Driving on Sunshine: Aligning Electric Vehicle Charging and Household Electricity Production

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ABSTRACT

Electric vehicle seems to go well together with the growing societal trend of becoming more self-supplying with renewable electricity produced in the household. However, aligning household electricity production and electric vehicle charging have received little attention in HCI although both areas have been pursued separately for a number of years. In this paper, we present findings from a qualitative study that explore the potential of aligning electric vehicle charging with times where renewable electricity is being produced in the household. We present an empirical qualitative study of 5 households (19 persons) that own electric vehicles and also produce their own renewable electricity. Our findings, described in five themes, reveal that aligning charging and electricity production can be a challenge and tension exist for aligning consumption such as motivation, roles, mobility patterns, and electricity producing technology. We further discuss our findings and possible directions for future HCI research in the field.

Author Keywords

Electric vehicles; household electricity production; user study; sustainability

ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous;

INTRODUCTION

In the last years we have seen an increasing growth and adoption of electricity producing technologies for the home, such as wind turbines and photovoltaic panels have allowed households to become more self-supplying with energy [7]. The produced electricity can be used in several household activities like heating, lighting, washing, and cooking. Further, mobility can also be added to the set of self-supplying activities, as adoption rates of electric vehicles (EVs) that have the ability to be charged from home have increased in the last years [7]. However, producing electricity from renewable energy sources might present a challenge when trying to combine it with EVs as the supply from renewables is not constant, but rely heavily on weather conditions. Unless the electricity can be stored, it must be consumed when it is available, at the right time [28,42].

In the HCI research community, we have seen an interest in studying how to be self-supplying with electricity and how to align production with the consumption of various appliances in the household. However, aligning EV consumption with produced electricity is still a unique combination and HCI research has mostly treated them as two separate topics [7]. As such, HCI research into EVs has had a strong focus on driving related challenges, for example, range anxiety [18,33,38] and the lack of driving feedback [32,34]. In contrast, HCI research into household production has looked into how to assist appliance consumption of produced electricity. As examples, assisting electricity consumption through smart-agents [2,23] and eco-feedback [20] through lighting [25,39], art and ambience [22,47], or physical materials [9,45,59]. Much of this research suggests that consuming energy is deeply woven into household structures and requires a deeper understanding of not only technologies but also the practices of the home [30,43,44].

The technologies associated with both electricity production in the home and EVs are moving quickly forward and into our everyday lives. However, despite ongoing research, we lack studies that provide detailed understandings of how and if they can be aligned. In this paper, we extend current HCI literature with an empirical qualitative study of 5 households (19 persons) that both produce their own electricity and owns an EV. We combine in-depth semi-structured interviews and informal conversational technology tours to answer the questions of if and how EVs and home-produced electricity can be aligned and who is involved in the process. To do this we investigate household structures, practices, and the opportunities and challenges householders face in the combination of these two technologies. We present our findings in five themes revealing that aligning faces challenges by current household structures, such as motivation, roles, mobility patterns, and electricity producing technology We further discuss the opportunities and challenges in relation to our findings under four headings that provide inspiration for future HCI research and design.

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RELATED

In the next two sections, we will unfold the current HCI research. Firstly, we describe research that has focused on aligning electricity consumption and production and second, we describe research with electric vehicles and household integration.

Aligning Electricity Consumption and Production

The HCI research community has for at least a decade engaged in design challenges surrounding raising awareness of the consumption of resources as a mean to promote sustainable behaviour [4]. Different resources have been investigated such as, consumption of water (e.g., [20,37]), heat (e.g., [1,2,15,23,60]), food [62] and electricity (e.g., [8,16,24,28,29,40,48,49]). A considerable amount of this work investigates how to influence consumption through the design of eco-feedback [19] by using different means to visualise resource consumption e.g., lighting [25,39], art and ambience [22,47], or physical materials [9,45,59].

A body of research falls into a more technical category with a goal of automating energy alignment through smart agents, for example, Alan et al.'s Tariff Agent [2], Jensen et al.'s HeatDial [23], Yun et al.'s Intelligent Dashboard [61], and Alan et al.'s SmartThermo [1]. Together these studies illustrate a potential of letting an automated system assist households to align consumption. However, some of these studies also report a loss of engagement over time that potentially may undermine the sustainable benefits of the smart agent [60].

Recent research has suggested that desires to become self-sufficient with renewable electricity (e.g., through home-owned technologies like photovoltaics and wind turbines) appear to positively influence a households' engagement with their electricity consumption [8,29,41]. However, due to the varying output of these technologies (a photovoltaic panel only produces electricity when the sun shines), sustainable behaviour also becomes a matter of a household's willingness to change electricity-consuming activities in time and place to be able to *align* these activities to when renewable electricity is available [41,42]. Towards this end, a number of papers address the potential of aligning or shifting the consumption of electricity. For example, Kjeldskov et al. [28], Pierce and Paulos [41], Simm et al. [49], and Rasmussen et al. [46] investigate the potential of aligning electricity consumption and renewable production by studying the impact of forecasting various information about electricity consumption via feedback displays.

More recent research suggests that energy consumption is woven into household practices that involve complex social dynamics and expectations [53]. Changing the consumption requires a broader understanding that also involve the energy-consuming practices, we are attempting to intervene in through our designs [30,43,44]. Towards a deeper understanding of household practices, some HCI studies aim at understanding specific situations, most noticeable washing, for example, Costanza et al. [16], Bourgeois et al. [8], and Jensen et al. [24]. Findings from these studies suggest that there is a difference in the kinds of practices households are willing to change in an effort to align consumption. For example, it appears households are more willing to align consumption of practices where some tasks have already been delegated to semi-automated technology [14] such as washing (washing machines) [8,16], or heating (smart agents) [15,23] while people are less willing to align practices such as cooking [28,41,46,48].

Electric Vehicles and Household Integration

Electric vehicles (EVs) have had the attention of the HCI community for some time. A considerable amount of research on EVs has focused on the challenges related to adopting and driving them as they form a new kind of driving experience compared to the traditional car experience [12,31,32]. For EVs, there has been a strong focus on drivers worrying about the depletion of the battery, which is often referred to as range anxiety [27]. As such, this has resulted in research addressing these challenges (e.g., [26,31,32,34,54]]). As examples, Jung et al. explore impact of displayed uncertainty in instrumental estimates of range [27], while Landau focuses on creating an interface that makes up for the lack of feedback in EVs, for example, the lack of sound or vibration, or knowing when the EV is ready to drive [31]. More recently, we have also seen research focusing on the connected features of EVs and how they support daily practices [55].

A number of papers (e.g., [10,13,58]) are addressing more technical aspects of how EV charging can be merged into the household by, for example, investigating algorithms for EV energy storage during off-peak hours [10]). In contrast, there are significantly fewer HCI studies that address the merging of EVs and home-produced electricity, with an outset in household practices and if the combination is even feasible. One HCI study that has explored this unique combination is Bourgeois et al. [7]. In their study, they investigated the feasibility of self-sustaining electrical mobility and provide an understanding of how EVs are integrated into the household. They further argue that there is a need for technology to increase the visibility of produced electricity and improve and personalise how its managed.

STUDY

With an emerging societal interest of electric vehicles along with a desire of becoming more self-supplying with energy, we argue that there is a need for research on combining the two. In this paper, we address this gap and contribute to HCI research with an understanding of current household structures and practices that surround the combination of EVs and home-produced electricity. We do this by reporting from an empirical study of five Danish households with both EVs and household electricity production.

Participants

We recruited 5 households for our study. We recruited the participants through online forums for renewable energy and EV (for example, through Facebook groups). To ensure diversity, we chose the five households from the following five criteria: (i) either PVs or wind turbines, (ii) different EV models, (iii) different composition of the households (e.g. couples or with/ without children), (iv), how long they have had their EV, and (v) with and without a secondary fossil-fuelled car.

As seen in Table 1, the five households consisted of 19 persons of which 11 were adults (with a driving license) and 8 were children. Four households owned PVs. However, to present a different perspective, we also chose to include one household owning a wind turbine. Although household PVs are far more common in Denmark, an alternative is household wind turbines, that present a rather unique combination when combined with electric vehicles. Four households had children living at home and the remaining had children that had moved away from home. All households were located in Denmark in city suburbs or in rural areas. Two households were exclusively EV households (H1 and H2) while the remaining three households were hybrid households owning both an electric EV and a secondary fossil-fuelled car. Adults in all households were in permanent jobs, except (H2), were both adults had retired. All families were middle-class households, where four were living in single-family houses and one (H2) lived in an apartment during winter and in a rural residency in the summer. Household mobility needs would vary between 15.000 km pr. year (H2) to 70.000 km pr. year (H1).

The households owned either solar panels or wind turbines, thus producing their own electricity. Four households (H1, H3, H4, H5) were connected to the power grid and could, therefore, export part of their production to influence their import and consequently their electricity bill. The import price (buy from the grid) of electricity in Denmark is around $0.40. The Danish energy system consists of a number of different schemes that apply to home electricity producers that allow households to export (sell to the grid) electricity. These schemes are supported through political decisions and vary on a number of factors such as; the year equipment was acquired, type of equipment, and production capacity. Effectually, for most of our participating households, the income of exporting electricity to the power grid was one of the following three schemes; i) they export to the same price as they import from the grid which is around $0.40 pr. kWh (H1, H3), ii) they export to a reduced rate approximately 2/3 of the import price ($0.25 pr. kWh), and iii) they export to a very reduced rate of the import price ($0.1 pr. kWh) (H4). None of these households had the option of storing electricity apart from their battery on the EV. The remaining household (H2) was not connected to the grid, meaning they were not able to export their own produced electricity. Consequently, they had to use this electricity when it was available, as it would otherwise go to waste. Their produced electricity they used to charge small batteries, power small household appliances and charge their EV.

	H1	**H2**	**H3**	**H4**	**H5**
Adults (kids)	3 (2)	2	2 (2)	2 (2)	2 (2)
Years w. EV	4,5	2	1	3	2
Years w. home production	6	2	3	7	1
Number of EVs	3	1	1	1	1
Electricity source	PV	PV	PV	Wind turbine	PV
Living area	Rural	City	City	Rural	Rural
Second fossil fuelled car	No	No	Yes	Yes	Yes
Production capacity	6 kW	1 kW	4 kW	11 kW	4 kW

Table 1: Overview of participating households.

Data Collection and Analysis

Data collection was based on semi-structured interviews. We interviewed the primary users of the household's cars (the ones that had a driving license) who were between the age of 17 and 70. We conducted informal, conversational technology tours with each household before the actual interview [5]. Here we asked the participants to show us their EV(s), their charging facilities, their households electricity production. Further, we asked them to show examples of how they used these technologies and how they did not use them. The purpose of the technology tour was twofold. Firstly, we wanted the participants to speak more openly about their EV and electricity production by revealing possible tacit knowledge. Secondly, we wanted to be able to get a richer and concrete understanding of their EV and electricity producing technology. This sometimes resulted in the participants wanted us to try their EV (H1, H4), or show us how certain technologies such as apps and charging infrastructure worked. We took notes, pictures, and recorded audio during the technology tour for later analysis.

The following semi-structured interviews consisted of two parts where we first interviewed the individual household members and afterward did an interview with all household members. The first part consisted of questions related to motivation, charging their EV, electricity consumption and production, and mobility. For example, we asked them individually about motivation towards owning the EV, individual activities involved in charging, and awareness towards electricity consumption for their EV along with production from renewables. The purpose of the first part was to identify individual opinions and use, but also to highlight differences. The second part of the interviews consisted of an interview session with all adult household members. In the second part, we asked more general questions about social structures in the households and technologies used to assist them in charging. We grounded this interview in the prior individual interviews that sometimes this would result in some discussion between our participants about what opinion was the "most correct". Questions asked here were more about household activities and how they as a family ensured that the EV was charged when they needed it.

The interviews were audio-recorded. A total of ten and a half hours of audio were transcribed and coded for thematic analysis by two of the authors. The analysis was done in three steps. Firstly, we familiarised ourselves with the data by reading the transcribed interviews several times and identified suggestions for codes (e.g., “charging technology”). Secondly, we added specific codes to interview quotes (e.g., the code “tinkering” for this quote “*I find it fascinating that you can buy stuff from eBay and create new more effective stuff, so logically I’ve applied that line of thought to my home*”). Thirdly, we created themes using affinity diagramming [3], where quotes were put on a bulletin board and reorganised into themes over several iterations. From this analysis, five themes emerged.

FINDINGS

Surprisingly, we found that although all members of the participating households were aware and interested in aligning their EV consumption with their electricity production, it wasn’t reflected in their behaviour. Our findings indicate that charging the household EV relies on many different factors such as mobility patterns, charging routines and household attitudes. Towards this end, aligning household production with EV consumption indicates dynamic and complex relationships. In the following sections these relationships will be presented in 5 themes of; *Attitudes Towards Aligning, Willingness and Leveraging Convenience, Household Mobility, Charging Routines and Electricity Production,* and *Technology Assisted Charging.*

All data presented have been anonymized, and we refer to them as H1-H5 (as in Table 1). Occasionally, we refer to the number of households behind an observation, for example, (3/5) would mean three out of five households.

Attitudes Towards Aligning

During the interviews the underlying structure of the members of the households became evident. When we asked the different members about aligning EV consumption, some were very interested and were very motivated, and others had no real interest which was also reflected in their roles in the household and their attitudes.

Household Roles and Motivation

At least one member of the households was very interested in the production and consumption of electricity. This member was very empowered to optimise consumption and who knew the exact amount of produced electricity without having to resort to looking at an app. It was also this member of the household who initially had suggested an investment in the electricity producing technology of the household (Illustrated in figure 1). Further, it was this member who kept up to date with production and ensured that the production facility was always produced at an optimal level. For example, as a member of **H4** articulated: "*I simply cannot ignore that our wind turbine is not running optimal, even if it's just for half a day. Even though we won’t lose a lot of money on it it's still important to me, it was my idea to get it and I'm responsible for it running. I like it, then I get to tinker with all sorts of tech*".

Figure 1. PV installation in H3 (left) and wind turbine in H4 (right).

We found a number of reasons why these members were interested in producing energy. None of them had chosen renewables solely with a purpose of wanting to earn money or because they were technology interested. For example, **H1** articulated: "*Yeah, I don't know how to divide it, but it was probably 75-80 percent resource or environmental awareness or something like that. But then again there’s also an economic aspect. I have an expectation that it won't cost us any money, on the contrary, I think that it's a reasonable business case. And then I think it's interesting and fun*". These members with a strong interest in producing and consuming electricity seemed very motivated by the idea of aligning although they saw some difficulties, for example, **H3**: "*it's a good idea, then we can save even more. However, there are some practical issues such as production time that make it difficult*".

Although all members of our households agreed that producing their own electricity was a good thing, many members (typically persons with less interest in technology and optimising it) seemed less motivated. We found that they would often not share the same reasons for becoming producers of energy, for example, **H3**: "*I just think it's nice to earn money on our PVs, I don't really have an interest in the technology or being green*" and **H5**: "*It’s my spouse who* *does all the technical stuff with the PVs and know how much is being produced, I just think it's nice being green*".

Willingness to Align and Leveraging Convenience

To most household members aligning electricity consumption with production was perceived as an inconvenience. Although some members (usually one) of the households did seem interested and willing to align, we found that economic factors such as tariff schemes and convenience played a role.

Willingness to Align

During the interviews, we asked households about aligning the consumption of different appliances with their production. We noticed a difference in how willing some members of the household were to actually align their consumption with the household production of electricity. The difference was best exemplified between household members that were very interested in household electricity consumption and the rest of the members of the household. These individuals seemed willing to optimise their consumption and was very positive to the idea of aligning the consumption of different appliances, and some even had suggestions of how to increase how much of their own electricity the household could consume, for example, **H4**: "*I've played around with the idea of installing a new water heater that consumed our own electricity when we produce it*" and **H2**: "*Since we cannot export our electricity to the grid it makes sense to store it, so what I've done is that I have installed two batteries so that I can save it for later, we're still producing more than that, so in the future, if we could get more batteries then we could also run ordinary appliances from them like a curling iron that takes up a lot of power*".

Although the more willing members of the households seemed willing to change consumption behavior if they could remaining members were not as enthusiastic. As this annoyed the members with a higher willing we found several indications that they had tried to convince other members of the household to change behavior which was not always received positively. Members of the household with little interest in changing consumption behavior often related aligning to other everyday practices such as doing the laundry or washing dishes, that had a high priority for them, for example, **H1**: "*He has told me several times that it's time to wash the clothes or dishes because the sun shines, but I don't, because the sun doesn't decide when I'm supposed to wash*" and to **H4**: "*Sometimes if I'm about to do the laundry he tells me to look out at the turbine if it's running, but that's impractical. For me, the laundry basket always has to be empty. It's the same with the EV, if you need to drive you plug it in, you don't wait for the wind*".

Leveraging Price and Convenience

Although some members of the households found the idea of aligning interesting we found that actual behaviour towards aligning was reflected through perceived convenience and how it was judged. For the households (H1, H3) who imported electricity to the same price as they bought it, it mattered less when they charged and they had no real incentive for aligning other than ideological reasons, as **P1** articulated: "*I've thought about plugging in when the sun shines many times, I like the thought of being green, but it doesn't matter, I pay the same anyway, I think humans are like, you know, lazy*". For the household that exported at a lower price (H5) it still didn't seem to matter because they weighted convenience over the little they could save in the long run, **H5**: "*We have to charge the EV during the night, but maybe if I got home in the afternoon and there was still some hours of sun left, but then I have to remember an hour or two later to go out and stop it and then set the timer to at night. I'm not doing that, that would require too much planning. Then it's easier to just charge once. It is convenience over price and the monetary benefit is too small for me*". It was very important for the household (H4) with the very low export price to use as much of their produced electricity as possible. Consequently, the one that was technology interested used as much as he could for powering their EV along with other appliances, **H4**:

"*The more I export, the more I'm punished by myself. I will almost do anything to use the electricity I produce. I'm not supposed to earn anything, but the finances should even out*"

Household Mobility

It became evident to us that all households were active users of the EV, which meant that often it wasn't home and thus were difficult to align with their own electricity production.

Mobility Patterns

During the interviews, we found that the EV was the preferred type of transportation in the households. We identified two ride patterns; planned and ad-hoc rides. Everyday trips such as going to work had become routine and therefore required less or no planning. For household driving every day, residents knew the EV and that it could drive the distance to make the full trip, as **H3** articulated: "*I know the EV and I know that I can get from home to work on a single charge*". We also found that trips connected with going on holidays fell under the planned pattern because routes would be researched well in advance.

Although EVs take some time getting used to, all household members felt comfortable driving it for planned rides. In contrast to planned rides, we found rides with an ad-hoc nature required more planning in the form of thinking about the available range and the need for additional charging. Examples of these rides from the households included getting groceries and driving kids to and from sports or friends, as **H4** expressed:

"*When you run out of milk and have to go get it you have to think about available range because if you've just come home for work there's sometimes not enough power*".

Secondary Vehicles

While the EV was the households primary and preferred kind of transportation, some households (3/5) also owned a secondary fossil-fuelled car that served a backup purpose for ad-hoc driving. Interestingly, we found that if the household had more members there was also more ad-hoc driving and that they could report of incidents where they had to take the secondary car because the EV didn't have sufficient charge. We found that this was closely connected to the amount of planning that could be done, as **H5** articulated: "*We try to plan the day, but every now and then you just need to drive somewhere and the EV is unavailable because it's charging, for example, if my spouse drove it to work. Then we just take the secondary car*". In contrast, in the household where the adults had retired (**H2**), we found a less strict structure: "*We always know where we're driving, there are very few surprises, and if there are we'll just wait, we're not in a rush*".

The secondary cars primary function was as a mean for transportation for the person with the shortest distance to work, like **H5**: "*It's my wife that drives the EV to work because she has to drive the furthest, then I will have to suffice with the other one. However, I'm changing jobs soon, so I'll get the EV, that's how it is, it's the rule*". The secondary car also served as an extra security for some persons in the households (typically the driver with less experience driving the EV), especially on longer trips. For example, a member of **H4** explained:

"*The other car serves as a backup. I'm not as comfortable driving it as my spouse especially not on long trips if I'm driving far I'd much rather drive the diesel car rather than electricity*".

Charging routines and Electricity Production

All members of the households agreed that charging their EV was important and they all helped facilitate that the car would have available range. We found that they were motivated in doing so because many had unfortunate experiences in the past due to lack of charging. To support the availability of range in the EV, households had developed a set of charging routines. However, these routines also seemed to clash with household electricity production.

Charging Routines

One of the more regular routines that we found in all households was to always begin charging their EV when returning home after a drive. This was often connected with returning home from work late in the afternoon. The purpose of this routine was to leave the EV charging overnight where its use was very minimal. To the households with only one EV, this was a simple activity, as the rule was that the person who drove the EV plugged it in when returning home. However, in the household with several EVs (**H1**) we found that it was more difficult to schedule charging as the infrastructure of their house didn't allow multiple EVs to be plugged in at the same time (Figure 2): "*Right now it's a practicality, but we can only charge one car at a time. If we charge two the fuses will blow*".

Figure 2. H1's garage. Three EVs had to be charged in sequence and overnight.

To all households, the most preferred place to charge the EV was in the home. This enabled most households to drive to work and back again with power from their household. Because charging was often scheduled to overnight, households ensured continuous charging. However, we did find situations where charging had to be done in a more ad-hoc manner in the home. We found a greater need for mobility during the day for ad-hoc driving, although households explained that then the EV would just be charged for a brief amount of time. Such situations were often connected with the small ad-hoc trips where the EVs state of charge wasn't perceived to be enough to drive them all the way, for example, **H4**: "*Sometimes we just have to charge the EV a little during the day, especially if we go on many smaller trips, it probably has enough charge, better be safe than sorry*"

A scenario that householders often faced was charging while the EV was away from home, for example for work or holidays. In such situations, charging had to be done on public chargers. Surprisingly, we found that charging on most public chargers was disliked by all household as it would often be associated with an additional fee. As an example of this, a member of **H4** that had to charge at work every day to be able to make it home had made an agreement with a friend to charge on his power, thus avoiding the additional fees of the public chargers. Another example is **H5** that had used the power outlets of different hotels when going on vacation to avoid the fees. We also found a household that frequently used free public chargers. A member of **H3** explained that she often used charging on public free chargers on her way to and from work as an explicit strategy to always have enough charge to drive and to minimise charging at home to avoid importing too much electricity: "*We use the free public charger at least twice a week rather than charging at home, it's a strategy because the car consumes a lot of power and it's very expensive if we have to buy it*".

Electricity Production

Not surprising, the PV owning households mentioned charging on households produced electricity as a major challenge, as production from PVs during night time is minimal. The household owning a wind turbine (**H4**), didn't seem to have the same challenges, as wind occurred frequently during the night especially during the winter: "*The* *wind is usually more powerful during the night and that's great, then we can use the electricity to charge the car*". To the PV owners, not being able to use their produced power during the night, was an unfortunate consequence of solar panels which they hoped that their production during the day would make up for, however for **H1** this was an annoyance that had made him, without luck, experiment with combining PV's and wind turbines: "*The reason why I played around with a wind turbine was that it was supposed to produce during the night and then the PV's would produce during the day. That way we would always produce power, but unfortunately, it broke down*". It should be noted that all participants agreed that charging the EV using the produced electricity potentially wasn't a problem during the day on weekends when they were home and the car was plugged in.

We also found that time of the year would have a potential impact on aligning. For the households owning solar panels charging on produced electricity was perceived significantly more flexible during the summer months, with more sun hours, as mentioned by **H3**: "*It's easier during the summer because we can charge when we get home. We can't do that during winter because when we get home the sun has already set*". In contrast, the household that owned a wind turbine explained that they produced significantly less electricity during the summer months, because of lacking wind. However, this wasn't perceived as a big problem, because even though they sometimes had to import electricity during the summer months they used more electricity during winter months **H4**:

"*The wind turbine and the seasons go well hand in hand. It produces a lot of electricity during the winter when it's cold and we need the power. So, the power I produce in the winter more than makes up for the power I have to import in the summer when there's no wind*".

Technology Assisted Charging

During our technology tours, we found several indications of technology supporting EV charging. Most households (4/5) explained that charging their EV, was much easier done with the aid of technologies.

Using Existing Technology

We found two technologies which were important to our household in relation to charging their EV; feedback displays and charging timers. Feedback displays include information on charging status and remaining charging time. This feedback was accessed through an app on their smartphone or the EVs display. The importance of this feature is expressed by **H4**: "*I often use the charging feedback I get from the EV to see how much time it takes to charge the car just enough to make it to the grocery store. If I can see that it will just be 15 minutes I'll wait, and I won't have to take our secondary car*".

Charging timers, included features to time charging, for example during the night. The functionality of timing charging could in most of the households EVs be accessed through the EVs display or the app. This importance of this functionality was exemplified by **H5**:

"*I use the timer in the car to make sure it stops charging just before I leave in the morning. In an EV you really want to stop charging right before you drive as the battery will be warm and the car brakes work much better*"

One household (**H4**), however, with older children was not using the timer functionality due to mobility needs also during the night: "*I was trying to get the charger to postpone charging until just before we leave in the morning, but I gave up, because what if we had to pick up one of our children somewhere, that's just not ideal*". Feedback and timers were also used together, which seemed powerful combination to **H1**, with three EVs:

"*Typically, we plug in the Fluence when we get home, then that charges during the evening and then we start charging the Tesla when that's done, we can schedule that because it has a timer function and I can see in the display of the Fluence when it's scheduled to be fully charged*".

Improving Technology and Tinkering

We found a potential of aligning electricity production and EV charging through tinkering with technology. As there was at least one member of the household that was interested in technology all households had experimented with tinkering and modifying technologies to fit their needs and were part of their personality, for example, **H4**: "*I'm originally a technician but I've always been interested in technology, I think that's where I got it from, I need to tinker with everything*" and **H1**: "*I find it fascinating that you can buy stuff from eBay and create new and more effective stuff, so logically I've applied that line of thought to my home*". However, not surprisingly, tinkering did not meet the same enthusiasm from the rest of the household members, as exemplified by **H5**: "*I don't need to tinker with the EV, I just need it to be able to have a full charge in the morning so that I can drive to work*" and **H3**: "*I don't share the same enthusiasm for tinkering as my spouse, if the EV is able to drive, I'm happy*".

Interestingly, it was through the discussion of tinkering that we found that technology support for aligning electricity production and EV charging could be a challenge to some households, for example, as **H3** explained: "*The real challenge for me is that I can't see when I produce electricity and therefore it's hard to know when to consume it, there's simply no technical support for that, well there is, there's a web portal but that requires a username and a password, and I'm not going to go there every time*". We found that this lack of control had made some households (4/5) to make or tweak technologies. During our technology tours, we found several indications of household members tinkering with technology and creating their own solutions to their problems. We found that many of the households had installed additional electricity monitoring meters to check how much power was used for charging the EV and then later plotting the numbers into homemade spreadsheets, as **H3** explained: "*I don't trust the numbers in the car, so I have installed a second power meter on my EV charger. I plot those numbers into a homemade spreadsheet and track that the numbers match*". Further, we also found homebuilt timers to automate scheduling charging between EVs, as **H1** articulated: "*I have created my own timer that tracks power consumption and starts charging our third EV when we're not home*". Examples of the homemade technologies are illustrated in Figure 3.

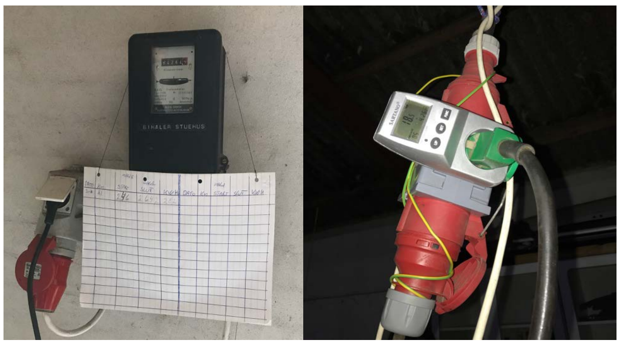

Figure 3. Examples of tinkering, additional power meter from H3 to keep track consumption (left) and homebuilt timer from H1 (right).

DISCUSSION

Our findings indicate that aligning EV consumption with electricity production in the household can seem like a difficult accomplishment for many householders. As an extension of our findings, we will in the following sections outline and discuss four topics that relate to aligning EV consumption and household electricity production.

Relying on People to Align

A tendency in our findings seems to indicate that ideology alone is not enough to overcome aligning EV consumption with household electricity production, at least when relying on them taking an initiative to align themselves. It was clear from both observations and interviews that most household members thought that it was a good idea to align EV consumption and electricity production. However, in reality, practicality and monetary reasoning were two reasons for why it was not worth going through the hassle of postponing charging, i.e., the amount money they could earn or save was not enough to make them actually align consumption and production. This tendency also has a strong link to the type of electricity export scheme the household had, which is exemplified by H4 that was on an export scheme that paid of poorly which had actually made them invest in an EV to use some of the produced electricity. Many studies in HCI also find similar results. For example, Kjeldskov et al. [28] and Jensen et al. [24] both find that it can be difficult to make people change their consumption patterns by themselves without considerable motivation such earning or saving money.

In a similar study to ours, Bourgeois et al. [7], has a related discussion and concludes that householders need increased visibility of green electricity and personalized management to make smarter decisions. Thus, another line of enquiry could also be how smart-agents can assist these households to align charging EV's and home-produced electricity by automating some of the decision making like explored in similar studies with heating [1,2,23,60]. Some of these studies also suggest that other household members with less interest in alignment and rational energy decision making may adapt these smart agents into everyday life if it is convenient and comfortable to do so [2,23].

Electricity Production and Mobility

It was clear that challenges such as the EV actually being available in the household for charging made it difficult for householders to align charging with the production of electricity from PVs. Firstly, EVs were often away from home during the day where most of the electricity was produced and secondly, the preferred charging time was at night when no electricity was produced. Using home-produced electricity from PVs during the daytime might, therefore, seem difficult and might, be utilized more efficiently on other household appliances. Similarly, Bourgeois et al. [7] find that household mobility is a challenge for consuming household-produced electricity from PVs. Our findings reveal that several households actually saw a potential to charge the EV during the few hours of production time when they came home from work, although they suggested that technology was probably needed to support it due to convenience. For PVs, it might be interesting to investigate this further to see if aligning can be done in smaller intervals.

Charging an EV was mostly done at night and according to our households takes a considerable amount of time (almost all night). Even though this might not seem like an optimal choice when considering self-supply of electricity, it potentially solves another difficult challenge in sustainable HCI which is moving consumption away from peak hours on the grid. As other research looking at household appliances points out (e.g., [40]), consuming electricity during the night might actually contribute to lowing load on the grid. In contrast to PVs, the one household with a wind turbine did not have the same problems as the wind often is stronger during the night where the car is at home. Although seasonal weather changes play a role in electricity generation it would seem like wind turbines, that could perhaps complement PVs during the night, are prime candidates for supporting EV mobility and aligning charging with electricity production. However, we argue that further investigation into how household mobility patterns can be supported better through different electricity production technologies.

Supporting the Engaged and Tinkering Householder

While many studies illustrate that eco-feedback rarely leads to changed behaviour that is sustained over a long time [43], our study shows that engagement, tinkering with technology, and ‘micro-management’ of energy become imminent for some householders when they start to produce their own energy. This finding is aligned with studies conducted by Zapico et al. [62] and Simm et al. [49] that highlights that people are more likely to use technologies, such as eco-feedback, in everyday life if they are already committed and involved themselves in sustainable issues. Hence, the participating householders that engaged themselves with using, improving and tinkering with the technology resemble Strengers’ Resource Man [51,52] - an ideal, rational energy consumer empowered by information and functional tools.

We agree with the critique that the design of eco-feedback and forecasting [20,28,36] can be limiting in instigating desired change in energy-consuming practices [11,53]. However, based on the findings in this study, we also see a potential of better our understandings of what ‘triggers’ this engagement in the Resource Man and looking for ways to better support this through our design efforts. The ‘resource men’ in our study found little assistance in the tools they had at hand. However, their engagement seemed to be carried by a burning curiosity to explore and tinker ‘first movers’ technology. Hence, this engagement resembles the bricolage [57] and maker [56] movement. We believe support for such practices is an interesting a line of enquiry for HCI researchers to engage in as it is a fairly unexplored topic in sustainable HCI.

Spatial Alignment of Consumption

An interesting observation we found while interviewing the households was that they were restricted in charging when they were not at home. They had the option of charging out, but this was disliked by many due to extra fees on electricity. From a self-sufficient perspective being away from home can indeed seem like a restriction which also is reflected in the literature. Pierce [42] talks about the term shifting consumption, as being in time and place. However, looking through the HCI literature aligning consumption in time has had a strong focus (e.g., [8,16,24,28,46,49]), however, moving consumption in place seems to have received little attention. Nonetheless, we believe that the question of aligning consumption in place becomes highly relevant in relation to mobility and charging the EV. We argue that this is indeed a challenge that will need the attention from HCI researchers and practitioners.

An observation we did during our interviews was that householders that needed to charge out sometimes borrowed electricity from others to avoid fees on public chargers. Research in HCI has for many years been interested in the sharing resources, for example in transportation, such as cars and rides (e.g., [17,35,50]). Further, many see sharing as one of the future economies (e.g., [6,21]) However, sharing could also be applied to other resources, for example, electricity. A different perspective on aligning in place could, therefore, be to enable and support sharing amongst householders with self-sufficient electricity. This could potentially enable sharing in place although it is not their own produced power. We encourage other researchers in this field to pursue this line of thought.

CONCLUSIONS

In this paper, we have presented a study of households' potential to align electric vehicle charging with electricity production. Through a mixed-methods study with interviews and informal technology tours with five Danish households, we identified five themes that describe current household structures such as motivation, routines, and technologies. Our findings reveal that although some members of the households find the concept of aligning very interesting and were motivated by it, aligning electricity production and charging is challenged by mobility patterns, charging routines and household attitudes.

To inspire further research in HCI with aligning electric vehicle charging and household produced electricity, we have discussed our findings. Drawing on current research in sustainable HCI we have discussed that even though potential exist for aligning EV consumption with produced electricity we currently see challenges such as lack of motivation for householders to align by themselves. Further, due to the mobile nature of EVs we also discuss how mobility patterns, spatiality, and individual household roles could pose a challenge for aligning We further discuss future directions for HCI research building on the discussion points mentioned above.

Our study has some limitations. Firstly, it should be noted that we only recruited one household with a wind turbine (H4). This is primarily due to the fact that this is still a rather unique combination in Denmark. Further investigation into this technology might, therefore, be interesting to pursue in further studies. Secondly, we would also like to point out that some of our households might have been early adopters of PV, Wind turbines, and EVs. We realise that this might influence how the different household members perceive and use the technologies.

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