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Using Mobile Phones to Support Sustainability: A Field Study of Residential Electricity Consumption

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ABSTRACT
Recent focus on sustainability has made consumers more aware of our joint responsibility for conserving energy resources such as electricity. However, reducing electricity use can be difficult with only a meter and a monthly or annual electricity bill. With the emergence of new power meters units, information on electricity consumption is now available digitally and wirelessly. This enables the design and deployment of a new class of persuasive systems giving consumers insight into their use of energy resources and means for reducing it. In this paper, we explore the design and use of one such system, Power Advisor, promoting electricity conservation through tailored information on a mobile phone or tablet. The use of the system in 10 households was studied over 7 weeks. Findings provide insight into peoples awareness of electricity consumption in their home and how this may be influenced through design.

Author Keywords
Sustainability; electricity consumption; households

ACM Classification Keywords
H.5.m. [Information interfaces and presentation (e.g., HCI)]: Miscellaneous;

General Terms
Design, Human Factors.

INTRODUCTION
In recent years, we have seen a significant increase in people's awareness and interest in sustainability and environmental impact of resource use [8]. Hence, we are now witnessing a strong focus on people's responsibility for, and ability to, save energy [3]. However, people are often unaware about their own, or their household's, consumption of resources such as water, gas and electricity because they are being metered out of sight, and details about patterns of consumption are not available. Research has shown that consumers mainly rely on their monthly or annual bills, which typically reports limited or irrelevant consumption information and such feedback information is insufficient for efficient energy management [2]. This prevents people from successfully reducing, for example, the amount of electricity that they use at home [2, 4]. Research has also shown that, in order to raise awareness about electricity consumption, timely feedback and guidance is required to stimulate conservation and enable users to change their behaviour in a way that decreases their power usage. For example, by providing daily feedback, consumers can potentially save between 5% and 15% of the electrical household energy consumption [2].

Emerging digital "smart" power meter units provide new opportunities for collecting and storing data about electricity consumption in households. Such units, often referred to as eco-feedback technology appliances, can provide households with detailed information about power consumption wirelessly and regularly with the goal of reducing environmental impact [6]. The development of eco-feedback appliances is based on the hypothesis that the majority of consumers are unaware of how their everyday activities impact the environment, and that better awareness about this will help preserve the environment. The growing availability of such sensing systems for environmentally related activities and interactive feedback displays provides a great opportunity for exploring new types of eco-feedback solutions [11, 14, 19, 22]. However, with the growth in eco-feedback technologies, the amount of data available to the user is also increasing, and ways of using it to make people more aware remains largely unexplored [2, 7].

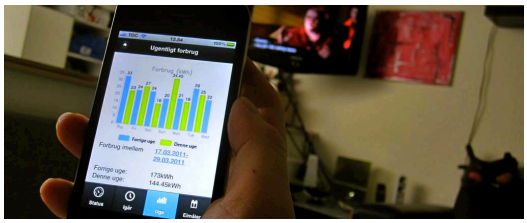

Figure 1. Power Advisor in use at home while watching TV.

In this paper we present Power Advisor and findings from a case study of electricity consumption and awareness in 10 households. Our findings provide insight into how people access and view different types of feedback on their household electricity consumption on a mobile technology and when they use such information. This insight is used to inspire ideas for designing mobile applications that can support people in understanding their own consumption, reduce it, and potentially contribute to the sustainability of our energy resources.

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RELATED WORK

Sustainability has received increased attention over the last few years in HCI research [3, 15]. Numerous studies have investigated and experimented with the use of energy consumption feedback technologies [e.g. 3, 11, 18, 22, 24]. Froehlich et al. [8] conducted a comparative survey on 133 HCI and environmental psychology papers. They identified key motivational techniques that HCI-designers should be aware of when promoting pro-environmental behaviour. In particular, they outline persuasive information as means for changing people's environmental attitudes and behaviour. Such persuasive information should be easy to understand, trusted, and presented in a way that attracts attention and is remembered [8].

Domestic interactions and energy consumption habits were investigated by Pierce et al. [15] in their study of energy consumption in 12 residential households. They developed a unique vocabulary for analyzing and designing energy-conserving interactions. This vocabulary consists of operational terms that capture actions and strategies of energy conservation, including: cutting, trimming, switching, upgrading, and shifting. They concluded that everyday interactions with home technologies are mostly performed without conscious consideration of energy consumption, stating that interactions tend to be unconscious, habitual, and irrational [15]. However, Shiraishi et al. [19] show that people tend to increase their energy consumption awareness and knowledge by simply viewing a list of advice.

Some research show that consumers need better and more frequent information in order to reduce consumption of energy. Yann et al. investigated electricity usage by looking at requirements for always-on feedback electricity in private homes [24]. They outline a three-stage approach for supporting electricity conservation routines. These stages are (i) raise awareness, (ii) inform complex changes, and (iii) maintain sustainable routines. Several of the participants in their study expressed that they would become more aware of their consumption if they could get detailed information about their past history of use – for example, one day ago or a comparison between the previous week and the current week. Weiss et al. identified a similar result where consumption history information raised awareness about the consumption patterns of electricity consumers [22].

Future technologies for consumption awareness can present information in different ways and normative information can influence people's behaviour and attitudes [18]. Schultz et al. conducted a study with 290 households over a period of 7 weeks. The households were divided into two groups who received two types of feedback messages: half of their participants received descriptive-norm-only feedback messages while the other half received descriptive-plus-injunction messages. The descriptive-norm-only message condition contained information about how much energy (kilowatt hours per day) they had used in the previous week. The descriptive-plus-injunction-messages included the same information but also injunction information. The message included a happy face (☺) if the household had consumed less energy than the average in their community, and a sad face (☹) if their consumption was above average [18]. Their findings showed that households consuming less than average (thus receiving descriptive-norm-information) actually increased their consumption, creating an unintended boomerang effect. On the other hand, by adding a happy face (injunctive), households consuming less than average continued to consume at a desirable low level.

One of the pioneers of persuasive technology B.J. Fogg has conducted several studies on computers as persuasive social actors. In his book on persuasive technology, he outlines five types of social cues: physical, psychological, language, social dynamics, and social roles [5]. He states that praise such as words, images, symbols, or sound in computing technology can lead users to be more open to persuasion. He further stresses the use of reciprocity because consumers like to reciprocate actions and favours. According to Fogg [5], using roles of authority in computing technology also enhances its power for persuasion.

To understand and motivate behavioural change, Kirman et al. explored persuasive technologies in many ways [11]. They claim that many technologies fail to take advantage of the established body of empirical research within behavioural science, for example, in the way that current persuasive technologies rely too much on positive reinforcement [5]. They highlight that existing persuasive technology products fail to take advantage of negative reinforcement such as sad faces or negative tone texts [11]. They argue that one can achieve positive changes in behaviour using negative reinforcement, and it is therefore important to make use of this to promote behaviour change.

Within motivational psychology, Helen et al. conducted an analysis synthesizing a wide range of studies to develop a motivational framework of different stages of readiness and motivation to change [9]. The Trans Theoretical Model splits behavioural change of individuals into several stages [17] and lists recommendations to motivate individuals at different stages. One way to make consumers more aware of their electricity consumption is to provide personalized feedback that acknowledges benefits and consequences of the individual's non-sustainable energy-behaviour in a neutral non-biased way. Another recommendation is to use injunctive normative messages and provide understandable feedback to consumers with already known symbols and signs. For example, one could utilize a smiley or thumbs-up sign. The third recommendation is to use personal self-set goals, which have the possibility of leading to higher performance and commitment [9].

As argued by DiSalvo et al. [3], the majority of research on sustainability target users as individual consumers, e.g. to understand them or to change their behaviour. This is a

result of the fact that many studies see people's behaviour as causing environmental problems. Foth et al. have argued for research on sustainability at the group or national levels [6]. In this paper we investigate electricity consumption, but while maintaining focus on the individual; we also perceive them as community members. Therefore, we integrate two different information sources as feedback to residential members for creating awareness of their own power usage. These are (i) information on own consumption (individual), and (ii) information on electricity usage of other consumers (community). Whilst changing behaviour and maintaining sustained behaviour is important for electricity consumption [24], it is not the primary focus of our study. Rather we aim to raise consumer awareness by providing different kinds of feedback on own consumption as related to the surrounding communities. Finally, we choose to use mobile technology (Smart phones) as platform in order to provide ubiquitous access to the consumption data.

POWER ADVISOR DESIGN

We designed a mobile application called Power Advisor to explore different kinds of information and feedback on power consumption in residential households. Inspired by previous research [e.g. 3, 18, 22], we designed Power Advisor to include descriptive and injunctive information. Descriptive information gives information about power consumption as historical data, for example, power usage during the last week, whereas injunctive information includes assessments or judgements of average consumption over a period compared to user's own goals or other consumer averages, for example, smiley's. When comparing consumption to averages of other residential households, we used data from the Danish Energy Saving Trust (both regional and national usage information), but also data from the participants in our study. When using data from the Danish Energy Saving Trust, we used calculated usage averages based on similar residential type (e.g. house, apartment), size (e.g. m^2, number of bedrooms), and home inhabitants (e.g. number of adults and children).

The Power Advisor application integrates four menu items: *My Consumption, Inbox, Enoks Guide*, and *Tip of the day*. The first two are illustrated in the following sections. The other two provide general information and advice about power consumption in private residential households in Denmark. This advice included information about lighting, household appliances, IT and home office settings, and indoor climate and originates from the Danish Energy Saving Trust [21]. The application is illustrated in [16].

Consumption Views

As suggested in existing research [5, 22], self-monitoring can lead to changed or adjusted behaviour as consumers become more aware of their own behaviour and actions. Under the menu item *My Consumption*, the Power Advisor provides self-monitoring through personalized information about the user's power consumption through four different views (three views are illustrated in figure 2).

The first view visualizes the total household power usage (measured as kilowatt hour) for the last week compared to the average consumption rate for a similar household in the northern part of Denmark (figure 2, left). The assessment shows whether their consumption is low, average, or high and the inclusion of a smiley supports the assessment – as suggested by [18]. The second view shows household consumption over the last 24 hours (with one measurement every hour). This is visualized as a graph (see figure 2, middle). The third view shows consumption per day for the last week compared to the week before (inspired by [22] and shown in figure 2, right). The fourth view (not shown in figure 2) displays the last meter reading. Thus, Power Advisor seeks to provide different kinds of information for assessing one's own power consumption.

Figure 2. Three views on power consumption namely last week (injunction), last week consumption (descriptive), and last week compared to the week before (descriptive).

Consumption Messages

Power Advisor integrates personalized information for the user through a messaging service. All messages are placed in the *Inbox* and we use three different types of persuasive messages– (i) expert advice, (ii) community behaviour, and (iii) personal consumption performance.

Figure 3. Messages in Power Advisor.

Expert advice messages give expert advice on power consumption. Based on the user's power consumption, Power Advisor compares the consumption with information from knowledge databases of the Danish Energy Saving Trust [21] and generates a message with information about whether users should change their power-consumption behaviour. We named the expert Enok (an animated Eskimo) based on a TV-advert from the Danish Energy Saving Trust aired during the same period as our study (illustrated in figure 3, left including a positive smiley).

Community messages consist of information about what other consumers are planning, or are already doing, in their residential households. This information includes whether the majority of the community achieved their goals to

reduce power consumption for the week, and how the user is doing in relation to the wider community. Personal consumption performance messages contain information about the user's own personal power consumption. The information provided in these messages is objective information about the user's consumption and is detailed, compared to the other sources mentioned above. This information is also provided to have a diversity of information in the provided messages, from using smiley's to graphs and bars.

Technical Implementation

The system was implemented as a mobile web application to avoid issues of platform compatibility. It was developed using the open-source framework jQuery Mobile, which is touch-optimized for smart phones and tablets. The system communicates with a MySQL database in real-time using PHP, in order to ensure that user actions are logged.

POWER ADVISOR DEPLOYMENT

We conducted a case study over 7 weeks with Power Advisor deployed in 10 different households for 3 of those weeks. Our aim was to study the power consumption in these residential households and to explore how users responded to the different kinds of information feedback on power consumption provided by Power Advisor.

Apparatus

We collected usage data from the participating households through a product called Automatic Meter Reader designed by the utility company "Modstrøm" (a play on the Danish word for electricity indicating an anti-establishment view). The automatic meter reader is mounted on the existing power meter in the household and takes a picture of the readout every hour. This is then submitted to Modstrøm's server and passed on to the Power Advisor application [12].

Figure 4. Modstrøm's Automatic Meter Reader mounted on the readout of an old mechanical power meter

One Automatic Meter Reader (AMR) was installed at each of the participating households, enabling us to collect power usage data automatically and unobtrusively throughout the entire study. The collected usage data from the households was used in the Power Advisor application as described in the previous section.

Household Recruitment

We recruited the participating residential households through the Modstrøm company's customer database. The requirements for participating in the study were that (i) they should have a mechanical power meter unit, (ii) at least one member of the household should have a Smartphone or Tablet PC, (iii) they should have an active customer plan with a phone company, and (iv) they should be a customer of an energy provider company.

Of the ten different households recruited, five already had an Automatic Meter Reader installed in their home and were aware of and users of Modstrøm's website to track their own power usage. The five other households had never used AMR before. Eight of the households owned their house while two households were renting houses. All households were based in the northern part of Denmark.

Most of our participants had standard household appliances, like fridges, freezers, washing machines (except for F and G), ovens, microwave ovens etc., and also a wide collection of other power-consuming devices, e.g., laptops, TVs, stereos, gaming consoles. Three households indicated high awareness of their own power consumption and 5 households indicated limited awareness. Two households expressed low or no awareness and they did not really care about their consumption.

- *Household A:* 2 parents (36 and 34 years old) and 3 children. Expressed high awareness of their consumption and used energy saving bulbs if possible.
- *Household B:* 2 adults (51 and 49 years old) and 2 children. Were only slightly aware of their power consumption and still used incandescent bulb.
- *Household C:* 2 parents (38 and 38 years old) and 1 child. Were not very aware of power consumption but mostly used A-level light bulbs.
- *Household D:* 1 adult (23 years old). Stated low (almost no) interest in saving power energy.
- *Household E:* 2 adults (45 and 50 years old). Indicated limited awareness of their own consumption, but had chosen to use only energy saving bulbs.
- *Household F:* 2 adults (25 and 28 years old). Were somewhat aware of the consumption and had a mixture of different light bulbs.
- *Household G:* 2 adults (24 and 28 years old). Stated only limited awareness of power usage and had only a few energy saving bulbs.
- *Household H:* 2 adults (37 and 37 years old). Were highly aware of their energy usage, and they used some energy saving light bulbs.
- *Household I:* 2 adults (40 and 40 years old). Were very aware of power consumption, and they used different kinds of energy saving light bulbs.
- *Household J:* 2 adults (40 and 41 years old). Indicated low interest in energy consumption and had a few different kinds of light bulbs.

The participants were requested to use Power Advisor every day to achieve a day-to-day experience with the application

and their power consumption. Furthermore they were asked during the case study to check for incoming SMS-messages on their mobile phones as well as to read and respond to the messages in the system.

Study Protocol

Over 7 weeks of study, we conducted interviews, power usage monitoring, and deployment. Our households were visited at least three times where each visit lasted between 45 minutes and 2 hours.

During the first visit, we initiated the study by installing automatic meter readers (AMR) at the five households that had no reader in advance, and we introduced and explained the study to all household members. We further conducted a semi-structured interview to profile the participants on power consumption awareness and attitudes. We did this to get a sense of their behaviour when it comes to energy consumption and saving of energy, and we wanted to introduce them to the study. We also collected household demographics about inhabitants, age, income, appliances, etc. Interviews were audio recorded for later transcription. After the first visit, we logged data about their consumption using the installed AMR over one week. This was to achieve an understanding of the different households' power consumption and usage patterns before deployment of Power Advisor.

The second visit was carried out in the third week of the study, one week before the actual deployment of Power Advisor. The purpose of this meeting was to introduce them to system. We guided them through the system and explained how the different views and messages worked. With this introduction, participants also received a small manual that described the system and a video tutorial on how to use the system to minimize use and interaction problems during the deployment. They were also told that they would receive an SMS on their mobile phone if they had unread messages in their *Inbox*. On the day before the deployment, they received an email with instructions on how to log in to the system.

During the deployment period (3 weeks), we continuously and remotely monitored the use of the system as well as logged power consumption data through the AMR. During these three weeks, each participant received nine different messages in their *Inbox*, containing information about their power usage. Each participant received exactly three persuasive messages about personal power consumption, three messages about the community, and three messages with expert advice. After ten days of deployment, we sent a message to all participants *Inbox* with information about their own power consumption for the previous two weeks. They were requested to set a goal for power consumption for the forthcoming week. After the deployment period, the participants stopped using the system.

The last visit was conducted after the three-week period of deployment. We conducted a semi-structured interview where the aim was to explore how the participants found the different information sources they received in the incoming messages and the different views of consumption and what information sources they liked and disliked. The second interview started with questions reflecting on using a mobile device as a supportive tool in household. The incoming messages were discussed one by one. We used laminated cards with a physical illustration of each message to help the participants to remember the messages. Again, the interviews were audio recorded for later transcription.

Data Analysis

We analyzed our data (primarily the transcribed interviews) using techniques from qualitative research [20]. During the transcription, we strived to identify interesting and relevant topics and themes. Hence, while in this process, whenever an interesting topic was mentioned, the direct transcription of the speech was coloured-coded and given a specific number representing the properties in open coding [20]. We identified 601 properties during this process. They were subsequently categorized into 22 different phenomena. By using axial coding [20], relations between the different phenomena were made and refined into 12 categories. These categories were then split among 3 themes. Finally, logged data on interaction with Power Advisor and logged usage data were analyzed to determine behaviour during the deployment period and to support qualitative findings from the interviews. The entire data analysis, including interview conduction, transcribing the audio recording, and using selective coding to find themes, took around 87 hours.

FINDINGS

Our findings stem from the two interviews with the households, their interaction with Power Advisor, and their consumption data for the period of use. Participants from the 10 households made a total of 347 logins in Power Advisor during the 3 weeks of deployment, thus households had on average 1.65 log-ins per day. We logged a total of 1851 interactions, the highest number per household being 299 entries (Household H) and the lowest number being 121 entries (Household C).

Mobile Usage of Power Advisor

The participants used Power Advisor in various situations and in different locations. As instructed, participants used Power Advisor during the entire deployment. However, we noticed major differences in how often they used the application, and how and when they used the application. For example, Household H accessed the second view in the menu, My Consumption (shows consumption for the last 24 hours), 35 times. Whereas, Household C only accessed this view once during the entire period of deployment and accessed any type of consumption data only 13 times: "I only used the application when I received a reminder" (C).

Eight participant households used mobile phones as their primary access to the application. They preferred to use the system on a Smartphone because of the flexibility to

receive messages on the phone and the ability to check the system on the same platform quickly and easily.

Some used the Smartphone access to the system for convenience: "It is easier to monitor the usage on the phone than going to the basement to check the power meter" (C). Most participants stated that the implemented SMS service was very useful as a prompt for starting to use the system. They liked to be notified and reminded when they had unread messages in the Inbox: "When you have an unread message, you will be notified immediately. This raises your awareness of the application, and it works pretty well" (F). For those who did not routinely check their power usage, the SMS triggering service influenced their behavior, effectively raising their awareness of their power consumption.

Quite interestingly, a few participants used the application during idle time, for example, while waiting for the bus or metro. They said that they often used mobile phones for "killing time" by playing games and that Power Advisor had some of the same characteristics as mobile games as it was both quick to use and fun. This actually led to an extension of the domestic space beyond the walls of their house where inhabitants could follow consumption while away from home (which was made possible by the system). We anticipated that people would prefer to use the application at home (and thus be able to change power consuming behaviour), but the short-sprint usage sessions with Power Advisor seemed well suited for idle time.

Two participant households mainly used Power Advisor on their iPads. They received reminders on their mobile phones and then used the application on the iPad. However, they did comment on the overhead involved in using a multi-platform setup. One iPad participant stated: "I see some advantages on using the application on a mobile phone because I would still get an SMS on my mobile. Therefore it is easier to check the application on it than to pull my iPad up for that purpose. Furthermore, it is not always I have my iPad with me, but I always keep my phone with me" (C).

Raising Awareness of Power Consumption

After the three weeks of system deployment all participants had increased their awareness of power consumption. The seven households who had little or no interest in their own power consumption found the application very useful as they suddenly achieved an understanding and awareness of their power usage: "I think the study has been very good as I had no idea on how much I used before. It was also nice to get to know which group I belong to, so I can relate my consumption to others" (D).

Participants from households A, H, and I indicated high awareness of power consumption before the deployment and they did not achieve the same benefits from the application even though they appreciated the opportunities for visualization of usage: "The fact that you can have different views on your consumption makes this application useful" (A). In fact, all participants found that the power consumption information provided the best informative illustration. They stated that the messages containing information about their own power consumption had a higher chance of persuading them to be more conscious of their own behaviour.

All ten participating households appreciated the personal and tailored information and messages in the system. This led to an increase in perceived applicability and credibility, which in turn were seen as necessary for persuasion: "It is all linked to my personal consumption and provides with an opportunity to act and react" (J). As a related point, the general advice in the application (Enoks Guide and Tip of the Day) was only used 18 times during the deployment. Two participant households (C and J) never used the advice component while three others (A, D, and E) only used the advice once. Surprisingly, almost all participants rated the general advice functionality as good value, easy to use and rather useful, even though when it came to changing behaviour and attitude, it was not particularly successful. Participants also added that other forms of general information, such as brochures or TV campaigns, should be more closely linked to users' own consumption in order to persuade them to change behaviour.

The participant households received three messages consisting only of information about their personal power consumption. The first message contained a bar showing the participant's highest consumption, their lowest consumption and the average consumption for a household of equivalent size. The participants expressed that this made them aware of their average consumption rate compared to others. The second and third messages consisted of information about their prior consumption and made the participants set up a goal for their own consumption for the forthcoming week. These messages were rated as most useful out of all messages received during the case study. As one participant enthused: "With these messages, I have become more conscious of how much we consume and then you can maybe try to work with it, if you want to bring it down" (E).

While general awareness of electricity consumption was raised during the study, it also became obvious that some participants were unfamiliar with the kWh (kilowatt/hour) unit of electricity use. This was a particular challenge for the participants in households where the initial awareness of power consumption was low. Participants from A, H, and I found it particularly difficult to perceive current and prior usage measured in kWh: "You have to know something about the unit kilowatt-hour to able to assess your consumption and to decide whether you are satisfied with your current consumption rate … kilowatt/hour is an arbitrary unit for me as I don't know how much it means money-wise" (A).

After ten days of deployment of the system, we sent participants a message containing information about the previous two weeks of power consumption. We asked the participants to set a goal for the power consumption for the forthcoming week, triggering their involvement in the process. Most participants enjoyed setting up goals for themselves as it motivated competition: "This is interesting as it made me active in the process. It forced me to reflect upon my

own consumption" (I). While discussing this goal setting, a few participants mentioned that it was very important to keep reminding them about their own goals. This ensured that they were kept aware of their goals, in order to achieve them. Some participants suggested that this goal-setting function should be an integral part of the system. Involving consumers in goal setting seems to raise awareness of consumption, as suggested by Helen et al. [9].

Power Consumption in the Community

The majority of the participants felt the information messages about how the other participants in the community were doing was very useful. Some participants expressed that they used the information about the others in the community, to compare with their own consumption. One participant noted: "Absolutely, measuring up against other people gives me some feeling about my own consumption as I need to identify whether I'm doing something wrong or right." (A)

It felt natural for some of the participants to be compared with others, and as one participant said: "We are gregarious animals in a way. We measure ourselves and consider ourselves in relation to each other all the time" (I). The majority of the participants said it was important to have information about what others were doing in order to be persuaded to consume less electricity themselves.

In reality, there were mixed feelings about the community messages. Two out of the ten households spoke against the benefit of having information about others. The appliances in the participants' households could be different and other parameters such as income, household-size and occupation, could mean that it was hard to compare against them. One participant said: "I really do not care how others are, it does not change anything for my consumption. So therefore it has no value to me to be compared with others".

While discussing the visualization of the community messages, an important issue was raised. When showing information about what and how well the community is doing compared to the participant, it was important for the information being presented to the participant to be persuasive. For example, participants felt that if the community average was a bit better than the participant's average, the percentage or number should not be displayed but instead a smiley and a coloured message. This would prevent negative reactions to marginal changes. If the community average was much better than the participant then percentage and power consumption units showing the difference would be more helpful. Even so, a common discussion point was the importance of being compared to one's own consumption all the time as opposed to being able to persuade through community messages.

Some participants (e.g. C and H) argued that comparison with others did not affect their attitudes or consumption "I don't really care about the other consumers, it does not affect my consumption. For me, there is no added value in being compared and measured against others" (H). However, one participant from household J said that it would be more interesting to have consumption information about neighbours or friends as you could compete at a different level with people you know in advance.

Finally, involving the entire household was considered vital for successful power consumption management. Several participants (A, B, and I) stated that to reduce consumption in the household, all household members had to be involved actively, which was difficult during this study.

Reinforcement and Injunctive Information

We designed Power Advisor to include descriptive-plus-injunction-messages where usage data was associated with either approval or disapproval. Most participants indicated that smileys were easy to understand and interpret. They were then asked about when it would be good to make use of smileys. One participant who received a happy smiley when being only 3% percent better than the average responded: "I would here perhaps have a tendency to rest on its laurels" (D). Another participant expressed the options faced when receiving a "bad" smiley: "Either you think that this performance was bad and you try to do something different to avoid receiving a red smiley next time, or then you are indifferent and are opposed to the message next time" (H).

Our findings align with the conclusions of Schultz et al. [18] who claim that you should consider when to use injunctive messages to promote more pro-environmental behaviour. When discussing the use of smileys, several participants raised issues on the use of positive and negative comments to promote behavioural change. Participant households A, B and D said that positive comments on behaviour acted as a motivator while participants from households E and J stated that the positive messages did not make them do anything different and they suggested a more effective positive message might be: "You are doing excellent, but you are 10% behind the best people in the group"(J).

There were mixed attitudes towards negative messages, because they did motivate some of the participants: "Then you become more motivated for improving your consumption and setup realistic goals" (F), while others argued that the negative messages were discouraging:"If there are too many negative messages, I might be thinking, this does not interest me any more – these stupid messages" (A), and, "I perceive a negative comment as a raised finger on your behaviour and it is not likely that I would read messages in the future" (H).

There are mixed potentials in using positive and negative messages. While they support the persuasive principles on using praise with words [5] and the use of negative reinforcement to promote behaviour change [11], they can cause frustration, which is potentially a pitfall when using negative verbal comments in persuasive feedback. However, Household E did suggest that negative messages could be used as a notification (alarm) if your power consumption suddenly increases significantly.

Motivating Behaviour Change and Barriers for Change

While behaviour change is fundamentally longitudinal by nature, we did identify aspects of the system that motivated

behaviour change. All participants stated that Power Advisor helped raise awareness of their own power consumption. One participant argued that continuous information and feedback made him more aware of consumption and made it easier to adjust his behaviour: "Before the study, I was already tracking my consumption through the Modstrøm website, but every now and then I would forget to check usage for several weeks … and furthermore, you really need to compare your usage with others" (F).

Several participants gave the impression that while they were happy to received information and feedback on their own consumption, they seemed less inclined to change their behaviour. Households C and E indicated that they perceived their current consumption as reasonable. Others saw barriers to changing behaviour, as they did not know exactly why they consumed more power one day compared to another day: "I was surprised to observe a difference in power consumption even when we talked about the same weekday, same people at home, etc." (G), and, "I had no idea on how to reduce power consumption (kWh) besides turning off the lights or watching less television" (G). Such lack of understanding potentially undermines the effects of introducing such a system into residential homes. For people to change behaviour, they need to understand and be aware of their different options.

Some participants reported that changing behaviour towards power consumption had to do with cultural change and thus, they required continuous support and feedback on their actions – as exemplified by this participant: "You have to keep reminding people to change behaviour. I remember when I was a child; our parents kept telling us not to let the water running while brushing teeth. We don't tell this to our children today as it is not necessary" (G). In fact, Household G felt that the advice given was tailored to their interests and motivated a change in behaviour. In the past they had tried to control power consumption by adjusting their fridge temperature. On getting the advice from the system, they again changed the temperature in the fridge and placed a glass of water with a thermometer in it to check the actual temperature. However, it was by chance that this piece of advice resonated so strongly with this household.

Changing behaviour or attitude is extremely individual and motivated by several different factors. Most participants would reduce their power consumption to gain economical benefits (Households A, D, F, and J), but other factors were also given, including reduction of pollution in the environment: "Instead of using kilowatt-hour as energy unit, one could also apply environmental units, e.g. how much your consumption affects the environment with pollution" (E).

DISCUSSION

Our aim was to study electricity consumption in residential households to achieve insights into how people view different types of feedback on their household electricity consumption and how they could use such knowledge to reduce electricity consumption. We found that people in our study gained a significant understanding of their own power consumption by interacting with our mobile solution. They especially found the different views of consumption and the prompting in the message service (with SMS) very useful as these provided multiple ways of usage visualization and triggered use of the application. Whilst we achieved insight on power consumption and people's need for feedback as one contribution for the paper, we identified a number of themes that constitute a second contribution of the paper. These are elaborated in the below sections.

Comparative Electricity Consumption

Electricity consumption is still very difficult to understand and assess for ordinary people. To understand power usage, households have to track consumption systematically and regularly to achieve awareness and it requires knowledge of "reasonable" usage, e.g. measured in recommendations or average usage in similar households. As Froehlich argues, energy consumption is abstract, invisible, and untouchable and without tangible manifestation, energy usage often goes unnoticed [8]. Back in the late 1970's, Winett et al. wrote that people are unaware of when and where electricity usage occurs in the home [23]. In 2011, we still experienced that problem. Usage varies a lot from day-to-day or week-to-week, as conditions for consumption changes over time, e.g. seasons, guests, extra laundry. Some households articulated this and they stated that they had no idea on why their usage would be very different for the same weekday having the same people at home. Additionally, the unit of electricity use (kWh) was rather poorly understood by people making it impossible for them to achieve awareness and then even more impossible to change behavior. While people increase their consumption knowledge over time, it is questionable if all people will achieve a basic level of knowledge that enables them to fully understand electricity consumption (as the study of Winett et al. [23] shows).

We found that multiple views (visualizations) of usage data could assist consumers' awareness and understanding of their own consumption. We need ways of communicating electricity consumption where comparable visualizations compliment absolute measures (e.g. last weeks usage in kWh) with other measures (e.g. previous week or other households). This potentially enables the consumer to judge own consumption as a comparable condition where the user does not have to understand if e.g. 15 kWh is a highly daily electricity consumption rate. However, they can rather see their consumption against similar households. We found that people appreciated more abstract representations of electricity consumption, e.g. an assessment of usage as low, medium, or high as compared to other households. The comparative usage visualization was found useful not only by households with limited awareness of electricity usage but also those households with high awareness.

Social Power in Consumption Communities

Sustainability and energy resource conservation literature has mainly focused on doing research where target users are seen as individual consumers rather than groups or societies

[3, 6]. DiSalvo et al. [3] state that studies tend to perceive user behaviour as causing environmental problems and therefore we need to change the individual. Petersen et al. [13] found that residents in dormitories could reduce their electricity consumption when exposed to real-time visual feedback. Interestingly, their study showed that reduction effects were achieved at not only for individuals, but also at the collective level (the entire dormitory community) where residents started to educate each other on usage to achieve lower collective consumption. Further, Haakana et al. found that a high number of households requested comparison between their own consumption and similar houses in Finland [9]. Thus, targeting users as part of communities may produce even stronger results.

Including data on community members introduces roles of social power between community members. Whilst the dormitory study displayed strong social power [13], social relations between our participants were significantly lower as they did now know each other. The lack of influence on social power was exemplified as households argued that comparison with others did not affect their attitudes or usage, although some appreciated the included community usage data. As a participant argued, it does not make you any better that other people perform really well or really poor. Thus, while usage data of other households can induce increased user awareness on consumption, user attitudes seem unchanged. Integrating information about members with a stronger social relation, like the dormitory, could potentially lead to action. One household member illustrated this by saying that it would be more interesting to include consumption data about neighbours, families, or friends, as this would provide other opportunities for action, e.g. discussing consumption in person.

Motivation, Reward, and Charity

People's motivation for reducing usage of electricity (and perhaps other energy resources) differs quite substantially. Monetary reasons were often raised as the single primary reason for becoming more aware of your consumption and hence, therefore being able to take action and reduce usage. Our study seems to confirm this observation, as several households requested new and different measures (not only kWh kilowatt-hour as used in our study), but also units like consumption as an absolute cost (local currency) or as a relative cost where you can see how much you have earned (or lost) during the previous period. Froehlich [8] also categorizes different units measures, e.g. kWh, cost, or environmental impact.

Unit measures trigger questions of reward. How can we reward people when they try to make an effort to reduce their own consumption? While saving money on the monthly bill, different reward schemes seem suitable for motivating people. E.g. people could collect member points that could be used for purchase of goods or services (like airlines' mileage reward programs). It potentially provides another tangible manifestation of usage reduction attempts.

Furthermore, a second type of motivation was uncovered in our study. Some people found it appealing to reduce their usage if their reduction could be used for donation, e.g. money to an official charity organisation or a local football club. We have recently seen similar arrangements in several Danish supermarkets where you can donate money to charity from returned deposit bottles and cans. This has been quite successful (measured in revenue). Brandon and Lewis [1] found that people with positive environmental attitudes were more likely to change their consumption during a 9-month study. Environmental attitudes played also a major role for some our households, as they would like to know how their actions could reduce pollution. Thus, some mentioned that a motivational factor could, for example, be to express power consumption as CO_2 units to illustrate the environmental impact. Summarized, people are highly individual when it comes to motivation and our work support that systems should be tailored to individual households to capture the more fine details of reward and motivation.

CONCLUSION

This paper has explored power consumption in residential households introducing the mobile application called Power Advisor that enables feedback on electricity usage. We integrated different kinds of information in the application (i) data on own consumption, and (ii) data on usage of other consumers. We studied electricity consumption and power consumption awareness in a case study over seven weeks where we conducted interviews, power usage monitoring, and deployment of Power Advisor.

Our findings suggest that households in our study gained a deeper understanding of their own power consumption by interacting with our mobile solution. They especially found the different views of consumption and the prompting in the message service (with SMS) very useful as these provided multiple ways of usage visualization and triggered use of the application. We further identified three themes. First, households found comparative usage visualizations useful as they enabled them to compare their consumption with other community members. This helped raise awareness. Secondly, the social power between community members influenced motivation of the households in terms of behavior change. Finally, the mobile nature of the system proved useful, as participants would access consumption data e.g. while away from home or while sitting in the lounge area.

While we conducted our case study over seven weeks, we profoundly need more and longer longitudinal studies to uncover motivation for change and sustained change. From our study, we see at least two avenues for future research. First, we need to investigate how such technology can support people over longer periods of time, and how people will adopt and alter such technologies. Are they primary educational tools, where people stop using them after some period of time? Or will they serve as tools that continuously

support and persuade them to change and maintain actions. Secondly, we need to explore communities and their roles in power (and energy) consumption. Making data and information accessible to community members could have an effect on consumers' attitudes towards themselves and towards others.

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