-fueled car, (2) living areas, e.g., rural or metropolitan areas), (3) family composition, i.e. couples with/ without children, (4) how long they have had their car, and (5) annual driven electric kilometres.

From the 13 participating households, a total of 19 electric car drivers (10 Male, 9 Female) were interviewed, see Table 1. In six households, we interviewed two adults, and in seven households, we interviewed the primary driver of the electric car. All households had at least one electric car. The 19 interviewed drivers were between 32 and 59 years old (M=47). Ten households had children

Household	Drivers	Adults (Children)	Age of driver(s)	Car model (Years of ownership)	Annual Electric Km	Living Area
H1	D1, D2	2 (3)	42,40	Tesla S (2), Renault Fluence (5)	50.000	Rural
H2	D3, D4	2	56, 53	Nissan Leaf	9.000	Rural
H3	D5, D6	2 (2)	55,52	VW E-golf (2)	45.000	Urban
H4	D7, D8	2 (2)	52,56	Nissan Leaf (1)	45.000	Rural
H5	D9, D10	2 (2)	35, 33	Tesla S (1)	35.000	Urban
H6	D11, D12	2 (3)	34, 32	Nissan E-NV (1/2)	2.500	Rural
H7	D13	2 (3)	39	Nissan Leaf (2)	20.000	Urban
H8	D14	2	52	Nissan Leaf (2)	15.000	Urban
H9	D15	2 (2)	38	Tesla S (2), Renault Zoe (2)	44.000	Urban
H10	D16	2 (1)	57	Tesla S (1)	60.000	Rural
H11	D17	2 (3)	52	Tesla S (3)	30.000	Urban
H12	D18	2	59	VW E-golf (1)	20.000	Urban
H13	D19	2 (2)	50	Nissan Leaf (3)	20.000	Urban

Table 1: Driver overview

living at home. All households were distributed across Denmark in urban (8) or in rural areas (5) in single-family houses. Six households only had one electric car, while seven households had an electric car and a fossil-fueled car. Two households had two electric cars. All households had a home charger installed. In eleven households, the adults had full-time jobs, except H2 and H11 where both adults were retired or part-time employed. The households drove between 2.500 km and 60.000 km per year in their electric car alone. Two of the households drove less as they drove their electric car primarily in the Summer (H2) or because they had a leased electric car with a kilometre limit (H6).

3.3 Data Collection and Analysis

Each household or driver was followed on a technology tour [2] where we observed and asked questions about their electric car charging setup. We also observed charging in public by driving with them. The purpose was to explore the domain and get insights into their experiences with charging electric cars. Data were recorded in field notes and pictures during the technology tour. The data was then utilised in the following interviews in which the details of the tour were talked about and reflected on.

We conducted two rounds of qualitative interviews [21] with each household. We interviewed drivers together in the households where we interviewed both adults. Questions were based on Yins question forms of How, What, Where, and Why [43]. The questions in the interview guide for the first round were exploratory and open-ended based on: How?, What?, and Where? questions. The purpose was to explore the domain and get insights into drivers' experiences with charging electric cars. The questions for the interview guide for the second round were exploratory and open-ended, where we focused on explaining: Why? questions. We asked questions such as why they experienced specific problems when charging and why their related activities were important to them. The purpose was to reach a deeper understanding, follow up on initial findings and investigate their reasons for and explanations of their experiences. The two rounds of interviews were two months apart. All interviews were audio-recorded and subsequently transcribed.

We analysed the first round of qualitative data through content analysis [24] and two of the authors coded the data. Three overall themes emerged from the data analysis. This initial analysis directed the second round of interviews. We analysed the data from the second round through directed content analysis [12]. From this second round of analysis, we selected exemplary quotes, coded these, and related them to features of infrastructure and breakdown [38], and infrastructuring [34], e.g., navigating as an example of infrastructuring and blocked chargers as an example of breakdown. In this manner, we moved attention back and forth between the specifics and uniqueness in the interviews, the identified themes, and the theoretical concepts until analytical saturation was reached. Saturation was reached when all quotes deemed important from the analysis were clustered into either a breakdown or an infrastructuring activity. In the next section, we report on the three most reoccurring types of infrastructuring with inherent breakdowns found in our data.

4 FINDINGS

All drivers used their electric cars daily, mostly for commuting where everyday charging was done at home. They were in general satisfied with the experience of driving their electric car and used words to describe this experience such as "pleasurable", "zen inducing" and "completely silent". However, even though driving their electric car was a positive experience, all drivers also encountered breakdowns when charging. In this section, we illustrate the three most, from the data, reoccurring types of infrastructuring conducted to recover from breakdowns in the charging infrastructure for electric cars of (1) Adjusting to conventions of parking, (2) Navigating the standards of charging services, and (3) Learning through community participation.

For each type of infrastructuring, we unfold the breakdowns and recovery associated with it. We have anonymized the drivers, and we refer to them as D1-D19 (as in Table 1).

4.1 Adjusting to conventions of parking

The first type of infrastructuring our drivers conducted was adjusting to other drivers' conventions of parking. When referring to conventions, we refer to how infrastructure use is shaped by the conventions of a community of practice [38]. Prevalent breakdowns inherent to this type of infrastructuring were in urban areas where infrastructure (parking spaces) has multiple purposes and has multiple conventions for how they should be used, e.g., both for charging and parking.

Drivers reported that accessing public chargers worked well along highway exits where parking spaces were dedicated for charging. In contrast to this, urban chargers were more difficult to access because the physical space in which they were located (parking spaces) were often used for other purposes than charging, e.g., fossil-fueled cars using charging spots for parking (see left image in Figure 1). D15, who used public chargers, reported that he often found chargers occupied by fossil-fueled cars:

> *"The most frequent problem we encounter charging in public is that the parking spaces where we are supposed to charge our electric car are blocked. Often, it's ordinary cars with internal combustion engines that haven't heard that we need the space to be able to get to our destination, or maybe they just don't care"* - **D15**

D15 was frustrated, and he believed that the few chargers located in the city should be dedicated to electric cars. However, while legislation that makes it illegal to park at a charging spot has been implemented in some larger urban areas, for many rural areas, it has not. He argued that whenever a new charger was installed, it was often done without much consideration of location. For example, many chargers are placed in attractive places in front of attractions or grocery stores where other cars also find it tempting to park. As a result, the drivers needed to adjust to this situation because the occupying cars were not breaking any laws and followed the conventional way of using the parking space. Instead, D15 argued that it would be more beneficial to place chargers away from attractive parking spots or simply legislate parking. Consequently, many drivers used resources to adjust to these other ways of using the charging spots.

Some participants reported that they sometimes would wait for chargers to become unoccupied. However, we found that adjusting to parking conventions was most often done using smart-phone applications for planning alternatives. Some drivers prepared their trip in advance to entirely circumvent occupied chargers by already having alternatives at hand. Drivers were using charging provider-specific applications as a way to find alternative chargers ad-hoc when an occupied charger was encountered, for example, D2:

> *"Of course, this means that I can't charge at the place where I wanted to. But it's much quicker to look up another charger on the phone than to wait for the other driver to move, I do that a lot"* - **D2**

D2 had found that looking up a charger on a smartphone application was much faster than waiting for a potential driver to return to his car. Between interviews, D2 had found an app that allowed him to see the availability of chargers (e.g., if someone was charging there or not) and further expressed that he would target charging in rural areas where the probability of occupied chargers was low.

Another way of adjusting to the parking conventions was for some drivers to circumvent other cars occupying a charger by appropriating technology to create their solutions. These were creative and often simple solutions that could, for example, extend the reach of a single charger beyond a designated parking space. D5, who was also frustrated when he encountered an occupied charger, had created his own solution, admittedly circumventing the rules of parking, especially when running low on battery:

> *"Sometimes I park very... creatively. Sometimes on a sidewalk or bike lane, or sometimes I park behind the occupying car [...] Then I usually have a 15m charging cable with me so that I can reach the charger anyway. Of course, that means that I'm parked illegally, It's not optimal, but it works"* - **D5**

Breaking the parking rules was a risk D5 was willing to take to charge his car when needed to continue a trip. For D5, blocked chargers were a frustrating problem that he frequently encountered. To him, charging was important as his car had a small battery, and therefore it forced him to find an alternative solution. He had bought an extra-long charging cable to increase his charging range when parked as an alternative to the longer driving range provided by a more expensive car with a large battery (see for example the right image of Figure 1). However, he was not satisfied with this solution and argued that it would be more optimal if chargers were just used for charging instead of parking.

Drivers also had to deal with other electric or hybrid cars occupying chargers and not charging although plugged in. Although drivers reported these breakdowns were experienced less often, it was considered more problematic because it meant that drivers could not charge. Examples of this type of breakdown were encountered in urban areas where electric cars were plugged in but not charging with no driver nearby or where charging spots were used for conventional parking. This frustrated some drivers more than others, especially D3, who believed that electric car drivers should conform to certain charging conventions:

> *"I often find that other electric cars are parked in front of a charger while not charging. This is really something that can piss me off. It just shows how selfish people can be and there really should be a higher sense of right and wrong amongst the electrified drivers. So, if I want to continue driving I have to find another charger [..] I'm actually using an app that can do it for me, that is, point me to the nearest charger"* - **D3**

For D3, occupied chargers forced him to find alternatives and although it was a great source of frustration it was work he had to do to keep on driving using an application he had found. Between interviews, he could report on several occasions where chargers had been occupied. D16 further mentioned slow charging hybrids to be a problem too, because they occupy a charger that prevents him to continue his journey even though they can continue on fuel. However, although these drivers' conventions were seen as problematic, some of our participants had conformed to a set of

Figure 1: Left: Fossil fueled cars occupying chargers placed in front of regular parking spaces. Right: Circumventing an occupied parking space next to the charger by parking on the bike lane.

practices to help each other as a community. While finding alternative chargers through applications was also part of solving this type of breakdown we found that some drivers also actively tried contacting each other through electric car communities (e.g., Facebook or specific applications for the purpose). As an example, D7 admitted that he sometimes used a charger for parking but left in the charging plug so that the car was at least charging although he might not need the extra power and he, therefore, developed his own practice:

> *"Sometimes they have placed a phone number in the windshield so you can get a hold of them if their car is finished or nearly finished charging. I like that, it's a good charging practice. I usually do the same. I've even subscribed to an app that does the same thing and where people can contact me through if they need me to come to move the car"* - **D7**

While D7 did break with D3's suggested conventions for electric car parking, he had created a way for others to get in contact with him through the electric car community. D6 and D10 adjusted in a similar way by using discussion forums to contact drivers for example by posting an image of the occupying car. This was also seen as a way of drawing attention to the general problem of occupied chargers. Further, D1, D7, and D19 also subscribed to an online service making their home charger available as a public charging station for others. To these drivers, the community aspect of electric car drivers was important in letting others know that they needed to use the charging spots.

4.2 Navigating the standards of charging services

The second type of infrastructuring is navigating the standards of charging services. With standards of charging services, we refer to how the electric car plugs into the infrastructure in a standardized fashion [38] through different subscriptions and plug types available for charging the electric car. Navigating these charging services was important for finding the right chargers for drivers' cars with which charging plug, charging power, payment method, and geographical area. However, this navigation was also seen by many drivers as highly complex.

Breakdowns happened when trying to find the right charging service to match individual driver needs. We found that work had to be done to find the right subscriptions. Most drivers had one or more subscriptions always to have an available charger. Navigating these charging services could be difficult because of the sheer quantity of different subscriptions available. Not having a subscription for the right charger could mean a depleted battery. D7 was aware of the consequence of not having a subscription to the right charging services:

> *"In the beginning, it was really a hassle to figure out which subscription to get. Both because of price, but certainly also not to get in the situation where we are stuck somewhere without being able to charge. You have to do your homework to go for a drive without problems"* - **D7**

D7 focused on subscribing to the right service. She reported that she had become better at planning between interviews but was still unsure whenever she went somewhere new. She often did her homework beforehand but argued that the initial learning curve could be overwhelming because of the many choices. To always ensure having access to a charger, stitching together subscriptions to fit individual needs was important to drivers. Most drivers had subscribed to a charging service a home, which also provided free charging on public chargers. Some of these drivers had chosen a subscription for a company providing chargers located along the highway. Others had subscriptions for chargers located primarily in cities. Also, many drivers combined their subscriptions with an additional roaming solution to ensure access to charging. For example, D9 had experienced that the chargers he subscribed for were out of service:

> *"[...] We use a roaming solution as a backup. Although it is a much more expensive way to charge, it offers a safety net if there's a breakdown in a charger somewhere and we need to charge elsewhere on a charger we don't have a specific subscription for"* - **D9**

Roaming was seen as a backup if they were ever in a situation where they needed to charge at a different charger. Although D9 knew that roaming was more expensive when charging, the initial subscription was free and could always default to the roaming subscription as a way of ensuring an alternative if a breakdown

Figure 2: Left: Charging from a specific provider with a particular plug type and own cable. Can only be activated through chip or app. Right: Trunk filled with home-made cables for most charging situations.

occurred. Between interviews, he had used roaming two times. Once because a charger was broken, and once because there were no available chargers nearby. Further, D11 also argued that since they did not drive very far, the only thing that made sense to them was roaming to ensure access to charging whenever needed without paying a monthly subscription.

In addition to charging services, many drivers also had to navigate to find the right chargers (i.e., the ones with the correct plug for their car). This work included taking the features of the car into consideration, but also the many different ways that the individual charging providers have implemented charging at specific chargers in several ways (an example can be seen on the left image of Figure 2). Firstly, some chargers could only be activated through a chip handed out by the charging provider upon subscribing, another kind could only be activated through an application, and none could be activated with a credit card. Secondly, some needed a brought cable, and others were fitted with one. Thirdly, no real price info was found on the charger itself but required divers to conform to an app to find the information. Finally, some only had specific plugs that did not necessarily fit specific car makes and models. For example, D5's cars were only compatible with certain AC and DC plugs that only allowed for a subset of chargers. Bringing the wrong cable or driving to the wrong type of charger could result in an inability to charge:

> *"Sometimes it can be a real mess to navigate the different plug types. For example, my car can charge with both type 2 and CCS, but it's two different cables, so I drive around with one in the back of my car because sometimes you have to bring it to the charger"* – **D5**

Some drivers (D7, D11, D15, D18) had experienced that they had to take the actual power delivered by each charger into consideration. Some drivers explained that although chargers would advertise a max charging power (e.g., 11kW), this rarely coincided with reality, which influenced how long the car had to charge. Further, some chargers didn't take credit cards and others were very expensive compared to others (ranging from $0.45 up to $1). To this end, almost all drivers mentioned payment and visible price info as important reasons why planning was needed to find the right chargers. Navigating breakdowns concerned with any of the above factors was done by preparing and planning trips. For example, by bringing cables and planning a trip on available smartphone applications that could be configured to take into account charging plug type, charging power, and price.

Because many new standards are introduced into the charging infrastructure, it becomes fragmented and hard to navigate. Especially drivers who had older electric cars that did not conform to new standards often had to use charging infrastructure less suitable for them using older chargers. For example, D19 argued that he had to charge slower in public because his car could only receive a limited amount of power from most modern public chargers, which meant that it took a long time to complete a journey. Similarly, new charging standards meant that D4 was frustrated because she was limited to using only certain chargers:

> *"If they only understood that they are making life harder for many people when they roll out infrastructure. It seems that every time there's a new solution out there the companies can't wait to implement it. But they don't think of all those people that can't use all that new technology, like CCS charging"* - **D4**

Having an older electric car often meant that D4 was limited to specific chargers and explained that the type of chargers they used, were not being installed or updated anymore. Although plenty of new chargers and subscriptions have been installed and offered lately it did not fit with older models. These chargers fit new cars but they did not fit their car. As such, they were confined to charging at home and in the few places where they offered the charging type for their car. This also involved planning longer trips, especially if having to go somewhere unfamiliar. Over time, D4 had become quite good at planning these trips, but still missed the freedom of being able to drive somewhere independently of the charger and plug types.

We also found drivers tailored technology to fit how they used the chargers (D5, D6, D8, D12). These were simple solutions comprised of physical hardware. For example, D5 and D6 brought with them a number of homemade charging cables (see the right image of Figure 2) anticipating different situations of where to charge. Instead of planning their trips and the charging spots beforehand,

they relied on their own solutions so that they were always capable of charging. Between the first interview to the second, D5 had created his own way of solving his problem with charging:

> *"You know, you would think that using an app for that would be easier, but I've made all these cables myself so that I have one for every situation. It's just standard components bought at the hardware store. Combine them, and we have the most common plugs in Denmark but also when we cross the border"* - **D5**

For D5, this was a result of driving to many different places where they needed different plugs to charge and as such increasing their options for moving around. They often went to camping sites to visit friends, where an electrical outlet was offered, although not compatible with their car. Through online forum advice, he had found that various adaptors could be made relatively cheap. He had learned that the easiest way to ensure options for charging was to bring their own set of plugs with them tailored for their needs but self-made with components from the hardware store [1]. Similarly, D8 and D12 also brought with them a number of charging cables to fit various outlets that they might encounter.

Lastly, drivers also reported that they occasionally borrowed power from friends or relatives, and some had even expected to be able to do so. However, sometimes this required some tailoring as some drivers also reported that they were denied charging in other houses. For example, D3, D9, and D18 reported that they initially were denied charging at relatives and had to do convincing to do it anyway. For D9, this issue occurred because current installations did not have a way to see how much power they had used and thus were afraid that they would get an additional electricity bill:

> *"I asked my friend, whom I visit quite often, politely if I could borrow some electricity, but he told me that he wasn't fond of the idea because he was unsure how much power I used. We eventually settled on a solution where I bring a meter so he can monitor how much electricity I use"* - **D9**

Although drivers like D9 had found a solution to their problem by bringing a meter other drivers found themselves in the dilemma of not having a way of recovering. For example, D8 had been completely denied charging in his friends' households because the friend was afraid that his electrical installations would be damaged. Although D8 believed that he had the proper wiring, He had recovered from this breakdown by settling with a public charger instead and did not want to go through the hassle of convincing his friend to let him charge.

4.3 Learning through community participation

The third type of infrastructuring is learning about electric cars, breakdowns, and recovery through electric car communities' participation. With learning through community participation, we refer to how drivers become familiarized with the objects of electric car charging [38]. Participating in electric car communities enabled much of the infrastructuring work mentioned in the previous sections. All drivers said that they had participated in the community by either asking for help or giving it.

Several participants regularly asked for help on online forums. Through our interviews, we identified many reasons for seeking knowledge through online communities. Participants reported common questions such as how to report car and software problems to professionals, how to operate and find public chargers, pricing information about subscriptions and cars, how to configure the car, and how to operate associated complementary applications, so it fits better to the charging on the infrastructure. A few participants (D1, D5, D12) reported that they would often try to figure things out first, which came from an interest in technology. For example, D5 argued that he liked exploring solutions and would go through the whole manual before giving in and asking for help. However, as D12 argued, eventually, most knowledge and inspiration to how to recover from breakdowns was gained in the communities:

> *"I usually try to figure things out myself, like scrolling through the menus in the car or calling the support line, but eventually I succumb to the forums, there's always someone who knows how to fix it"* - **D12**

Like D12, all drivers mentioned that they, at some point, had drawn on the communities to prevent breakdowns at the beginning of ownership. D7 explained that online forums like Facebook were used for information retrieval. She used them to discuss breakdowns or potential breakdowns in using the charging infrastructure, such as problems with their specific car model that were not revealed upon initial purchase. D7 stated that driving electric cars is different from fossil-fueled cars, and so it takes time to learn the individual things that are often unique to the individual car model. Many drivers used the electric car community to ask for help when dealing with breakdowns to solve these problems. As examples, D17 had asked for help with problems with his home charger. D3 and D14 had asked for help for payment on public chargers. D15 had received help with one of his cars that would not charge on a public charger:

> *"When we initially acquired the car, we tried being stuck at an out-of-service charger with 1 or 2 percent left on the battery. The tech support wasn't helpful and couldn't tell me what the problem was. It turns out that the car was in an error state, and through one of the Facebook groups, we were able to get it going."* - **D15**

Because tech support could not help, he had asked the community what had worked. Interestingly, many drivers argued that they would much rather ask the community than professionals for help. For most drivers, this was perceived as a more reliable way of receiving help, much faster than professionals' official support. Also, the electric car community was seen as having more experience than professionals like mechanics, for whom electric cars were a new area. For example, D1 had asked questions about his car's onboard charger in the community and informed the mechanic, which solved his problem. As electric cars still are considered novel and a subject most professionals did not know about, the consensus amongst most drivers was that they should not be blamed if no immediate fix was found. However, although many had used professionals to, e.g., install a home charger, some drivers (D4, D7, D8, D14) also argued that whenever they talked to or used professionals,

[1] Warning! Electric car charging involves dangerous voltages and currents. We strongly advice against this practice unless one actually know what they are doing.

it was always with a sense of distrust. Similarly, D7 had multiple questionable experiences with professionals:

> *"I've tried a couple of times now that a mechanic has approved the car, and afterward, we found that it was not working. I mean, an electric car is always supposed to have a special type of circuit breaker to be charged safely. So I always check on the forums before trusting what they say and inform them if they don't follow it. Otherwise, it could lead to a dangerous situation"* - **D7**

For D7, trust was important as safe installations are governed by safety regulations that must be followed. He had experienced some situations that made him distrust professionals' help and their knowledge and thus always asked the community and gave others similar advice. In the last interviews, he reported that he had similar experiences with a mechanic who could not figure out the problem with his car. After asking the community for help, he came to a solution with his mechanic. Similar breakdowns with mechanics were also reported by other drivers (D4, D9, D11, D13), who argued that they still lacked the expertise to repair electric cars.

Besides receiving help from communities, some drivers were also contributing by sharing their knowledge and helping the community solve problems. This typically happened at a later stage when experienced drivers share their knowledge to solve less experienced drivers' breakdowns. We found different reasons for this, like, doing it to feel better by helping others out and promoting electric cars. Through experience and engagement, these drivers were active contributors to the community. D1, D3, D6, D7, D14, and D17 helped because it was important for them to open up the community to new drivers and help others. For D6, this had come as a consequence of also being helped when he was a new driver:

> *"I think it's good karma to help others, I like to think that it comes back to you in the end. It's important to invite new people in. Hopefully, it will result in more drivers and cars, and in the end, maybe more chargers or special privileges for electric cars"* - **D6**

D6 also advised other drivers because he believed that it would benefit electric car driving in the end. Some drivers mentioned contributing as a way to help improve the adoption of electric cars. Between our interviews, we found that some drivers (D6, D7, D14) had gone from solely asking questions on the forums to actually contributing to answering questions from new drivers over time. It had been a natural transition to help other drivers ensure in D14's own words "good karma" to these drivers.

We also found that helping others was a way to promote electric cars and to show how drivers with experience easily solve problems. D3 was very engaged in the community; he was passionate about electric cars and wanted people to learn about driving. He had experienced many rumors (good and bad) about the experience of electric cars. He also saw it as a way of promoting electric cars as he believed it was the future of driving:

> *"Sometimes it's just necessary to ask someone who knows about it beforehand, you know because there's so much misinformation. Then sometimes, they need to ask whether or not it is true and how it would affect them given their situation. I've often given my advice. Hopefully, that will make people more comfortable around electric cars and the exciting future we are heading towards"* - **D3**

D3 did not only want to help with advice on the forums; he wanted to help others have the experience of driving. Between interviews, D3 even requested us to go for a drive to, in his words, the pleasure of electric driving. He believed that experiencing the electric car in situ was a better way for us to learn about the workings of electric driving. He thought it was better for the people he helped on the forums better to learn things firsthand than to take advice from salespeople. He reported that people could make a more informed decision about a purchase after trying out an electric car and resolving unanswered questions.

5 DISCUSSION

We see plenty of opportunities for HCI research and design going forward. The current societal discourse on electric cars seems to discuss both making better electric cars but also making better and more available charging infrastructure. However, it seems like contemporary HCI research and design mostly focus on the cars themselves (i.e., designing better interfaces for the cars and reporting on using them) and thus, we argue that research on infrastructure can complement this existing perspective. While some of our findings can and should be addressed top-down through policy and legislation, these are often slow processes and meanwhile there are plenty of opportunities and challenges of interest to HCI research and design right now. To this end, we also see a need for reports of infrastructuring to support areas that are still early in their planning and development of EV infrastructure. Reports from actual owners and what they do can act as inspiration for what to support and perhaps what to avoid going forward. Following our observations we discuss two contributions of our work below.

5.1 Infrastructuring: By whom, why, and where?

Infrastructuring reveals that people perform infrastructuring in different ways, and it is important that designers of infrastructure understand and support these so they do not create unnecessary barriers that create breakdowns.

Not everyone might be willing to do infrastructuring while others enjoy it, which goes well with the notion of "one person's standard is in fact anothers' chaos" [38]. Our study found that some drivers are interested in learning how things work, tinkering with technology, questioning officials, and creating their own solutions. Other drivers did not want to deal with the additional complexity of creating their own solutions. This indicates two types of characteristics within electric car infrastructuring. We do not argue that the two characteristics are mutually exclusive (e.g., D7 is a good example of being a driver being both). However. that does not mean that we cannot design for it, and such considerations need to be reflected in the charging infrastructure.

In relation to the engaged and tinkering drivers, HCI studies show similar tendencies of people who like to tinker with technology and invent their own creative and playful solutions to problems in the home (e.g., [16, 17, 41]). For example, in investigating heat

consumption practices, Jensen et al. [16] describes the 'proactive' consumer as people who like to engage in their heat consumption and play around with their heat settings. As argued by Strengers [40], these consumers are often first movers and can be described as 'resource men', that is, rational users that will go an extra length to solve their problems, regardless of constraints such as individual resources. Supporting this, HCI studies of electric cars indicate that drivers create their own strategies to support driving (e.g., [41, 42]). These characteristics fit well with the results of our investigation as we add the perspective of charging in public. Our results confirm that some drivers do indeed go to the extra lengths to solve their problems i.e., inventing their own charging timers, combining different applications, or charging from a side-walk even though it is formally illegal. In contrast, we also see the drivers that need infrastructure to be ready at hand [38] and do not require them to initiate strategies to fix breakdowns. [40] argue that such users are often not in focus when it comes to the design of technology because their daily practices do often not fit well with designers' visions (e.g., for how people can act sustainable) of use. However, they probably account for the majority of users. From our perspective, a consequence is that what these users do to fix infrastructural breakdowns and why they might not like it may fade into the background because to outsiders, it seems like everything works. However, for the user, it might not work. Our study flesh out that some drivers are willing to pay to circumvent infrastructural breakdowns.

Our study indicates that much of the infrastructuring carried out when charging lies within two scales; an individual and a community scale. First, we found that individuals carried out infrastructuring to fix breakdowns. This was sometimes carried out with inspiration found through information searching, supported by communities, or tinkering with technology. Previous HCI studies have mostly looked at what can be characterized as individual infrastructuring within the home (e.g., Jensen et al. [17], Svangren et al. [42]). While we, from our findings, can confirm infrastructuring within the home we also extend the literature by illustrating that infrastructure by individuals also is initiated when charging in public. On an individual scale, digital services are used to complement the physical infrastructure while also utilizing home-built physical solutions. Second, we also found that infrastructuring was carried out in communities (e.g., online platforms and knowledge sharing apps) through both receiving and giving help. HCI research has also shown online communities to be of importance for the anticipation of electric car ownership [25, 26]. Lindgren et al. [26] found that anticipations of electric car ownership develop through the use of online discussion forums by sharing experiences with each other. We extend these studies by illustrating that "in situ" breakdowns are solved with help from online communities and suggest that drivers turn to these to complement information and solutions found elsewhere. We argue that HCI research should also focus on what happens after purchase, as these communities are important aspects of electric car driving. HCI design and research might adopt methods such as digital ethnography [33] to look towards communities (as also argued by Lindgren et al. [25, 26]) to see which opinions, experiences, and solutions drivers embargo to solve breakdowns.

5.2 Two strategies for informing research and design

Inspired by the former section, we also believe that infrastructuring can be used to inform design for infrastructure and infrastructuring. We are inspired by Zuboff [44, 45] design strategies; automate and informate.

The *automate* design strategy (e.g., removing or hiding breakdowns) relates to the everyday driver that needs infrastructure to be ready at hand, and as such, infrastructuring should be avoided. It seems that some breakdowns disappear over time, e.g., they become less visible to drivers, but that is not mean that they disappear and that they are not annoyed by the fact that they had recovered from the breakdowns they face every day because it does not match their expectations. Automating does not necessarily aim to solve the breakdowns on the technological side but could merely seek to hide them from drivers to fit their expectations [34]. We believe that designers of electric car infrastructure can find inspiration in our described infrastructuring activities and although many novel solutions are emerging we believe more can be done to support drivers. As an example, we found that most participants mentioned finding available public chargers. Although some of them had strategies for circumventing occupied chargers, they also expressed that it was frustrating to them. While legislation or many more charging spots (e.g., dedicated parking spaces to charging spots) seems to be obvious solutions to such breakdowns, we also know that such actions often can be slow. A different approach is to support the current physical infrastructure with digital solutions that support drivers in finding available chargers. Such infrastructure might take inspiration from navigation interfaces that automatically guide users to the nearest non-blocked charger without worrying about it. Similarly, charger booking systems could be created to support drivers of e.g., longer trips where time is of importance.

The *informate* design strategy (e.g., empowering drivers in their breakdown recovery) relates to the interested, engaged, and tinkering driver and has most in common with Strenger's resource man [40]. For these people, breakdown resolving or making technology work is meaningful in itself by, e.g., finding ways of acting sustainable or saving money. We argue that designers of infrastructure could facilitate such characteristics rather than limiting them by removing breakdowns. As such, we are inspired by Rogers [36] in the sense that the infrastructure could be designed 'not to do things for people but to engage them more actively in what they currently do'. To this end, for electric car drivers, a purely automated design would prevent these drivers from doing what they like and might de-skill their use of technology. One way of supporting the tinkering driver is making infrastructuring a feature of the design. Inspired by Ludwig et al. [27], we suggest that instead of aiming to fix or hide breakdowns, make the appropriation of technology a feature of the design. For example, allowing for activities such as car hackathons or tinkering days inspired by classic car communities by leaving standards and subscriptions sufficiently open allowing for transparency and appropriation in different ways. Looking into the informate design strategy is important and could be worth pursuing in future HCI research and designs for example through the support of online communities.

6 CONCLUSIONS

In this paper, we reported on the infrastructuring of 19 Danish electric car drivers based on technology tours and in-depth semi-structured interviews to unveil what they did to make charging work. Infrastructuring refers to what individual electric car drivers do to recover from breakdowns and make charging infrastructure work for them.

We report in the three reoccurring types of infrastructuring and their inherent breakdowns; First, they were *adjusting* to other drivers' conventions of parking, for example, because of fossil-fueled cars occupying charging spots. Second, they were *navigating* the standards of charging services, for example, because of the many choices of charging plugs and subscriptions available. Lastly, drivers were *learning* through electric car community participation, for example, because of limited support from professionals. These types of infrastructuring are contributions to HCI research on electric cars, which are deepening our understanding of charging infrastructure from the perspective of electric car drivers. We discuss our findings under two headings. First, we discuss how we contribute with a deeper understanding of by whom infrastructure is used, why they use it that way, and where infrastructuring occur. Second, we discuss two strategies on how to approach future research and design on electric car charging infrastructure.

Our study has some limitations. Firstly, it should be noted that we only recruited participants from online forums (e.g., Facebook), with fully electric cars (BEV's), and in single-family houses and realize that there are several other configurations that needs further investigation. Secondly, our participants can be considered early adopters of electric cars which have an influence on their activities charging their cars. Thirdly, the use of infrastructure varies across geographical locations. We realize that these circumstances influence drivers attitude towards the use of infrastructure and how they conduct infrastructuring. Considering our study and the limitations, we do not claim that our results can be generalized across wider populations or countries, although investigations covering these limitations would for certain be interesting in future work.

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