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Understanding Flexible Electricity Consumption in Domestic Households

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Abstract:

The focus of this master thesis is on empowering consumers to move their electricity consumption. We present our work in two articles.

In the first article, we present the design and implementation of FlexiViz, a flexibility-enabling eco-feedback display. The purpose of this display is to make users reflect on their electricity usage and consider the possibility of moving consumption.

In the second article, we present a study of consumers' understanding, motivation and interests towards moving electricity consumption within domestic households. We use FlexiViz as a technology probe to facilitate discussions about flexibility and moving usage on appliances.

We conclude this master thesis with proposals of how to engage users to move electricity consumption.

Resumé

The most common approach within sustainability is to conserve electricity by bringing down overall consumption. Conserving electricity is still of importance, however, it does not solve the problem of simultaneous use of electricity, which is referred to as *peak demands*. To overcome or reduce the peak demands, it is necessary for the consumers to move their electricity usage to other times of the day, where the load on infrastructure is low or there is a high availability of green energy. Moving electricity consumption and to reduce the simultaneous demand of electricity is in the literature referred to as *flexibility*.

Exploring the field of flexibility is needed as we do not yet know enough of consumers' motivation, interests and understanding of flexibility. In this project, we focus on empowering consumers to move their electricity consumption. We present our findings in two articles.

The first article presents the design and implementation of a flexibility-enabling eco-feedback display designed with the intent of showing information related to moving electricity consumption. The intention of the design is not to create a polished or commercialized system, but rather to use it to probe users. We call the system FlexiViz. The design of FlexiViz is created, so that it shows flexibility related information, which includes forecasts about the price of electricity, the availability of green energy and the load on infrastructure. Three domestic households evaluated the display for 10 weeks. Our findings indicate that some of the views were used more than others and that users preferred an overview of when to move electricity consumption. We also found that users forgot that they had postponed usage on some appliances with the intent of moving electricity consumption, because of limitations in the design. We discussed the amount of information that was needed, if FlexiViz was going to be useful as it would seem that too little information was less useful for the users. Furthermore, we argued that the design should evolve to fit user needs to be useful in the future.

The second article presents a study of users' understanding of and motivation for moving electricity consumption. We use FlexiViz, the system presented in the first article, as a technology probe to facilitate discussions about flexibility. It was deployed for 10 weeks in three domestic households. We conducted a total of 12 in-home, semi-structured interviews in iterations where parts of the system were introduced gradually. Our participants stated that it was difficult to move electricity consumption, because it required them to reflect upon and move daily interconnected routines. We discussed that to be able to move usage would require the users to acquire new routines, which required a strong motivation, which participants stated to be an economic benefit. We found that the usage of appliances used in activities which can be planned, have a greater potential for being moved. To support moving electricity consumption, we argued that consumers should have supporting technologies built into appliances. We discussed that future technologies should support automation, while enabling consumers to make an active choice to move electricity consumption.

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Contents

1 Introduction

In the last decade the amount of HCI research in the field of electricity consumption has increased. The production of electricity still depends on fossil fuels despite an increase in green energy utilization. As fossil fuels are pollutants and a limited resource, this has increased the interest in sustainability research.

Reducing Domestic Electricity Consumption

Domestic households are an especially interesting field of research due to the large share of electricity consumption taking place there. Gram-Hanssen points out that one third of the electricity consumption in Denmark takes place within domestic households [1]. In an average Danish household the electricity consumed for cooling and freezing uses in average 25 % of a households total electricity consumption, and standby appliances account for 8 % of the total usage in average [1]. As population grows and the number of electricity consuming appliances in households increases, a solution is needed to deal with the increasing amount of electricity consumed. Two different solutions come to mind to solve the problem: *Conservation* and *flexibility*.

To conserve electricity consumers need to limit the use of existing electricity consuming equipment or invest in new electricity efficient appliances. From the consumers point of view the primary motivation factor is saving money. An additional benefit of conserving energy is that it also reduces the environmental impact. To get the consumers to conserve electricity they need a certain level of awareness of their electricity consumption behaviour. From a electricity suppliers point of view, electricity conservation reduces the overall load on the infrastructure and thereby reduces CO_2 emissions. Conserving electricity is important, however, it does not enable electricity suppliers to move away from fossil fuels. Because of the increasing population and increase in the number of devices, the simultaneous use of electricity results in *peak demands* [2, 3].
Denmark has previously been self-sufficient with electricity for many years [4]. Denmark has lately been focusing on wind as a potential replacement for fossil fuels and numerous wind farms have been established to produce electricity. However, as a result of shutting down one third of the power plants, Denmark is not self-sufficient during peak demand periods, unless there is a high availability of wind energy. Previously the need for importing electricity from neighbouring countries was limited to a few weeks a year. However, lately the increased demand has resulted in electricity import every week [4].

Moving Domestic Electricity Consumption

To overcome or reduce the peak demands it is necessary for the consumers to move their electricity usage to other times of the day. Moving electricity consumption and to reduce the simultaneous demand of electricity is in the literature referred to as *flexibility* [2, 3] or *peak shaving* [3]. Flexibility is another way to address the problem towards making the consumers more sustainable, but instead of conserving electricity, users can simply move their usage to achieve a sustainable behaviour. Seen from a flexibility point of view there are three ways to achieve a more sustainable behaviour through moving consumption.

1. Move Away from Peak Demand Periods

The electricity consumers can achieve a more sustainable behaviour by moving parts of their electricity consumption away from the peak demand periods which often occurs during the morning or evening. This in turn would allow for a much more reliable distribution of electricity. The consumer should use the appliances when the load on infrastructure is low (e.g. at night).

2. Utilize Green Energy

Another way to address the problem of peak demand periods is to utilize the available green energy. This means that the consumer should move their consumption to times during the day where the availability of green energy is high. The primary green energy source in Denmark is wind energy, so consumers should be encouraged to consume electricity when the weather is windy.

3. The Most Favourable Time

The two above mentioned ways to address the problem of peak demand periods are useful, if the consumer wants to become more sustainable. However, the most favourable time to consume electricity is when both conditions are met. This means that the optimal time to use electricity is when the availability of green energy is high and the load on infrastructure is low.

Expanding Infrastructure

Because of the peak demand periods the infrastructure supplying electricity to consumers is under pressure. As the number of consumers is increasing, it is expected that the load on infrastructure will increase in the near future. A way to solve this problem is by expanding the infrastructure to manage flexibility. This transition requires massive changes in the way it is structured. Morris mentions two problems with the current infrastructure [5]. The first problem is that there always is an idle backup of electricity. Power plants are always producing more electricity than is actually needed with the purpose of being able to deal with sudden fluctuations. As a result, green energy is often ignored because the production cannot be effectively predicted, which means that a lot of energy is wasted. To solve the problem of overproduction, the amount of idle backup electricity should be reduced. Morris suggests that this can be achieved by using gas turbines as they are more responsive and have lower carbon emissions than coal power. Gas turbines can generate electricity on sudden demand, effectively reducing the need for idle backup electricity. This in return makes utilizing green energy much more feasible. The second problem is that the infrastructure is under pressure during the peak demand periods. To solve this requires the infrastructure to be expanded to cope with the increase in demand for electricity.

Hogan argues that two solutions to achieve a flexible infrastructure should be considered [6]. The first is the expensive solution where Hogan agrees with Morris that infrastructure should be expanded. This, however, is an inevitable consequence of an increasing population. The second solution is the less expensive alternative, which requires investments to ensure the development of tools to better forecast electricity demand. Through this the value of various forms of flexibility can be explored. This, Hogan argues, will allow for better predictions of the demand for electricity and thereby effectively postponing expansion of infrastructure.

Flexibility-Enabling Technologies

The problem of peak demand periods can be addressed by enabling users to move their electricity consumption to periods with limited load on infrastructure. Work in other fields have had an approach of using automated technologies to sort the peak demand problem. Such work includes the development of peak shaving algorithms to delegate and control appliances that have been developed with the purpose of supporting automated flexibility [7, 8]. This means that the users have to put a minimal effort into moving electricity consumption. For example automating the dishwasher to run where it would be favourable for either the production of green energy or the load on infrastructure. Furthermore the work focusing on automating appliances for achieving flexibility have been studied with a focus on quantitative data. The everyday life impact of the flexibility-enabling technologies has therefore remained largely unexplored. The need to explore and understand the impact of these technologies on consumers (e.g. motivation and interests) is important for electricity suppliers when generating business models [9].

Approaching Flexibility

In this project we focus on empowering consumers to move their electricity consumption. To do this we will create a system that contains flexibility related information with the intention of making users reflect on their electricity usage and consider the possibility of moving consumption. Furthermore we want to examine the consumers' understanding (e.g. motivation and interests) of moving electricity consumption. We argue that it is necessary for consumers to have a basic understanding of their electricity consumption behaviour to be able to move usage. Furthermore we argue that we do not yet have sufficient understanding of how and why users interact with flexibility-enabling technologies. We present the results of our study in two articles.

FlexiViz: A Flexibility-Enabling Eco-Feedback Display for Domestic Electricity Consumption

The first article (see page 9) describes the design and implementation of an flexibility-enabling eco-feedback display designed with the intent of showing information related to moving electricity consumption. The intention of the design is not to create a polished or commercialised system, but rather to use it to probe users. We call the system FlexiViz. The design of FlexiViz is created so that it shows flexibility related information on a series of views. This information includes forecasts about price of electricity, availability of green energy and the load on infrastructure. Early design sketches of FlexiViz can be found in the Appendix.

Towards Domestic Flexibility: Empowering Consumers to Move Electricity Consumption

The second article (see page 21) describes a study of users' understanding of and motivation for moving electricity consumption. We use FlexiViz, the system presented in the first article, as a technology probe to facilitate discussions about flexibility. During the study period 12 in-home interviews were conducted with participants. Transcriptions of the interviews can be found in the Appendix.

The work presented in this report has been conducted as part of our master thesis in Informatics at Aalborg University.

2 Project Context

The work described in this report is part of an ongoing study of flexibility. This chapter will give a brief overview of the project context and our previous work.

TotalFlex

Through this project we have been working with the TotalFlex project, which brings together a number of the leading public and private actors of Smart Grid technology in Denmark (e.g. Energinet.dk, Aalborg University and Nyfors). The project started in 2012 and ends in 2015 and is based on earlier research within the areas of Smart Grids and Home Automation.

The HCI research unit at Aalborg University, which is involved in the TotalFlex project, aims to explore the opportunities and limitations for flexible electricity consumption. As electricity consumption is highly dependent on daily routines, it is difficult to change the electricity usage behaviour of the consumers. In the future it is expected that we need to become more flexible with our electricity consumption as the production of electricity is getting more and more dependent on green energy sources (e.g. wind and solar). Through studies of electricity consumption within domestic households, the HCI research unit aim to identify and categorize consumption as flexible or non-flexible and subsequent explore the use of flexibility-enabling technologies [10].

9th Semester

On our 9th semester we aimed to raise consumers' awareness of their electricity consumption. Our previous study ran over a period of 16 weeks. This resulted in two contributions to this project. The first contribution was a system which were intended to be used as a technology probe in this project. We named that system PowerViz. The second contribution was findings towards what users preferred in a system that had the intention of increasing awareness of electricity consumption. An interesting finding from this study was that the participants preferred simple representations of their electricity consumption, as multiple participants mentioned that it offered them a fast overview of their electricity usage. It became a routine over time for participants to look at these representations. The other parts of the system, which offered more detailed information, were only used if something deviated from what was expected [11].

Based on findings from this study we will redesign and direct PowerViz towards a more flexible usage scenario. We named the new system FlexiViz. By using FlexiViz as a technology probe to facilitate discussions towards moving electricity consumption, we aim to gain knowledge about users' understanding of flexibility and their willingness to adapt to certain conditions. Both PowerViz and FlexiViz is part of an ongoing longitudinal study of flexibility. At the moment the study has run for 26 weeks. Participants in the two studies are the same.

Empowering Consumer Sustainability

The work in this report is concerned with consumers moving their electricity consumption. Riche et al. argued that a three stage approach is required to change users' consumption behaviour. The three steps are *raise awareness*, *informing complex changes* and *maintaining sustainable routines* [12]. The first step is to make consumers aware of their electricity consumption, and to obtain knowledge about when and where the consumption occurs. The second step is concerned with informing complex changes, and this requires an extra layer to the systems in the form of additional information such as context specific information. The last step focuses on maintaining sustainable routines by keeping the users interested in the continued use of the systems by make it fit into the home and evolve with the users evolving information needs [12]. In our 9. semester project we worked with awareness. In this report we are concerned with the second step, leaving the last step for further work.

3 Article Summaries

In the following two chapters we present our work in two articles. This chapter gives a brief overview of the two articles that relates to our research of flexibility.

FlexiViz: A Flexibility-Enabling Eco-Feedback Display for Domestic Electricity Consumption

In the first article we present FlexiViz, a flexibility-enabling eco-feedback display. In the last decade an increased amount of research in sustainable HCI has gone into conserving energy and systems that support it. Research in other fields has taken an more automated approach which often result in solutions that excludes human factors. The impact of flexibility-enabling technologies has therefore remained largely unexplored.

We developed FlexiViz to create a platform for researchers to study human factors in the context of flexibility. The design of Flexiviz is based on the two first steps of Riche et al.'s three stages approach of creating sustainable behaviour: Raise awareness and informing complex changes. To raise awareness we introduced electricity consumption information. To inform complex changes we introduced forecasts and flexibility related information such as electricity price, availability of green energy and the load on infrastructure. FlexiViz was implemented as a web application for an Android tablet. It fetches information from websites and a smart home metering system. The information was processed on a central server and sent to the application that displayed them.

Three domestic households evaluated the display for 10 weeks. Through this period 12 in-home, semi-structured interviews were conducted. Our findings indicate that some of the views were used more than others and that users preferred an overview of when to move electricity consumption. We also found that users forgot to move electricity consumption because of limitations in the design. We discussed the amount of information that was needed if FlexiViz was going to be useful as it would seem that too little information was less useful for users. Furthermore we argued that the design should evolve to user needs to be useful in the future.

Towards Domestic Flexibility: Empowering Consumers to Move Electricity Consumption

In the second article we presented a study of user motivation, understanding and interests towards moving electricity consumption. We used FlexiViz, a flexibility-enabling eco-feedback display showing information related to moving electricity consumption, as an technology probe for facilitating discussions about flexibility with participants. FlexiViz was deployed for 10 weeks in three domestic households. We conducted a total of 12 in-home, semi-structured interviews in iterations where parts of the system were introduced gradually. Furthermore, interaction and electricity consumption data was logged to support the interviews.

Our findings suggest that the learning curve into moving electricity consumption rather than conserving energy is steep. Our participants stated that it was difficult because it required them to move daily interconnected routines. We discussed that to be able to move electricity consumption would require the users to acquire new routines. To be able to move routines required a strong motivation, which participants stated to be an economic benefit. We argued that electricity suppliers could introduce dynamic pricing which could depend on either availability of green energy or the load on infrastructure. We found that the usage of appliances used in activities which can be planned, have a greater potential for being moved. To support moving electricity consumption consumers should have supporting technologies built into appliances. We discussed that future technologies should support automation while still enabling consumers to make an active choice to move electricity consumption.

4 FlexiViz: A Flexibility-Enabling Eco-Feedback Display for Domestic Electricity Consumption

FlexiViz: A Flexibility-Enabling Eco-Feedback Display for Domestic Electricity Consumption

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ABSTRACT
The concern for the environment has increased during the last decade. A general focus has been to reduce electricity consumption. The reduction of electricity usage is still of importance, but does not solve the problem of *peak demands*. Another way to address the problem could be for the consumer to move electricity consumption, which is referred to as *flexibility*. Flexibility in electricity usage is to move consumption to a time when availability of green energy is high or when the load on infrastructure is low. As other research has taken an automated approach, we do not yet know enough about the use of flexibility enabling systems or how willing users are to move consumption. This article describes a design for an flexibility-enabling eco-feedback display. We have intentionally created the display to facilitate discussions with users by giving flexibility related information (e.g. electricity price forecasts). The system was deployed in three households for 10 weeks.

Author Keywords
Sustainability; Electricity consumption; Eco-feedback; Flexibility; Misc.

INTRODUCTION
In the last decade there has been an increased focus on domestic electricity consumption and how to make consumers more sustainable in their energy usage behaviour. The general focus so far has been on conserving energy and minimizing the environmental impact [20]. The reduction of electricity consumption within domestic households has its limits as the population and the number of electronic devices increase. Another approach to reduce environmental impact is to utilize green energy (e.g. wind energy). However, the two major problems with green energy is that it cannot be stored for later consumption and the availability changes over time. The current consumer electricity consumption behaviour therefore needs to change to fully utilize the production of green energy.

As domestic electricity usage is usually connected to the routines of everyday life this poses a problem. These routines are often connected to activities which primarily occur during the evening where cooking, washing and other electricity consuming activities are performed [26]. This in turn results in *peak demands*, which is the result of accumulated electricity usage from simultaneous domestic activities [4, 26]. The peak demands cause two problems. Firstly, it makes it difficult to utilize the changing availability of green energy since peaks are concentrated around certain hours. Secondly, the electricity suppliers have difficulties providing electricity for the sudden demand using the existing infrastructure. Eliminating peaks requires users to move their consumption, which is referred to as *peak shaving* [26] or more commonly *flexibility* [26, 30].

The expensive solution would be to expand the infrastructure, for example replacing power cables and transformer substations [15]. The less expensive alternative would be to enable the consumers to move their usage away from peak demand periods (e.g. doing laundry during the night). When consumers are able to move their consumption away from peak demand periods and utilize the green energy available, we consider them flexible. A flexible result is achieved by meeting one of the above conditions. The most flexible result, however, is achieved when both conditions are met by utilizing green energy when the load on infrastructure is low.

A problem with domestic electricity consumption is that it is being metered out of sight, and it therefore remains invisible and intangible to consumers [6, 7, 19]. To empower user flexibility, emergent technologies are needed to visualise flexibility related information to enable users in moving electricity consumption. This could be done by showing prognoses of when the load on infrastructure is low or the availability of green energy is high. Technology is maturing and the amount of available data is increasing because of smart metering technologies. However, systems to present this data to the consumers are still largely unexplored [7]. The amount of available data presents us with the problem of how to present it to the consumers to support them in moving their electricity consumption.

This article presents the design and implementation of a system which creates a foundation for studying flexibility in the context of HCI. The system is implemented as a flexibility-enabling eco-feedback display giving information that could support users to move electricity consumption.

RELATED WORK

Flexibility lies within the field of sustainability. Within sustainability two approaches to design has been identified: *Sustainability in design* and *Sustainability through design* [21]. The former is to build technologies that are themselves more sustainable for example energy efficient devices. The latter is the design of information technologies that supports sustainability for example an application that visualizes information about electricity consumption to the consumer.

Within HCI a large amount of research has been focusing on reducing energy consumption to promote more sustainable behaviour. Flexibility in electricity consumption, however, is a relatively new field in the context of HCI. Research in other fields has taken an automated point of view by exploring technologies to automatically support flexibility (e.g. smart grids [1, 23] and peak shaving algorithms [17, 24]). The tendency has been that human factors have come in second compared to technology. The impact of these flexibility-enabling technologies on everyday life has therefore remained largely unexplored. The need to explore the impact on consumers (e.g. motivation, understanding and interests) is important when creating electricity market business models [1]. The literature that we have previously reviewed, has been focusing on electricity conservation and not on flexibility in consumption [20]. We assume that there is an overlap between flexibility and electricity conservation as changing consumption behaviour is a concern in both areas. Our starting point will therefore be within the field of electricity conservation.

Within energy conservation the term *eco-feedback* is frequently used. Froehlich et al. defines eco-feedback technology as *"technology that provides feedback on individual or group behaviours with a goal of reducing environmental impact"* [10]. A variety of technologies have been utilized to explore areas such as electricity and water consumption. These technologies can be divided into two categories: *Individual commitment* and *social commitment* [20]. The former is targeting individuals, and mobile applications are found to be the most common technology. The latter is aiming for groups or social contexts, and the most commonly used technology in this category is situated displays. Technologies found in both categories include regular PC applications, web portals and specialized hardware solutions [20].

We distinguish between two types of data visualization which are *pragmatic* and *artistic* [28]. Pragmatic visualization is designed to remove any sublimity and foster immediate understanding. An approach often used to visualize electricity consumption in a pragmatic way is using graphs that display the amount of kWh used over time [8, 9, 19, 22]. In contrast to this, the artistic visualization should keep the audience interested by showing data in an abstract way. For example by representing electricity consumption data as different colours or pictograms [9,18,19]. An example of this is displaying a coral that will change colour and condition according to electricity usage [16].

A majority of the previously reviewed literature is concerned with raising awareness by giving feedback on past events such as electricity consumption. Showing additional related information such as predictions of future electricity consumption or advice related to this is a relatively unexplored area of sustainable HCI research [20]. Presenting this information should be considered important, as adapting to availability of electricity is important when moving electricity usage. Froehlich et al. found that data granularity, time granularity and units of measurement are important when designing eco-feedback displays. Furthermore, the placement of the display is important since information must be accessible when needed [11].

Buxton indicates that when designing interactive experiences sketches can have valuable properties [2]. Since a sketch is considered disposable and part of a work in progress, users being presented with a sketch are more likely to comment on or criticize such work. Although systems are not disposable in nature like sketches, Greenberg & Buxton mention the possibility of developing systems with sketch like qualities, which can be used for identifying problems and refining current ideas [12].

DONG Energy, the Danish national energy supplier, created a system to support flexibility [26]. The system was implemented as a web portal running on mobile devices and targeting individuals. In addition to showing information about electricity consumption the web portal also presents information about electricity pricing and wind speeds, which were found to be motivational factors. The information primarily consists of prognoses so that users can see when to consume electricity.

Heberleins study of peak demand periods showed that the commitment to change electricity consumption behaviour depends on the amount of information available to the consumer about electricity related factors, such as electricity pricing [14]. In addition to this Erickson et al. found that prices and crisis engage people to concern about their electricity consumption [5]. To change behaviour, information about price should be considered.

Riche et al. mentions that former studies have often shown a change in user behaviour in the early stages, but as time passes users relapse to previous behaviour [29]. A problem related to changing behaviour is that the information in such systems does not evolve to fit users' information needs. Riche et al. proposes a three-stage approach to solve this problem and to effectively support behaviour change. The three stages are *raise awareness*, *inform complex changes* and *maintain sustainable routines*. Riche et al. argues that to raise awareness users need to obtain knowledge of their electricity consumption patterns. To inform complex changes the design needs to include three elements. To change behaviour users should be given *additional information* related to their electricity consumption. Furthermore they should be informed about the *changes they have made* and their *opportunities for further changes* [29].

FLEXIVIZ

We introduce FlexiViz, a flexibility-enabling eco-feedback display. With the system presented in this article we will shift the focus from electricity conservation to flexibility in consumption. FlexiViz visualizes information to users in domestic households with the focus on achieving sustainability through design. We introduce a new layer of flexibility related information, since the goal of traditional eco-feedback systems is to encourage energy conservation and reduce environmental impact. The display presents information related to moving electricity consumption, such as prognoses of electricity price, the availability of green energy and the load on infrastructure.

The system design is based on the first and second step in supporting behaviour change: Raise awareness and inform complex changes [29]. The system is implemented as an application for a tablet (Figure 1).

Figure 1. FlexiViz in use at home in the kitchen, next to the coffee maker.

FlexiViz consists of six views named *Price, Load, Environment, Overview, Flex Points* and *Flex Opportunities*. The users have two choices when it comes to navigating between the different views. They can either click the navigation buttons at the top of the screen, or swipe to navigate back and forth between views. If the users do not interact with the system it will automatically swipe between views to make sure all information is presented to the user.

Since the primary goal with the design is to make a foundation for further research in the field of flexibility, the visual design of FlexiViz was completed using a sketchy look. The sketchy look consists of hand-drawn line art on a slightly crumpled paper background. The intent of this approach is that it should encourage users to speak more openly about their thoughts towards the designs [2].

Each view has been designed with the primary focus of either raising awareness, providing additional information, giving feedback on changes made or providing information concerning opportunities for further changes.

Raising Awareness

The main problem with electricity consumption is that users are often unaware of when and where energy is consumed [29]. To make users more aware of their electricity consumption, systems need to provide information about their usage. The information should be detailed enough to be useful for the user. It should be emphasised that data should be realistic, so that users experience that the system reflects actual electricity consumption [3].

To raise awareness, FlexiViz present electricity consumption data fetched directly from a smart home metering system. Electricity consumption data is presented as a blue line that visualizes total household consumption, which is the lowest possible spatial granularity. Due to information complexity FlexiViz does visualize granularity at appliance-level. The views containing awareness related information are shown in figures 2 to 5.

Providing Additional Information

While raising awareness is the first step in achieving sustainability, additional context specific information is needed [29]. We introduce two types of information in FlexiViz: *Comparisons* and *prognoses*.

Comparisons. Comparison information can be divided into three types, which are the electricity price, the availability of green energy and the load on infrastructure. We integrated the first two types of comparison information into FlexiViz based on the findings from the eFlex study [26]. They found these to be motivational factors to why consumers move electricity consumption. The third type of information, the load on infrastructure, was integrated based on the assumption that users want to make a choice of moving their usage based on information about the infrastructure capacity.

Prognoses. Comparison information gives an overview that might be a motivation for moving consumption. This information, however, does not give an indication of what is going to happen in the future. FlexiViz therefore introduce the element of prognosis. Prognosis includes predictions that relates to flexibility and electricity consumption. FlexiViz includes predictions about electricity pricing, the load on infrastructure, the availability of green energy and households future electricity consumption. Due to the uncontrollable nature of these elements, we argue that users will need these predictions to be able to make a more flexible choice. We assume that to use electricity at more favourable times, user activities might need to be delayed, which require information about when to consume electricity.

Four of the previously mentioned views are very similar in design and representation of data (Price, Load, Environment and Overview). Each view contains a blue line that represents twelve hours of past consumption (solid), and twelve hours of forecast (dashed) of users expected electricity consumption. Additionally, each view contains one or more lines, each displaying one or more of the previously mentioned types of comparison information.

The lines share the same temporal space, but are not directly comparable because there are no y-axis scale (e.g. you cannot directly compare consumption to electricity price). The focus of the design is to present information in a low spatial granularity while still enabling the user to identify tendencies in consumption.

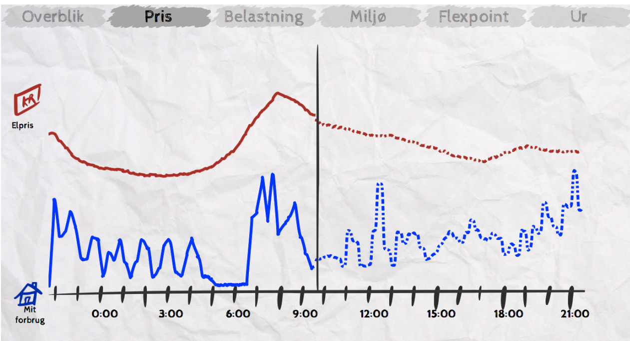

Figure 2. The Price view shows comparison between the price of electricity and consumption.

Price

The Price view (Figure 2) is designed to enable electricity consumers to compare their consumption with the price of electricity. The electricity price is represented by a red-brown line which represents the price from the past twelve hours (solid), and a prediction of the price for the next twelve hours (dashed). Electricity is expensive when the line is close to the top edge and cheap when the line is at the bottom. The price of electricity is fetched directly from the website of the leading power market in Europe, offering past and future electricity pricing.

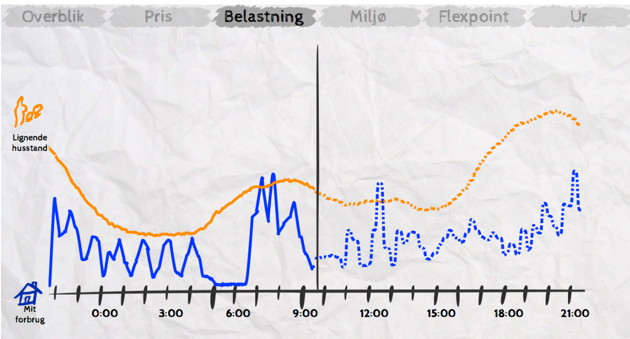

Figure 3. The Load view shows comparison between the load on infrastructure and electricity consumption.

Load

The Load view (Figure 3) is designed to give the users information about the load on infrastructure. In the view an orange line represents when the load on infrastructure is either high or low. The line represents the load in the past twelve hours (solid), and the predicted load for the next twelve hours (dashed). Data representing national consumption is available online, but as FlexiViz only depicts information related to domestic electricity consumption, it is not specific enough. The data presented is therefore based on participants' previous consumption to simulate similar households' consumption. The line is day-of-the-week based, which means that the predicted load on a Tuesday will be based on the consumption data of previous Tuesdays. This approach takes into account that electricity consumption habits vary depending on the day of the week.

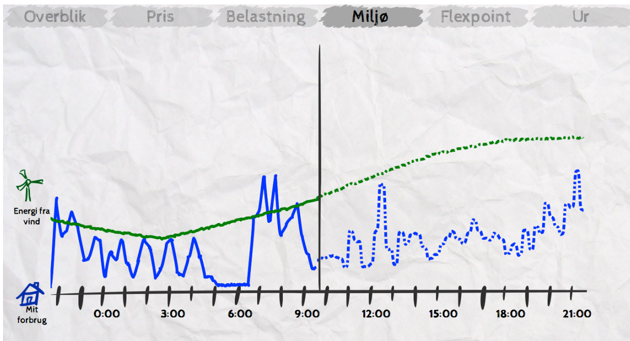

Figure 4. The environment view shows comparison between the availability of green energy and electricity consumption.

Environment

The Environment view (Figure 4) is designed to give the user information about the availability of green energy. Because wind energy is the primary source of green energy in Denmark, the view only depicts wind energy. The wind data is visualized by a green line, making the consumer able to compare it to their own electricity consumption. The line will rise and fall depending on local wind speed (m/s). The line represents the wind speed in the past twelve hours (solid), and the wind speed forecast for the next twelve hours (dashed). Local wind speed data is fetched from an online weather forecast service.

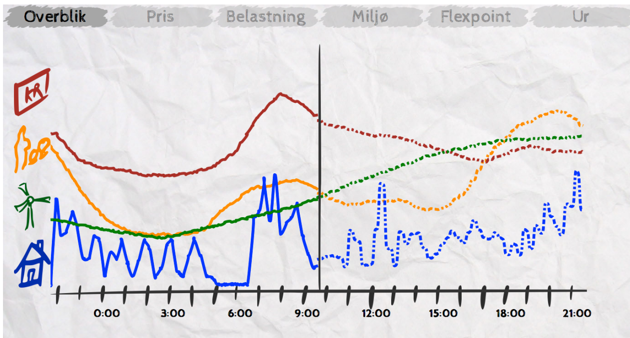

Figure 5. The Overview shows comparison between the price of electricity, the load on infrastructure, the availability of green energy and electricity consumption.

Overview

The Overview (Figure 5) is based on the same information as the three above mentioned views (Price, Load and Environment). Based on the three views there are three scenarios that state when to consume electricity: i) when the price of electricity is low, ii) when the load on infrastructure is low or iii) when the availability of green energy is high. The most favourable time to consume electricity is when all three factors are at their best, but to derive this from the individual views could be challenging. The Overview is designed to help consumers form an overall picture by joining all the information into one view. To enable the users to distinguish between the different lines, the colouring from the previously mentioned views were kept.

Giving Feedback on Changes
To enable users in moving electricity consumption, only providing additional information is not sufficient. All of the above mentioned views are intended to help the consumers becoming more flexible by giving them flexibility related information. The views do, however, not give any particular feedback on how flexible the user has been in the past. FlexiViz should give an indication of the users' progress in achieving flexibility by giving feedback on changes made.

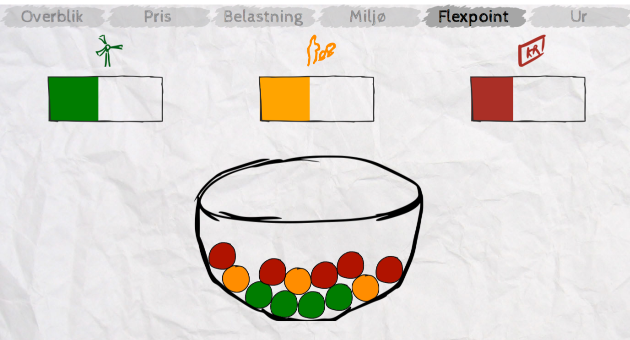

Figure 6. The Flex Points view shows an artistic representation of the consumers' flexibility status.

Flex Points
The Flex Points view (Figure 6) is designed to give the users information on how flexible they have been over a period of one week. Three types of flex points can be earned, one for each of the comparison information types. The view consists of three metering bars, each representing one of the flex point types, and a bowl containing balls. The intention of using a bowl containing balls to give the user an indication of their flexibility status, is to make the view more simple and artistic. Additionally it should provide a quick overall impression of where the user should increase their effort to become more flexible. For example if the bowl contains eight price balls, but only two environment balls, the user could strive to be more flexible in terms of consuming during times with a high availability of green energy.

Flex points are given based on user consumption compared to the price of electricity, the load on infrastructure or the availability of green energy. As points are earned the different meters will be filled. When a meter is full a coloured ball, matching the meter colour, will be added to the bowl and the meter will be emptied. The number of balls in the bowl and the meter position will indicate the consumers' flexibility status. However, there can be a maximum of ten balls of each colour at any given time. Balls will disappear one week after they have been earned. If the users consume electricity when it is favourable, this is considered flexible behaviour and they will earn points. If the users do not consume electricity when it is favourable, it is considered non-flexible behaviour. The user cannot lose points due to non-flexible behaviour.

Opportunities for Further Changes
To offer opportunities for further changes to the users, additional functionality is required. The two elements above do not provide any suggestions for further improvement of their current usage. The users should therefore be presented with information about when to use electricity in order to fulfil their goals. For example consuming when the price of electricity is low or the availability of green energy is high. The question is how detailed this information should be. If it is too detailed it could become difficult to read and thereby discourage users. If it is not detailed enough users might not get enough information and therefore cannot improve their current behaviour.

The above mentioned views are designed with the intent of helping users move electricity consumption by giving them flexibility related information, and by giving them feedback on their flexibility status. The views are, however, not intended to show any information related to opportunities for further changes.

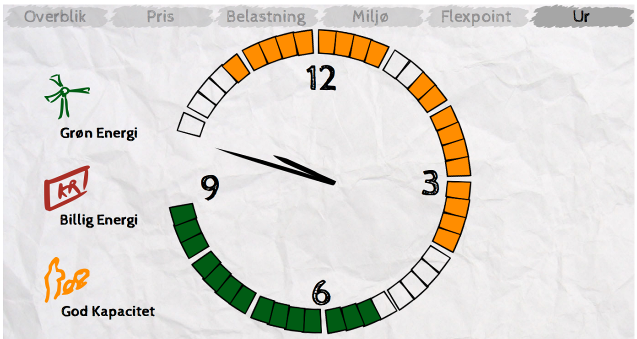

Figure 7. The Flex Opportunities view visualizes opportunities for further changes.

Flex Opportunities
The Flex Opportunities view (Figure 7) is designed to give the users a quick overview of when to consume electricity to become more flexible. The view represents data based on the price of electricity, the load on infrastructure and the availability of green energy.

The information from the Flex Opportunities view should be seen as a recommendation for when it would be favourable to consume electricity. The clock is divided into 15 minute time blocks to match the temporal granularity of the electricity consumption data. Each time block on the clock can be coloured to represent one of the three types of data. There are four colours to be aware of, which include red-brown (the electricity price), orange (the load on infrastructure), green (the availability of green energy) and white (not favourable). The colouring indicates boundaries for when it will be favourable to use electricity for example the wind speed has to reach a certain level to appear on the clock. To keep the design simple a time block can only have one colour. The colour shown on the clock indicates whether electricity consumption would be most favourable in relation to the price of electricity, the load on infrastructure or the availability of green energy. If the white colour is displayed it is not considered favourable to consume electricity at the specified point in time.

In addition the view also functions as an ordinary clock showing hours and minutes. The last hour is not displayed to avoid confusion about whether a time block indicates current or present opportunities. The clock representation was based on an assumption that the users would pass by and look at it more frequently if it resembles a common household item.

SYSTEM IMPLEMENTATION

The implementation of FlexiViz was split into two major components. It consists of a display application that the user interacts with and a backbone server that manages data from different sources (Figure 8). It is the responsibility of the display application to present information to the user and report information about the users interaction with the system. It is the responsibility of the backbone server to acquire data from different external data sources and retrieve participants' electricity consumption data.

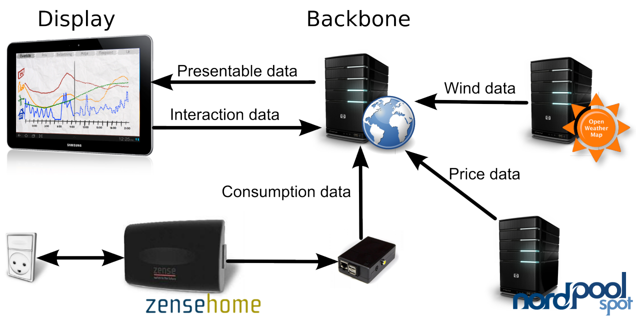

Figure 8. FlexiViz system layout.

The Display Application

The display application consists of two parts: A web application and an Android application. The web application has the responsibility of presenting data to the users, while the Android application encapsulates the web application and shows it on the tablet. The FlexiViz display application also supports user interaction logging. All user interactions are logged and sent to the backbone server.

The web application was developed using traditional web technologies such as HTML and CSS, but for structuring the application code TypeScript was chosen instead of regular JavaScript. FlexiViz was developed as a web application due to the iterative nature of the system design, and it would therefore be possible to roll out revisions to the users without manually updating the application on the actual devices. The application installed on the Android tablet includes special functionality for ensuring always-on behaviour, making the application turn on the screen and launch itself if the screen is turned off by the user.

The sketchy style presented in the design was implemented using a mix of hand-drawn graphics and dynamically calculated lines using a custom made sketchy look technique. Hand-drawn elements on screen are to some extend randomized in their position and scale, with the purpose of making them look non-uniform and organic.

The Backbone

To supply the display application with information, a backbone for handling information was implemented. This consists of a main component and a set of sub components. The main component of the backbone is a web server that retrieves and handles data from the sub components. The server also prepares data for, as well as storing interaction log data from, the display application. Each sub component is responsible for acquiring data from the electricity consumption, price or weather data sources.

To obtain electricity consumption data the backbone relies on the ZenseHome system, which is capable of collecting detailed consumption data in near real-time [31]. To retrieve data a Raspberry Pi is directly connected to the ZenseHome control box. The ZenseHome control box does not offer the retrieval of consumption data other than the current load on each connected outlet. The connected Raspberry Pi therefore needs to retrieve data from outlets every two seconds, using the control box as an interface. Since the ZenseHome system is not originally designed for retrieving electricity consumption data so rapidly, techniques for avoiding data collisions were a major focus during the implementation of the system. After data is acquired it is sent to the backbone web server, which then accumulates values and stores historical consumption data in 15 minute intervals.

Weather data used for making green energy forecasts is retrieved from the Open Weather Map weather service [27]. The data is fetched every 10 minutes. Local forecast data is available in three hour intervals, but is linearly interpolated when presented on the information display to match the 15 minute time granularity of the consumption data. Furthermore, weather data is limited to the 0 to 14 meters per second range, as modern wind turbines have peak output at winds of 14 meters per second [13].

Price data is obtained from Nord Pool Spot [25], the leading power market in Europe. Electricity pricing is negotiated at least 12 hours in advance, allowing FlexiViz to display the actual future price. All price data is fetched from the Nord Pool Spot website every 10 minutes using web scraping techniques, where HTML-documents are parsed to retrieve detailed information.

The data used for presenting the load on infrastructure is based on participants' own electricity consumption history. Past consumption data is averaged and treated using a moving average smoothing algorithm to make it appear as being a real average user trend line.

DISPLAY EVALUATION

FlexiViz was developed and evaluated iteratively. Before deployment, two focus groups were used to give feedback on design ideas. FlexiViz was later deployed in three households for a period of 10 weeks. Because of the iterative nature of the development process the system views were introduced to the participants in four steps. First the Price, Load and Environment views were introduced, followed by the Overview two weeks later. Four weeks into the study period the Flex Points view was introduced followed by the Flex Opportunities view two weeks later. After introducing a new view, a semi-structured interview was conducted. A total of 12 semi-structured interviews were conducted.

FINDINGS

During the evaluation period FlexiViz logged 357 interactions with an overweight on one household (287). In the following section we report findings based on the semi-structured interviews and interaction log data.

Information Capacity

FlexiViz consists of a set of views with different information capacity. Three of the views (Price, Load and Environment) were designed to be as simple as possible. As more of the participants stated, they would rarely use those views because they could not get an overview of all the information at once. This resulted in the creation of the Overview design. This view should help the user interconnect the various information and enable them to get an overview or understanding of when to consume. Participants stated that the Overview quickly became the most used view in FlexiViz, because this would help them in planning their electricity consuming activities.

Four of the views (Price, Load, Environment and Overview) were built with the purpose of making data granularity low. However, participants mentioned that this resulted in lines that were difficult to read due to a missing scale. The original thought of removing the y-axis was to let the consumers focus on tendencies rather than a one-to-one comparison.

During the study several participants expressed that the only motivational factor was the price of electricity. They would rarely look at the Environment and the Load views. Users stated that this was because the price had a more significant influence on their everyday lives.

Visualization of Data

Through the views of FlexiViz the same information has been visualized with different designs. The households overall electricity consumption was visualized as a blue line in several of the designs. Our participants mentioned that visualizing the overall electricity consumption was not sufficient to move consumption. To be able to do this, they would like more detailed information (e.g. showing consumption categorized as activities).

Participants reported that the different representations of data resulted in confusion from time to time. The four designs, Price, Load, Environment and Overview, generally looks the same as they all use the same pragmatic design to visualize data. The Flex Points view has a different and more artistic design. Each time the user receives points for moving electricity consumption the bar at the top of the view will increase. Despite the colours that were used were consistent throughout the system, this more artistic representation made it difficult for participants to relate it to the other views. This meant that participants weren't able to connect flex points with historical data. Furthermore, participants could not see the direct connection between the bars and the balls. They thought that the total amount of flex points was indicated by the bar and not the number of balls in the bowl.

We found that the representation and amount of data necessary, depended on specific use scenarios. Most of the time participants used the display as a peripheral device. In this scenario, participants stated that they would like to have visualizations that could help them perceive information more easily. In some cases, however, participants wanted more detailed information. This would often be when they interacted with the system. In this scenario, they requested more detailed information such as more specific data, such as the actual price of electricity.

Moving Consumption

The aim with the Flex Opportunities view was to integrate FlexiViz more into the home, by using a clock representation. However, some participants stated that the primary functionality, visualizing opportunities for further change, became secondary within the view. For example, one of the households stated that they would only look at the clock to see what the time was and therefore didn't notice the intended information. Another household mentioned that they planned to move the usage of their dishwasher, based on the information. However, they forgot to start it late on, because FlexiViz did not remind them.

Everyday Problems using FlexiViz

FlexiViz requests electricity consumption data every two seconds from the ZenseHome control box. As several participants mentioned this resulted in two problems. The first problem was that it would cause issues with the ZenseHome system (e.g. make the light flicker). The second problem was that the Raspberry Pi that was connected to the ZenseHome control box would fail to send data, which made data unavailable to FlexiViz application. However, these problems were eventually identified and corrected.

DISCUSSION

FlexiViz was designed to act as a foundation for researchers to explore flexibility in electricity consumption and human factors related to this. We do, however, have some considerations concerning the design.

Representing Data

The users stated that they used the Overview more frequently than the other views. When planning to move electricity consumption it would seem that an overview is preferred, because users have difficulties interconnecting information from the Price, Load and Environment views.

The Price and Load views indicate that the user should consume when the lines are close to the bottom, whereas the Environment line indicates that the user should consume when the line is close to the top. This might have confused the participants. They might not have been able to derive the most favourable time to move their electricity consumption. We argue that this could be solved, simply by inverting the Environment line, so that it will be near the top-edge when its unfavourable, and at the bottom when its favourable.

FlexiViz awarded flex points to users when they used electricity when one of the three types of comparison information was favourable. We do, however, see a potential problem as flex points could also be given, if the users consume electricity as they are used to and actually do not move any consumption. It can be discussed if using electricity as regularly should be rewarded. We could imagine that it would serve as a discouraging factor if users are already moving electricity consumption, but not gaining any flex points. We argue that the way of giving flex points can be changed if needed, to reward users only if they use outside their regular electricity consumption pattern.

The Flex Opportunities view presents information of when the consumers should use electricity if they want to become more flexible and earn flex points. Each of the 15 minute time blocks within the clock design can only contain one colour at a time. This choice was made to simplify when it would be favourable to consume. To avoid confusing the consumers only the most significant factor was presented to them. The Flex Opportunities view therefore only shows a single colour in each time block. The simple design, however, might have been a problem. If a user for example cares for the environment and there is green energy available, but the time blocks are coloured according to price, it might be irrelevant for the users to consume electricity based on the information given from the system. This could hinder a flexible choice and it should therefore be considered whether or not to make the Flex Opportunities view show more information. For example by showing multiple colours in each time block).

Data Granularity

The views, Price, Load, Environment and Overview, are aimed at giving the user an understanding of how electricity consumption could be related to other conditions that might have an influence on their electricity usage either now or in the future. Furthermore, FlexiViz is aimed at making the user reflect on their usage by showing them overall electricity consumption. This should give them the choice of moving some of their consumption to other times of the day, where it would be more favourable. Our participants mentioned that such information was not sufficient to decide when to move electricity consumption. It could be argued, whether it is even possible for the consumers to move consumption, when they only get information about the households overall usage. It could be questioned if they would know which appliances that consume where and when, to sufficiently move electricity usage. If users should be able to move the usage of specific appliances (e.g. the washing machine), then information on appliance-level might be helpful.

During the evaluation we identified two different usage scenarios for FlexiViz: Peripheral and non-peripheral. Our participants expressed that depending on the scenario the amount of information needed would vary. If the display was used as a peripheral device, the information should be simple and easy to read. If users were using the system actively the information should be more detailed. FlexiViz was not designed to give detailed information such as appliance-level electricity consumption data. We argue that if FlexiViz is to be used in its current state, it could be used as a peripheral device. If FlexiViz was to be used as a non-peripheral device, we recommend adding more detailed information (e.g. on activity or appliance-level).

Price as Motivation

FlexiViz visualizes data related to the price of electricity, the load on infrastructure and the availability of green energy. However, previous research within the field of energy conservation shows that price is the primary motivational factor. The environment is often referred to as the secondary motivational factor. The participants confirmed this by saying that they were most concerned with the price. This poses a problem as price of electricity does not have any influence on peak demand periods, because pricing is currently fixed.

It could be discussed how to use the price to directly influence peak demand periods. We argue that it could be achieved by making the price depend on either the load on infrastructure or the availability of green energy. Such initiatives could motivate the users to achieve a reduction on their electricity bill and allow them to move their electricity consumption away from peak demand periods. This would also allow FlexiViz to become more simple as some of the information presumably could have been left out.

Maintaining Sustainable Routines

A question remains of how to incorporate Riche et al.'s third and last stage, maintain sustainable routines [29]. The functionality of FlexiViz is based on the first and second stage. Riche et al. states that in order for the consumers to change behaviour, they need to become aware of their electricity consumption behaviour and be given additional information, feedback on the changes they have made and opportunities for further changes. It can be discussed what changes should be made or which functionality should be applied to FlexiViz if we should go to the next stage. This step mentions the need for long-term studies that should run for three months or more [29]. But to provide long-term feedback the system needs to evolve to fit the home environment and its users. It should especially evolve to fit the consumers information needs. One of the participating households mentioned that they forgot to turn on the dishwasher, even though they had planned to move consumption. It seems like that there is a need for systems that can support their intentions. We argue, that this need could be addressed in FlexiViz by giving notifications that remind users of when to turn on appliances.

Technical Improvements

A central challenge when developing FlexiViz was the retrieval of electricity consumption data from the ZenseHome control box. As the control box does not offer historical consumption data directly retrievable, the Raspberry Pi computer connected to the box had to request the ZenseHome system for data every two seconds. This resulted in stability issues which meant that the system either blocked user accessibility to the ZenseHome system or made consumption data unavailable. As the ZenseHome system saves data internally the request frequency could be reduced to every 15 minutes, which would increase stability considerably. In the future this should be taken care of by requestion the box less frequently, but this will require a change to the current ZenseHome API.

Technology Probing

FlexiViz is designed to support flexibility related research within HCI. We see the system as a technology probe that would support the retrieval of more context specific information in later interviews. The choice of a sketchy look would also support this scenario.

We see two distinct uses for FlexiViz. Firstly, the system could become part of a design implication study. The system would then allow researchers to gain insights into how flexibility-enabling eco-feedback systems could be designed. Secondly, the system could support researchers in revealing context specific flexibility related information about consumer motivation and understanding of moving electricity consumption. Findings from such studies could be used by electricity suppliers to develop more efficient technologies targeting consumers.

CONCLUSIONS

This paper presented the design of a flexibility-enabling eco-feedback display with the purpose of creating a foundation for other researchers to explore flexibility and to study human factors. We named this display FlexiViz.

The concern for the environment has increased in the last decade. Much effort has gone into conserving energy with the goal of to reducing CO_2 emissions. The reduction of electricity usage is still of importance, but does not solve the problem of *peak demands*. Another way to address the problem could be for the consumer to move electricity consumption, which is referred to as *flexibility*.

To achieve flexibility, the consumer should consume, when i) the load on the infrastructure is low or ii) there is a high availability of green energy. Moving electricity consumption solves two problems. The first problem is the load on infrastructure, which is under pressure in *peak demand periods* when simultaneous consumption occurs. The second problem is that green energy by nature is not always available and is therefore difficult to utilize.

We designed FlexiViz based on Riche et al.'s first and second stage of behaviour change: *Raise awareness* and *inform complex changes*. To raise awareness we visualized households overall electricity consumption on the display. To inform complex changes we visualized electricity price, the load on infrastructure and the availability of green energy. To make users able to derive when to move their consumption, we also added the element of predictions, such as the price of electricity for the next 12 hours. Furthermore we added the elements of flex points and flex opportunities, to let users know how flexible they have been and when they should consume to become more flexible.

FlexiViz was implemented as a web application for an Android tablet. We retrieve information from websites and smart home metering technology. The information is processed on a central server and sent to the application that displays them. We discussed how much information was needed if FlexiViz was going to be useful. Too much information and the system could become too complex, too little information and it could become less useful.

We argued that the information in FlexiViz should reflect the usage scenario. Used as a peripheral device the information visualization should be simple and easy to read. In contrast, used as a non-peripheral device, the information should be more detailed. We also discussed how price could be used to move electricity consumption even though it is not directly related to peak demand periods. The design of FlexiViz was based on Riche et al.'s first and second stage. We discussed how the last stage of maintaining sustainable routines could be implemented. Here we argued, based on Riche et al., that the system should evolve over time and it should evolve to user information needs.

FURTHER WORK

This article presented a design for a system that shows flexibility related information. While creating such a system can be a goal in itself, we also want to study the concept of flexibility in a user context. We propose that FlexiViz could be used to investigate consumers' understanding and motivation to move electricity consumption. Furthermore, FlexiViz could be used as a technology probe to facilitate discussions and the gathering of quantitative data.

The separation of views in the design could be used to gradually introduce new information as a part of the research method. This would allow for a more qualitative in depth approach to the various display information using interviews. FlexiViz also supports the gathering of quantitative data such as interaction logs and electricity consumption data.

We see data collected from such a study valuable in the understanding of how consumption can be moved and which factors impact this decision. Furthermore, electricity suppliers could benefit from knowing such details, so they can focus their effort.

REFERENCES

1. Analyses, E. E. *Intelligent energy systems. A white paper with Danish perspectives*. Ea, 2010.

2. Buxton, B. *Sketching User Experiences: Getting the Design Right and the Right Design*. Morgan Kaufmann Publishers Inc., San Francisco, CA, USA, 2007.

3. Costanza, E., Fischer, J. E., Colley, J. A., Rodden, T., Ramchurn, S. D., and Jennings, N. R. Doing the laundry with agents: A field trial of a future smart energy system in the home. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ACM (2014), 813–822.

4. Department of Energy and Climate Change. Demand Side Response in the domestic sector - a literature review of major trails, 2012.

5. Erickson, T., Li, M., Kim, Y., Deshpande, A., Sahu, S., Chao, T., Sukaviriya, P., and Naphade, M. The dubuque electricity portal: Evaluation of a city-scale residential electricity consumption feedback system. In *Proc. of the SIGCHI Conference on Human Factors in Computing Systems*, ACM (2013), 1203–1212.

6. Fischer, C. Feedback on household electricity consumption: a tool for saving energy? *Energy Efficiency 1*, 1 (Feb. 2008), 79–104.
7. Fitzpatrick, G., and Smith, G. Technology-enabled feedback on domestic energy consumption: Articulating a set of design concerns. *IEEE Pervasive Computing 8*, 1 (Jan. 2009), 37–44.
8. Foster, D., Lawson, S., Wardman, J., Blythe, M., and Linehan, C. "watts in it for me?": Design implications for implementing effective energy interventions in organisations. In *Proc. of the SIGCHI Conference on Human Factors in Computing Systems*, ACM (2012), 2357–2366.
9. Froehlich, J., Dillahunt, T., Klasnja, P., Mankoff, J., Consolvo, S., Harrison, B., and Landay, J. A. Ubigreen: Investigating a mobile tool for tracking and supporting green transportation habits. In *Proc. of the SIGCHI Conference on Human Factors in Computing Systems*, ACM (2009), 1043–1052.
10. Froehlich, J., Findlater, L., and Landay, J. The design of eco-feedback technology. In *Proc. of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '10, ACM (2010), 1999–2008.
11. Froehlich, J., Findlater, L., Ostergren, M., Ramanathan, S., Peterson, J., Wragg, I., Larson, E., Fu, F., Bai, M., Patel, S., and Landay, J. A. The design and evaluation of prototype eco-feedback displays for fixture-level water usage data. In *Proc. of the SIGCHI Conference on Human Factors in Computing Systems*, ACM (2012), 2367–2376.
12. Greenberg, S., and Buxton, B. Usability evaluation considered harmful (some of the time). In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '08, ACM (2008), 111–120.
13. Grogg, K. Harvesting the Wind: The Physics of Wind Turbines. *Digital CommonsCarleton College* (2005). `http://digitalcommons.carleton.edu/pacp/7/`, Online; accessed 2. May 2014.
14. Heberlein, T. A. The influence of price and attitude on shifting residential electricity consumption from on-to off peak periods. *Journal of economic psychology : research in economic psychology and behavioral economics* (1983).
15. Hogan, M. Aligning power markets to deliver value. *The Electricity Journal 26*, 8 (2013), 23 – 34.
16. Jacobs, R., Benford, S., Selby, M., Golembewski, M., Price, D., and Giannachi, G. A conversation between trees: What data feels like in the forest. In *Proc. of the SIGCHI Conference on Human Factors in Computing Systems*, ACM (2013), 129–138.
17. Johnson, M. P., Bar-Noy, A., Liu, O., and Feng, Y. Energy peak shaving with local storage. *Sustainable Computing: Informatics and Systems 1*, 3 (2011), 177 – 188.
18. Kim, T., Hong, H., and Magerko, B. Coralog: Use-aware visualization connecting human micro-activities to environmental change. In *CHI '09 Extended Abstracts on Human Factors in Computing Systems*, ACM (2009), 4303–4308.
19. Kjeldskov, J., Skov, M. B., Paay, J., and Pathmanathan, R. Using mobile phones to support sustainability: A field study of residential electricity consumption. In *Proc. of the SIGCHI Conference on Human Factors in Computing Systems*, ACM (2012), 2347–2356.
20. Lund, D., Nielsen, M. K., and Hald, T. H. An Overview of Eco-Feedback Research within HCI. (2014).
21. Mankoff, J. C., Blevis, E., Borning, A., Friedman, B., Fussell, S. R., Hasbrouck, J., Woodruff, A., and Sengers, P. Environmental sustainability and interaction. In *CHI '07 Extended Abstracts on Human Factors in Computing Systems*, ACM (2007), 2121–2124.
22. Milenkovic, M., Hanebutte, U., Huang, Y., Prendergast, D., and Pham, H. Improving user comfort and office energy efficiency with poem (personal office energy monitor). In *CHI '13 Extended Abstracts on Human Factors in Computing Systems*, ACM (2013), 1455–1460.
23. Mirabel Energy. `http://www.mirabel-project.eu/`, Online; accessed 2. May 2014.
24. Mishra, A., Irwin, D., Shenoy, P., and Zhu, T. Scaling distributed energy storage for grid peak reduction. In *Proceedings of the Fourth International Conference on Future Energy Systems*, e-Energy '13, ACM (2013), 3–14.
25. Nord Pool Spot. `http://www.nordpoolspot.com/`, Online; accessed 2. May 2014.
26. Nyborg, S., and Røpke, I. Constructing users in the smart grid - insights from the Danish eFlex project. *Energy Efficiency 6*, 6 (May 2013), 655–670.
27. Open Weather Map. `http://openweathermap.org/`, Online; accessed 2. May 2014.
28. Pierce, J., Odom, W., and Blevis, E. Energy aware dwelling: A critical survey of interaction design for eco-visualizations. In *Proc. of the 20th Australasian Conference on Computer-Human Interaction: Designing for Habitus and Habitat*, ACM (2008), 1–8.
29. Riche, Y., Dodge, J., and Metoyer, R. A. Studying always-on electricity feedback in the home. In *Proc. of the SIGCHI Conference on Human Factors in Computing Systems*, ACM (2010), 1995–1998.
30. TotalFlex. `http://www.totalflex.dk/`, Online; accessed 2. May 2014.
31. Zensehome. `http://www.zensehome.dk/`, Online; accessed 2. May 2014.

5 Towards Domestic Flexibility: Empowering Consumers to Move Electricity Consumption

Towards Domestic Flexibility: Empowering Consumers to Move Electricity Consumption

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ABSTRACT
Over the last decade a large amount of HCI research has gone into changing electricity consumption behaviour in domestic households. The general approach has been to reduce consumption. This does, however, not solve the problem of peak demand periods, which is a result of simultaneous electricity consumption. It can be addressed by empowering consumers to move electricity consumption, which is also referred to as *flexibility*. This paper, presents a study of consumers motivation and understanding to move electricity consumption using FlexiViz, a flexibility-enabling eco-feedback display. The display was deployed within three households for 10 weeks, and a total of 12 in-home, semi-structured interviews were conducted. Our findings are relevant not only for understanding consumers willingness to move electricity consumption, but also towards designing future flexibility-enabling systems.

Author Keywords
Sustainability; Electricity Consumption; Flexibility; Technology Probing; Misc.

INTRODUCTION
In the last decade there has been an increased focus on domestic electricity consumption and how to make consumers more sustainable in their energy consumption behaviour. The general focus so far has been on conserving energy and minimizing the environmental impact [17]. The reduction of electricity consumption within domestic households has its limits as the population and the number of electronic devices increase. Another approach to reduce environmental impact is to utilize green energy (e.g. wind energy). However, the two major problems with green energy is that it cannot be stored and the availability changes over time. The current consumer electricity consumption behaviour therefore needs to change to fully utilize the production of green energy.

As domestic electricity consumption is usually connected to the routines of everyday life this poses a problem. These routines are often connected to activities which primarily occur during the evening where cooking, washing and other electricity consuming activities are performed [22]. This in turn results in *peak demands*, which is the result of accumulated electricity usage from simultaneous domestic activities [2, 22]. The peak demands cause two problems. Firstly, it makes it difficult to utilize the changing availability of green energy since peaks are concentrated around certain hours. Secondly, the electricity suppliers have difficulties providing electricity for the sudden demand using the existing infrastructure. Eliminating peaks require users to move their electricity consumption, which is referred to as *peak shaving* [22] or more commonly *flexibility* [22, 26].

The expensive solution would be to expand the infrastructure (e.g. replacing power cables and transformer substations) [11]. The less expensive alternative would be to enable the consumers to move their electricity consumption away from peak demand periods (e.g. by doing laundry during the night). When consumers are able to move their consumption away from peak periods and utilize the green energy available, we consider them flexible. A flexible result is achieved by meeting one of the above conditions. The most flexible result, however, is achieved when both conditions are met by utilizing available green energy when the load on infrastructure is low.

Within HCI a large amount of work has been focusing on reducing electricity consumption to achieve more sustainable behaviour. Facilitating flexibility in electricity consumption, however, is a relatively new field. A majority of the research that explore flexibility has been focusing on exploring technologies for automating flexibility (e.g. smart grids [1, 20] and peak shaving algorithms [14, 21]). The tendency has been that human factors have come in second compared to technology. The impact of these flexibility-enabling technologies on everyday life has therefore remained largely unexplored. The need to explore the impact on electricity consumers (e.g. motivation, understanding and interests) is especially important to create effective business models [1].

In this article we present a study of consumers' motivation, understanding and interests towards moving electricity consumption in domestic households. A flexibility-enabling eco-feedback display is used as a technology probe with the intent of facilitating discussions about flexibility.

RELATED WORK

Domestic households are responsible for a large part of the overall electricity consumption [4, 5, 16]. The interest in exploring this area has been rapidly increasing over the last decade. This has resulted in a large amount of published HCI research [17]. The primary focus, however, has been on persuading users to conserve energy as a part of becoming sustainable consumers. We assume that flexibility and energy conservation has some overlap as they both try to change consumption behaviour. Our starting point will therefore be in the field of energy conservation.

In the field of energy conservation various research methods and systems have been used to achieve knowledge about user electricity behaviour within a given context (e.g. in the home or in the public) and which impact such systems have on the consumers. A general approach has been to give users information about their electricity usage patterns to make them more aware of their consumption behaviour. Within the field of energy conservation the term *eco-feedback* is frequently used. Froehlich et al. defines eco-feedback technology as *"technology that provides feedback on individual or group behaviours with a goal of reducing environmental impact"* [8].

A problem with domestic electricity consumption is that it is being metered out of sight, and it therefore remains invisible and intangible to consumers [4,5,16]. Technology is maturing and the amount of available data is increasing because of smart metering technologies. However, systems to present this data to the consumers are still largely unexplored [5]. To empower user sustainability, eco-feedback technologies can be used to visualize this information.

A variety of technologies have been utilized to explore areas such as electricity and water consumption in domestic households. Depending on the context of use these technologies can be divided into two categories: *Individual commitment* and *social commitment* [17]. The former is targeting individuals. In this category, mobile applications is found to be the most common technology. The latter is aimed at groups of individuals in either domestic or public contexts. The most commonly used technology in this category is situated displays. Technologies found to be common in both categories include regular PC applications, web portals and customized hardware [17].

We distinguish between two types of data visualization, which are *pragmatic* and *artistic* [23]. Pragmatic visualizations are designed to remove any sublimity and foster immediate understanding. An approach often used to visualize electricity consumption in a pragmatic way is using graphs that display the amount of electricity used over time [6, 7, 16, 19]. In contrast to this, the artistic visualization should keep the audience interested by showing data in an abstract way. This can be done by representing electricity consumption data as different colours or pictograms [7, 9, 15, 16]. An example of this is displaying a coral that will change colour and condition according to electricity usage [13].

A general tendency has been that studies of eco-feedback technologies have short evaluation periods [17]. Most of these technologies have been deployed for less than three months. Riche et al. argues that new behaviour has a tendency to relapse shortly after studies end, unless the changes have been adopted for at least three months [24]. Riche et al. made a proposal for a three-staged approach to support user behavioural change. The three stages are *raise awareness*, *inform complex changes* and *maintain sustainable routines* [24]. The first step is to make consumers aware of their electricity consumption behaviour, and to obtain knowledge about where and when it takes place. In the second step, inform complex changes, users should be given additional information related to their electricity consumption. Furthermore they should be informed of the changes they have made and opportunities for further changes. The last step, maintain sustainable routines, is about encouraging users to keep using the systems and maintaining adopted behaviour [24].

DONG Energy, a Danish energy supplier, worked on the project eFlex that aimed at finding how flexible consumers can be or are willing to be [22]. In the study it is argued that flexibility can be either automated (e.g. flexible appliances) or an active choice (e.g. the users move electricity usage themselves). The study shows that there are two types of electricity consumption practices, which are *necessary household practices* (e.g. cooking) and *'luxurious' practices* (e.g. watching TV). Furthermore, eFlex found that consumers seemed more willing to be flexible with necessary practices, rather than the 'luxurious' ones. The eFlex study furthermore identified two categories of user profiles: *Enthusiastic* and *interested*. Interested users participate due to a greater cause or to save money, while enthusiastic users participate to contribute to the project or to get further knowledge concerning electricity consumption. The project identified four factors that influence the flexibility potential of a household. These are *household infrastructure and smart technologies*, *willingness to flexibility*, *family composition* and *life situations*. They argue that different approaches to reach the consumer have to be considered depending on which of these factors are met.

Our own work in sustainability consists of an ongoing study of how always-on eco-feedback displays affect user awareness [18]. We found that motivational factors towards conserving electricity were economy and the environment. This relates to the work done by Erickson et al. that found that prices and crisis engages people to concern about their electricity consumption [3].

In this article we will describe a study of flexibility in domestic electricity consumption. Our particular focus is on consumers making a choice to actively move their electricity consumption. We therefore introduce users to information needed to move usage (e.g. forecasts), which relate to Riche et al.'s second step of informing complex changes. By doing this we hope to reveal contextual factors that can empower electricity consumers to achieve a more sustainable behaviour by moving electricity consumption.

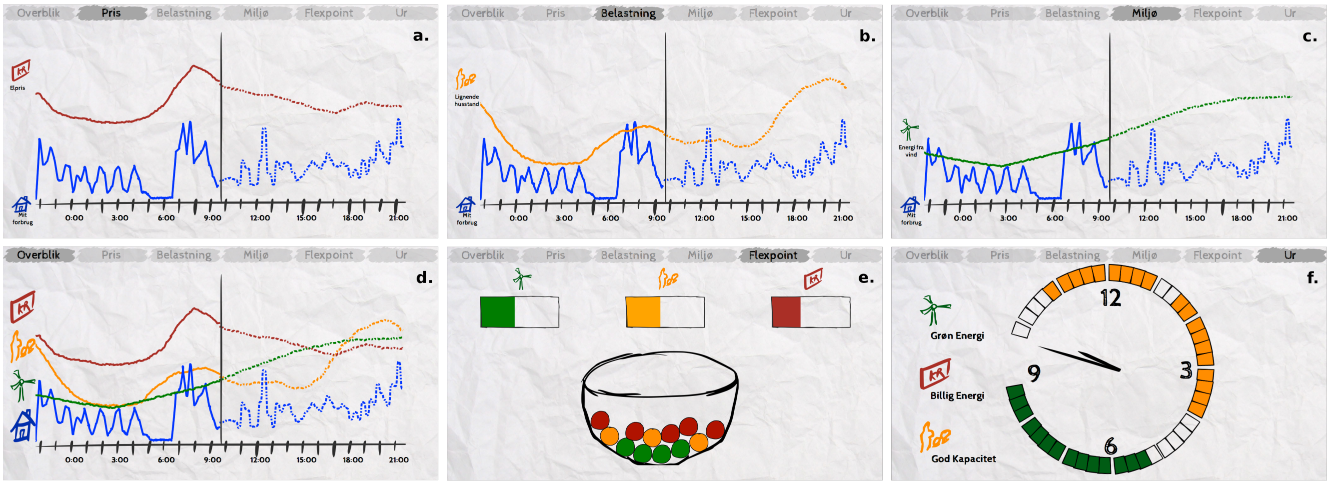

Figure 1. The first four views presents information about the comparison between electricity consumption and (a) the price of electricity; (b) the load on infrastructure; (c) the availability of green energy and an; (d) overview of the three. The fifth (e) gives feedback on moving consumption. The sixth (f) presents opportunities for further changes.

FLEXIVIZ

Exploring the field of flexibility is needed as we do not yet know enough about consumers' motivation, interests and understanding. To do this we developed a system that facilitates discussions concerning moving electricity consumption in domestic households. We call the system FlexiViz and it is implemented as a flexibility-enabling eco-feedback display. FlexiViz consists of six views which is based on the two first stages from Riche et al., which include raising awareness and informing complex changes. To raise awareness FlexiViz visualizes information about the consumers total electricity consumption. To inform complex changes FlexiViz visualizes three elements: Additional information, changes they have made and opportunities for further changes.

The additional information that was introduced in FlexiViz is based on two elements: Comparison and prognosis. The element of comparison enables users to compare their electricity consumption to flexibility related information such as the availability of green energy. FlexiViz includes three types of comparison information: The price of electricity, the load on infrastructure, and the availability of green energy. To give the users information about when to consume, FlexiViz includes the element of prognosis. FlexiViz includes four different types of prognoses based on the three types of comparison information and the users electricity consumption. Due to the uncontrollable nature of these external factors, we argue that users need additional information to be able to make a more flexible choice.

Three of the views in FlexiViz use a pragmatic approach to visualize the above mentioned information. We named these views Price (Figure 1a), Load (Figure 1b) and Environment (Figure 1c). The views consist of a blue electricity consumption line that provides past and future usage. The views also consists of a second line that visualizes one of the comparison information types mentioned above. A fourth view uses the same layout, but joins all of the above mentioned data into one overview. We named this view Overview (Figure 1d).

Besides giving additional information, FlexiViz also offers information of the users' current flexibility status. FlexiViz has a view dedicated to give feedback on the changes users have made in terms of moving electricity consumption. We named this view Flex Points (Figure 1e). This is visualized by using flex points to indicate how flexible the users have been over a period of one week. The design uses an artistic visualization, and displays status using a bowl containing balls. The status is indicated by the number of balls present in the bowl.

FlexiViz also displays information to inform users of opportunities for further changes to move electricity consumption. FlexiViz has a view, which indicates when it will be favourable to consume electricity. We named this view Flex Opportuinities (Figure 1f). The view was designed to look as a clock divided into 15 minute time blocks. Each time block indicates, depending on the colour, whether it is favourable to consume electricity or not.

FlexiViz is configured to automatically swipe between the different views if users do not interact with the display. The users can interrupt the automatic swiping and swipe between the views themselves. FlexiViz logs all interactions, making it possible to gain insights into which view the users tend to use the most and when. Graphically FlexiViz is designed in a sketchy style to indirectly encourage users to criticize and give feedback on the system design [10].

System Implementation

To ensure that users would get an authentic experience, the data presented on the display is obtained from real data sources. The electricity consumption data is retrieved using a smart home metering system, resulting in data with a 15 minute interval. Information about the availability of green energy is based on local weather forecasts from

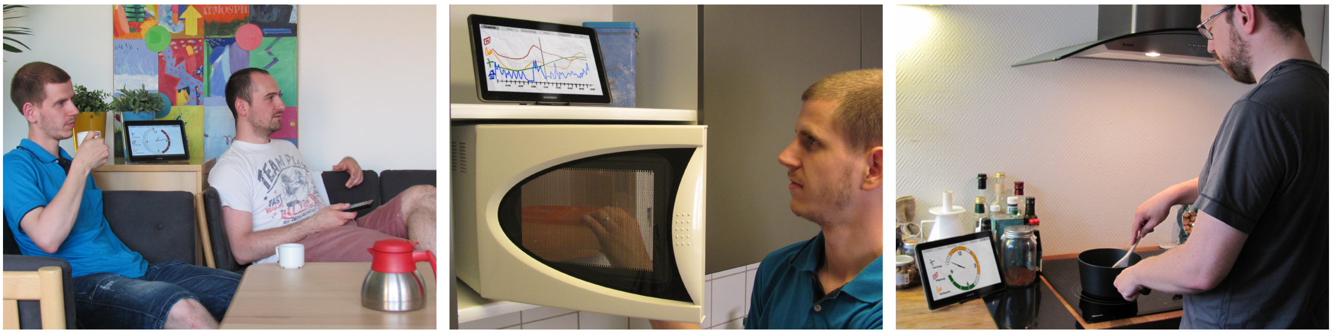

Figure 2. In the first interview, participants were asked to select a central location to place FlexiViz. They placed it in the living room or kitchen.

Open Weather Map. The load on infrastructure is based on participants' own electricity consumption history. Past consumption data is averaged and treated using a moving average smoothing algorithm to make it appear as being a real average user trend line. The price data is based on real market electricity pricing, retrieved from the leading power market in Europe, Nord Pool Spot.

THE STUDY

We used FlexiViz as a technology probe [12] to introduce users to flexibility related information. The probe was an instrument to facilitate discussions in the following in-home interviews. It was deployed within three households for 10 weeks, but is a continuation of the system from our previous study concerning electricity consumption awareness, which ran for a period of 16 weeks. A total of 12 in-home, semi-structured interviews, four with each household, were conducted during the study period.

Participants

We used the three families from our former study. These families are all interested in new technologies and in becoming more sustainable by conserving electricity. They all have a smart home metering system installed in their home. At least one in the household has a basic understanding of their overall electricity consumption.

Procedure

Semi-structured interviews were used to allow for a more open discussion towards flexibility. At the same time this would allow for a more in depth approach where the focus was on users motivation and understanding towards moving electricity consumption.

The interviews were conducted in the participants households to keep them in a context related to their electricity consumption and their everyday settings. It was mostly the adults within the households who participated in the interviews. We conducted four interviews with each household. At least two members of the household were present at each interview.

In the first interview we introduced the users to FlexiViz and the concept of flexibility. To make sure that the information in FlexiViz was presented to as many as possible, we intentionally asked participants to place the display in a central spot in the home (Figure 2). We guided them through the system views and explained their meaning and purpose. We also gave the participants a small user manual that they could use if they had any questions. The first interview introduced them to the Price, Load and Environment views. After each subsequent interview a new view was added in the following order: Overview, Flex Points and Flex Opportunities. The user manual was subsequently expanded with new information. The purpose of this approach was to make it easier to isolate findings.

As the participants became more familiar with the idea of moving consumption, we started to ask them more in depth questions with topics such as motivational factors and the usage of FlexiViz. Each interview started with an introduction to subjects that would be the focus of the discussions. The first part of the interview was concerned with any new thoughts towards moving electricity consumption, and the last part focused on the use of the system and its features.

Interview Setup and Data Analysis

The in-home interviews were conducted by three researchers: one led the interview, the other two were in charge of recording equipment and note taking. The interviews were audio recorded for transcription purposes.

Each of the in-home interviews was transcribed and analysed. As previously mentioned FlexiViz served as a technology probe. This, in addition to being a discussion facilitator, would let us to obtain information through logging such as the use of FlexiViz (e.g. which views were used and for how long). This enabled us to validate their statements with interaction data. Besides this, the users electricity consumption data was stored.

FINDINGS

Through the study period, FlexiViz logged a total of 357 interactions with an overweight on one household, which was responsible for 287 interactions. Furthermore, FlexiViz logged approximately 1.6 million electricity consumption data entries. Additionally 1680 price and 420 wind data entries were logged. We did not encounter any persistent changes in consumption behaviour during the study period. We did, however, find examples of an increase in consumer awareness towards flexibility.

Understanding Flexibility

It was generally difficult for the participants to understand flexibility as they had never been confronted with or encountered the peak demand problem before. When discussing electricity consumption the participants' main focus were towards conservation, where the purpose was to obtain a financial profit and to reduce environmental impact. During the interviews, participants used arguments such as:

"Well, we can turn off appliances during the peak demand hours." - Household 2

However, it is not necessary for the consumer to turn off appliances to become more sustainable, as the same can be achieved by moving electricity usage.

The participants prerequisite for moving consumption was good. They already had a high level of awareness of their electricity consumption due to the use of their smart home metering system, but they were clearly affected by an electricity conserving mindset. Even towards the end of the study several participants kept referring to conserving electricity. Through the study, most participants were focused on larger appliances such as the washing machine or the dishwasher. To our participants these appliances were the obvious candidates, where usage could be moved, because a large amount of electricity consumption would follow.

Learning Flexibility

The study period was characterized by a steep learning curve. It was difficult for the participants to understand why they had to move electricity consumption. This was related to their attitude towards consuming electricity. They saw electricity as a service offered by the electricity suppliers. The participants mentioned that since they paid a fixed price per kWh, they wanted to be able to use electricity at any given time. After we explained to them that expanding the infrastructure most likely would result in an increase in the electricity price, they started to understand the consequences of not moving their electricity consumption. However, even at the end of the study it was hard for the participants to understand why they do not necessarily have to conserve electricity to become sustainable. By moving some of their electricity consumption to more favourable times of the day, they would also achieve more sustainable behaviour.

It was quite difficult for participants to relate to the fact that they could use the same amount of electricity as they already did, or even more, if they just did it at a more favourable time. However, as we introduced possibilities such as automated appliances and dynamic electricity pricing one of the participants mentioned:

"An appliance might consume more per year than an average matching appliance, but it consumes at more favourable times of the day, which overtime will result in a financial saving. Then it would be worth investing in the flexible appliance." - Household 2

It was difficult for participants to understand, why moving heavy consuming activities would make a difference as their electricity consumption was just a small part of the overall infrastructural load. The participants stated that they believed that their actions would not affect the peak demand periods, as they believed that the impact of their usage was insignificant. After we explained that it was the actions of a joint effort that would make the difference, participants started to reflect on how moving their electricity consumption would have an influence on the overall national consumption.

The Non-Flexible Nature of Electricity Consumption

Our participants mentioned, that their everyday lives are centred around a set of routines. We found that some of these routines are highly interdependent.

"The everyday life of a young family is crammed with electricity consuming activities, which are dependent on non-domestic activities." - Household 3

Electricity consuming activities are tightly connected to everyday domestic routines. Moving electricity consumption to more favourable times of the day involves changing these routines. Moving electricity consumption therefore means altering the structure of domestic life, making flexibility in electricity consumption difficult. A general attitude towards electricity consumption observed in participants' statements is, that many activities determine when to operate appliances. Some activities have a very strict deadline (e.g. making breakfast or getting children ready for school), while other activities have a non-specific deadline (e.g. doing the laundry or dish washing).

"The mornings are characterized by a tight schedule, whereas evenings have no strict deadline." - Household 2

Morning activities have more strict deadlines than evening activities, where the time schedule is more tolerant. The main reason for this is that evening activities usually have no strict deadline depending on non-domestic activities, (e.g. leaving for work). However, activities like preparing dinner can have strict deadlines in households, where family members participate in non-domestic activities (e.g. leisure sports).

Activities, such as doing the laundry or operating the dishwasher do not have the same level of temporal importance as activities which are more directly connected to strict deadlines. As it is possible for some appliances, such as a dishwasher to operate with limited user interaction, the dish washing activity is not part of the set of activities with strict deadlines. Similarly washing and drying clothes can be done relatively independent of other activities. In contrast to this, using coffee makers and toasters are tightly connected to activities with strict deadlines.

In cases where everyday routines are deviated from or completely abandoned, electricity consumption is more likely to be moved. These deviations are possible in weekends or during holidays, where scheduling is not as strict as in everyday life. For example, one of our participants decided to move his electricity usage to a more favourable time, because he had some time off from work. We found that during periods participants deviated from routines, there was a greater tendency towards attempting to make changes in their electricity consumption.

Flexible Appliances

One of our participants stated that he, at a few occasions, had planned to move dish washing to a different time. Another participant stated that he had postponed doing the laundry. The dishwasher and the washing machine used for these activities, are appliances where the electricity consumption can be moved. When participants were asked why they could move usage on these appliances, they replied that using them required a minimum of user interaction. This pattern repeated across a number of appliances. The appliances with the greatest potential for flexibility were battery-powered devices (e.g. tablets and laptops). The reason for this was that they store electricity, so the need to charge it was not as urgent and could easily be planned.

"You can be very flexible with the portable music player as it is battery-powered. Because of this you aren't dependent on its here-and-now energy usage since it is charged or has energy accumulated." - Household 3

The use of battery-powered appliances are not limited to times where they are connected to an outlet. Battery-powered appliances can be used throughout the day, and can be charged over the night, which makes them potential candidates for moving electricity consumption.

Moving the use of appliances with strict deadlines, such as the toaster, were not a possibility. Participants mentioned that toasting bread could not be planned as it is driven by sudden needs, making the activity less likely to be moved.

"You cannot be flexible with the toaster, because you toast bread when you toast bread." - Household 1

The participants stated that devices, such as the TV, stove, kettle and coffee machine, were examples of appliances with strict deadlines. Because of the role of these appliances in the daily routine structure and their impact on other activities, they cannot be moved. For example, postponing the use of the stove would influence, when they were able to attend non-domestic activities.

Even though the usage of some appliances could be moved, participants explained that appliances that could automatically consume at favourable times would be a preferred solution. The participants stated that devices, such as the washing machine, dishwasher and tumble dryer, were examples of appliances that could be automated. However, participants stated that there should always be an option to overrule automation.

"The tumble dryer could be automated, however, you must have the option to overrule and start it right away" - Household 2

An example that came up frequently was to start the dishwasher and set it to finish within some time range. The idea was that it should automatically decide when to wash to be flexible within the time range, but they wanted the option of overruling the automation in case they needed dishes right away. The participants agreed that such initiatives were to be preferred, if they in their every day lives had to move electricity consumption continuously.

Encouraging Flexibility

The topic of motivation was frequently brought up during the in-home interviews. All participants expressed that the only incentive for moving consumption was the price of electricity.

"In my opinion the price is clearly the primary motivation. If the price was doubled in the high load hours, I would definitely start to move my electricity consumption." - Household 1

Participants mentioned two scenarios of how the economical aspect could influence their choice. There should either be an economic profit for flexible behaviour (e.g. reduced electricity bill) or a punishment for non-flexible behaviour (e.g. higher cost per kWh). Both the environment and the load on infrastructure were mentioned as negligible in terms of their influence on the choice of moving consumption. Reducing environmental impact were, however, mentioned as an additional benefit.

Despite the fact that the environment was stated to be a negligible motivational factor, one of the participants mentioned that he had used information about the availability of green energy to move the electricity usage of the washing machine. He explained that it was due to the disruption of the daily routines in either weekends or holidays and the fact that the price didn't have any direct correlation with their electricity bill. Due to the less structured routines more spare time was available to the families, which enabled them to coordinate and plan the electricity consumption of some appliances. The choice of moving the usage of his washing machine, was motivated by a concern for the environment.

Discouraging Flexibility

A problem with FlexiViz was that even though it visualized real data, participants did not react upon it because it had no consequence for them in the end.

"You would probably have to punish people, because if I'm avoiding these things and my neighbour have that 500 watts light bulb on all the time with no consequence [...] I would feel that my struggle was for nothing." - Household 2

The consequence could be an economical incentive (e.g. being punished depending on whether electricity consumption have been moved or not). Most participants emphasized that one of the discouraging elements towards moving electricity consumption, is that they pay for a service that the electricity suppliers provide. They mentioned that it is the suppliers that have a problem, and therefore it was not directly of their concern. One of the participants expressed that if the electricity suppliers gave information about the consequences of not moving some of their usage, it would probably make consumers reflect on their electricity consumption patterns.

Participants mentioned that there is a big difference between the choice of conserving electricity and moving electricity consumption. They explained that conservation often was a one time investment usually accomplished by replacing old equipment with new sustainable equipment. After the purchase of such equipment it was no longer required for the consumer to invest more time or money in the project to be more sustainable. The choice of moving electricity consumption would interfere with consumers' daily routines, and would be very time consuming as the consumers have to coordinate between the daily activities to see which usage can be moved.

Obstacles for Flexibility

One of the major obstacles for moving electricity consumption was the lack of time that families often experience. One of our households was a small family of two. The participants in this household expressed that they were more likely to be flexible, because they did not have any children to take care of. However, another one of the participating households had an especially busy schedule with three young children. While they did look on the display from time to time and received the information, they expressed that they failed to act upon it due to lack of time. They explained that in a busy schedule, activities are often depending on routines, and changing these would require a substantial amount of time, which they didn't have.

"As our life situation is right now, with 3 kids, it has to be automated. We don't have the time in our daily life to study the information and act upon it." - Household 1

For example, at night if their children were awake, it was not possible to move electricity consumption as warming a bottle of milk was important at that moment. Electricity had to be consumed at that specific time as this was a result of a sudden need. Likewise, there are other similar examples of such electricity consumption that participants were not willing to move due to the need for sudden usage (e.g. making a cup of coffee). This pattern repeated, where participants were less inclined to move electricity usage connected to activities that were the result of a sudden need or was highly dependent on other activities.

As a result of using FlexiViz one of our participants had already thought of moving his electricity consumption. As he stated:

"Sometimes we decided to postpone the dishwasher, however, we forgot to start it later on." - Household 2

The motivation for his planning was the price, but he expressed that he needed an indicator or reminder of when to start the dishwasher. As the participant explained, he decided to postpone the dishwasher, but then he was caught in some other activity and forgot all about the dishwasher. The participant told us that moving his electricity consumption, at least on the dishwasher, wouldn't be a problem if the system had notified him.

Another obstacle that made participants less inclined to move their electricity usage was the lack of information about the problem of peak demands. Some of the participants expressed that the availability of information related to moving electricity consumption through FlexiViz made them reflect upon their electricity usage behaviour. When we introduced participants to the concept of moving electricity usage, they were not aware of the problem. The problem was out of sight, and therefore it was difficult for them to relate to. As a consequence several participants initially thought that the problem might not directly affect them or that their effort would be insignificant. Later, when participants were properly introduced to move electricity usage, they began to reflect upon their earlier thoughts. Participants stated that being informed by electricity suppliers about the consequences of not moving electricity consumption would eventually direct their attention towards the problem. They also expressed that to make consumers change their electricity consumption behaviour, information about the problem was not in itself sufficient. However, information was considered a necessary starting point, if the consumers should invest time or money in technologies that facilitate moving electricity usage.

DISCUSSION

Our study exposed the participating households to information such as the electricity price and the availability of green energy. The participants reported how and why they used the information. The availability of information related to moving electricity consumption through FlexiViz made the participants reflect upon their electricity usage behaviour. We argue that FlexiViz made the concept of flexibility more tangible by exposing them to information related to moving electricity consumption.

Members of the participating households reported that they occasionally moved some of their electricity consuming activities to other times of the day. An example of this is that one household moved the laundering activity to later that day as the availability of green energy was increasing over the day. Another household stated that at a few occasions they had postponed the dish washing activity as a result of a descending price during the evening.

While this study did not result in any persistent changes in the participants' electricity consumption behaviour, we obtained knowledge about how difficult moving consumption is for the consumers. Furthermore, we have learned what should be considered to empower electricity consumers in moving electricity consumption.

Changing Routines

Our findings indicate that it is difficult to make consumers move their electricity usage. Making electricity consumers consider when to move usage forces them to reflect more on their daily routines. Tolmie et al. argues that routines might never have to be considered or decided upon [25]. Therefore it poses a challenge to consumers to continuously consider when to consume. We argue that consumers need to change the way they consume electricity for the idea of flexibility to become a reality. As electricity consumption is an integrated part of everyday life, consumers will need to continuously consider their consumption behaviour during the day.

It can be discussed whether family composition is important to the structure of routines. One of the participating households consisted of two adults and three small children, while another household consisted of only two adults. Their family composition clearly influenced the way they thought of their ability to move electricity consumption. The family with three small children was very much constricted to their daily routines as the children had to be fed at specific times. In contrast, the household with only two adults expressed that they had a better potential for moving usage, because of their different family composition. It would seem that family composition and routines are relevant, when considering the potential of moving usage.

When examining the possible flexibility of domestic activities, some activities appear to be potentially more flexible than others. Activities closely linked to deadlines, (e.g. breakfast and other ”getting out the door” activities) are less likely to be moved. Users mention that these activities are often placed in the morning. Other activities such as cooking are placed in the evening and should be considered as possible candidates which can be moved. It appears that morning routines are more difficult to affect, because they are well defined and users do not have the time to reflect on them in a busy schedule. Evening routines are in some cases easier to influence, because the evening schedule is more tolerant to change. This difference means that some activities will most likely not be considered when aiming to move consumption.

Motivation in Everyday Life

Motivating users can be difficult without them having knowledge of the problem of peak demand periods. Participants mentioned that the first thing electricity suppliers should do is to make consumers more aware of the problem by giving them information. Without informing electricity consumers, they will not be aware of the peak demand problem and therefore they won't be able to take action. Electricity suppliers have not yet had any real focus on making users move their electricity consumption. We argue that raising awareness of peak demand problems definitely should be considered in the future as one of the first steps in moving electricity consumption. A large part of the three-staged approach suggested by Riche et al. is concerned with giving information. He argues that information about the electricity consumption behaviour should be given as the first stage. Furthermore he argues that additional information is needed on the second stage [24]. We argue that information about the peak demand problem should be considered.

Motivating flexibility in everyday domestic households is not a trivial task. Our earlier work indicated that people conserved electricity because of the price or the environment. Price was perhaps a dominant motivation, however, the concern for the environment was still of importance. This has changed as the focus shifted from conservation to moving electricity consumption. As focus changes to flexibility, the price becomes the sole motivating factor. A possible explanation is that moving electricity usage is a time consuming and routine interrupting challenge. Our findings indicate that interrupting these routines could create the necessary window of opportunity to motivate users in other ways, such as consuming electricity when green energy is available. We, however, argue that it would not be a viable option as routines are so interdependent that interrupting them would be difficult without proper motivation.

Price as Motivation

As stated earlier there are two ways to cope with peak demands seen from a flexibility point of view. One can either move electricity consumption away from peak demand periods or by consuming when there is a large production of green energy. These factors are, however, mentioned as negligible from the consumers point of view when concerning the movement of usage, as such actions would intervene with daily routines. Our findings suggest that price is the strongest motivational factor to enable the consumers in moving their electricity usage. The current problem is that peak demands are not directly influenced by the price of electricity as price is currently fixed.

The question arises of how to use the price so it will directly influence peak demand periods. We see two ways of achieving this with a focus on price. Firstly, it could be achieved by making the price depend on either the load on infrastructure or the availability of green energy. Secondly, it could be achieved by making the price depend on both. Such initiatives could motivate users by reducing their electricity bill and allow them to move their electricity consumption away from peak demand periods.

It can be discussed whether the existing electricity price can influence electricity consumption behaviour. Several of our participants were well aware that the actual electricity price was a small amount of the total amount paid for electricity. Participants mentioned the possibility of dynamic pricing. If prices should be dynamic, it should therefore be considered by how much prices should vary. Our participants stated that it should be a substantial amount before they would consider moving their electricity consumption. The eFlex project also found that users were more likely to move electricity consumption if the price fluctuated a substantial amount [22]. They found that pricing with a minimum rate of 1,50 dkk and an upper rate of 4,30 dkk per kWh were enough to motivate consumers to move electricity consumption.

Maintaining Sustainable Routines

We developed FlexiViz as an example of a flexibility-enabling eco-feedback display to obtain knowledge about consumers motivation, understanding and interests to move electricity consumption. We designed the system based on the two first steps from Riche et al.: raise awareness and inform complex changes. It can be discussed what could be done to improve technologies further with focus on flexibility. The third step of the approach presented by Riche et al., maintaining sustainable routines, requires the user to continue flexible behaviour [24]. Riche et al. points out that the technology needs to fit the home, and the users evolving information needs.

We found that in some cases participants actually did plan to move electricity consumption, but forgot it later. FlexiViz did not support notifying users when they have planned to move electricity consumption. We argue that technologies should be further improved so that they can help consumers move their electricity consumption, such as issuing notifications that remind users to consume, or systems that will make postponing tasks easier.

Improving Current Devices

Previously we discussed factors that should enable users to move electricity consumption. It could be discussed which appliances should be considered as potential candidates to move consumption. We found that the use of appliances that are used for activities, which is a result of a sudden need has less potential of being moved. Coffee makers, kettles and toasters are examples of devices that users see less potential for flexibility in. This makes sense as using such appliances cannot be postponed for any greater amount of time (e.g. you need your coffee now and not in four hours).

Appliances such as the dishwasher or phone charger, are often less routine dependent. They are easier to move as the usage can be planned and are often not involved in daily routines. Moving electricity consumption on devices like the dishwasher or phone charger are more likely, as they only need a minimal amount of user interaction and can be postponed for longer periods of time. One possible reason for this is that the storage capacity of these devices provide users with a greater window of opportunity for moving electricity consumption. We found that usage on such devices can be planned by the consumer, but they tend to forget. To prevent this, automation could be used as a tool to move some of the responsibility away from the consumers so that they would not have to remember when to use electricity.

Several of our participants mentioned that they did not have the time to continuously move electricity consumption. It could therefore be discussed if asking the consumers to move consumption is the right approach. Moving electricity consumption can be achieved in two ways [22]. The first, *active flexibility*, relies on users to take an active part in moving electricity usage. The second, *automating flexibility*, relies on integrating functionality into appliances that can move electricity consumption without user interaction. By automating appliances you move the responsibility away from the consumers and enables the electricity suppliers to get some control of when those appliances are allowed to consume electricity.

It could be discussed whether electricity suppliers should focus on active or automated choices. Even though our participants expressed that they wanted automated appliances, they did not want to lose control. An example could be the dishwasher where they wanted an overrule option for sudden dish washing. We argue that the solution should be found somewhere in the intersection between an active choice and fully automated appliances. We argue that electricity suppliers, in the future, should focus on appliances, which usage can be scheduled and require less user interaction. We furthermore suggest that these devices should have some degree of automation (e.g. setting a timer), while still maintaining the possibility for control.

Probing Users

Although we had a large amount of data available, we were not able to infer when the participants had moved some of the electricity usage of their appliances. One of the reasons for this was due to the fact that we could not identify the specific appliances that was connected to a specific outlet at a given time. Most participants stated that moving appliances that only accounted for a minor part of their electricity consumption, such as charging devices, would have an insignificant impact on the entire load. This might have resulted in them not mentioning if they had moved the use of such appliances to other times of the day.

We used FlexiViz as a technology probe. One of the functionalities that could have been added was to allow the users to report actions, such as when they were about to move or had already moved, some of their electricity consumption. A simple solution to report such actions, could be to add a button that should be pushed by participants. Another way to solve the issue could be by getting the participants to keep a diary and write down the time of the action and the reason why. This would probably have enabled us to go more in depth in the interviews about what actually motivated them to take action and to see which appliances that they would eventually move.

CONCLUSIONS

This article presented a study of users' motivation, understanding and interests towards moving electricity consumption We used FlexiViz, a flexibility-enabling eco-feedback display, as a technology probe with the intent of facilitating discussions about moving consumption.

We designed FlexiViz based on Riche et al.'s first and second stage of changing electricity consumption behaviour. These steps are *raise awareness* and *inform complex changes*. To raise awareness we visualized electricity consumption in the display. To inform complex changes we visualized the electricity price, the load on infrastructure and the availability of green energy. We furthermore introduced prognoses so that users could see when to consume.

FlexiViz was deployed as a technology probe in three households. The study went on for 10 weeks and a total of 12 in-home, semi-structured interviews were conducted. Furthermore, FlexiViz gathered interaction and electricity consumption data that could be used in the interviews.

Our findings suggests that electricity consumers have a difficult time understanding and learning why they need to move electricity consumption. We found that moving usage was difficult, because it also required them to move daily interconnected activities. Moving electricity consumption was more realistic on appliances which usage could be planned (e.g. the washing machine or the phone charger). We found that the dominant motivation in moving electricity consumption was price.

We discussed that routines need to be changed to make electricity consumers reflect on their electricity consumption behaviour. To get users to move electricity consumption requires the right motivation, which we argue consists of both information about the problem and an economic benefit. We argue that electricity suppliers should focus on appliances, which usage can be scheduled and require less user interaction. We argued that they should lie in the intersection between full automation and users making an active choice of moving electricity consumption.

REFERENCES

1. Analyses, E. E. *Intelligent energy systems. A white paper with Danish perspectives*. Ea, 2010.
2. Department of Energy and Climate Change. Demand Side Response in the domestic sector - a literature review of major trails, 2012.
3. Erickson, T., Podlaseck, M., Sahu, S., Dai, J. D., Chao, T., and Naphade, M. The dubuque water portal: Evaluation of the uptake, use and impact of residential water consumption feedback. In *Proc. of the SIGCHI Conference on Human Factors in Computing Systems*, ACM (2012), 675–684.
4. Fischer, C. Feedback on household electricity consumption: a tool for saving energy? *Energy Efficiency 1*, 1 (Feb. 2008), 79–104.
5. Fitzpatrick, G., and Smith, G. Technology-enabled feedback on domestic energy consumption: Articulating a set of design concerns. *IEEE Pervasive Computing 8*, 1 (Jan. 2009), 37–44.
6. Foster, D., Lawson, S., Wardman, J., Blythe, M., and Linehan, C. "watts in it for me?": Design implications for implementing effective energy interventions in organisations. In *Proc. of the SIGCHI Conference on Human Factors in Computing Systems*, ACM (2012), 2357–2366.
7. Froehlich, J., Dillahunt, T., Klasnja, P., Mankoff, J., Consolvo, S., Harrison, B., and Landay, J. A. Ubigreen: Investigating a mobile tool for tracking and supporting green transportation habits. In *Proc. of the SIGCHI Conference on Human Factors in Computing Systems*, ACM (2009), 1043–1052.
8. Froehlich, J., Findlater, L., and Landay, J. The design of eco-feedback technology. In *Proc. of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '10, ACM (2010), 1999–2008.
9. Froehlich, J., Findlater, L., Ostergren, M., Ramanathan, S., Peterson, J., Wragg, I., Larson, E., Fu, F., Bai, M., Patel, S., and Landay, J. A. The design and evaluation of prototype eco-feedback displays for fixture-level water usage data. In *Proc. of the SIGCHI Conference on Human Factors in Computing Systems*, ACM (2012), 2367–2376.
10. Greenberg, S., and Buxton, B. Usability evaluation considered harmful (some of the time). In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '08, ACM (2008), 111–120.
11. Hogan, M. Aligning power markets to deliver value. *The Electricity Journal 26*, 8 (2013), 23 – 34.
12. Hutchinson, H., Mackay, W., Westerlund, B., Bederson, B. B., Druin, A., Plaisant, C., Beaudouin-Lafon, M., Conversy, S., Evans, H., Hansen, H., Roussel, N., and Eiderbäck, B. Technology probes: Inspiring design for and with families. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '03, ACM (2003), 17–24.
13. Jacobs, R., Benford, S., Selby, M., Golembewski, M., Price, D., and Giannachi, G. A conversation between trees: What data feels like in the forest. In *Proc. of the SIGCHI Conference on Human Factors in Computing Systems*, ACM (2013), 129–138.
14. Johnson, M. P., Bar-Noy, A., Liu, O., and Feng, Y. Energy peak shaving with local storage. *Sustainable Computing: Informatics and Systems 1*, 3 (2011), 177 – 188.
15. Kim, T., Hong, H., and Magerko, B. Coralog: Use-aware visualization connecting human micro-activities to environmental change. In *CHI '09 Extended Abstracts on Human Factors in Computing Systems*, ACM (2009), 4303–4308.
16. Kjeldskov, J., Skov, M. B., Paay, J., and Pathmanathan, R. Using mobile phones to support sustainability: A field study of residential electricity consumption. In *Proc. of the SIGCHI Conference on Human Factors in Computing Systems*, ACM (2012), 2347–2356.
17. Lund, D., Nielsen, M. K., and Hald, T. H. An Overview of Eco-Feedback Research within HCI. (2014).
18. Lund, D., Nielsen, M. K., and Hald, T. H. Powerviz: Investigating the impact of an always-on eco-feedback display for appliance level consumption. (2014).
19. Milenkovic, M., Hanebutte, U., Huang, Y., Prendergast, D., and Pham, H. Improving user comfort and office energy efficiency with poem (personal office energy monitor). In *CHI '13 Extended Abstracts on Human Factors in Computing Systems*, ACM (2013), 1455–1460.
20. Mirabel Energy. `http://www.mirabel-project.eu/`, Online; accessed 2. May 2014.
21. Mishra, A., Irwin, D., Shenoy, P., and Zhu, T. Scaling distributed energy storage for grid peak reduction. In *Proceedings of the Fourth International Conference on Future Energy Systems*, e-Energy '13, ACM (2013), 3–14.
22. Nyborg, S., and Røpke, I. Constructing users in the smart grid - insights from the Danish eFlex project. *Energy Efficiency 6*, 6 (May 2013), 655–670.
23. Pierce, J., Odom, W., and Blevis, E. Energy aware dwelling: A critical survey of interaction design for eco-visualizations. In *Proc. of the 20th Australasian Conference on Computer-Human Interaction: Designing for Habitus and Habitat*, ACM (2008), 1–8.
24. Riche, Y., Dodge, J., and Metoyer, R. A. Studying always-on electricity feedback in the home. In *Proc. of the SIGCHI Conference on Human Factors in Computing Systems*, ACM (2010), 1995–1998.
25. Tolmie, P., Pycock, J., Diggins, T., MacLean, A., and Karsenty, A. Unremarkable computing. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '02, ACM (2002), 399–406.
26. TotalFlex. `http://www.totalflex.dk/`, Online; accessed 2. May 2014.

6 Discussion

Throughout this report we have gained knowledge and insight into designing a flexibility-enabling eco-feedback display to support flexibility and how context specific factors influence users. To achieve this we used FlexiViz as a technology probe to investigate how electricity consumers can move their electricity consumption. Users' experiences with the system created a foundation for later semi-structured, in-home interviews. The findings presented in this report could be used as an insight into which impact the challenge of moving consumption has on electricity consumers. In a much wider perspective this could be used by electricity suppliers to know where to put their effort to enable households to take part in becoming sustainable.

The Everyday Life's Dependency on Routines

We deployed FlexiViz in three households and found that moving consumption was tightly connected to everyday life routines. Participants were highly dependent on routines and therefore had a difficult time moving their electricity consumption. The participants had to rethink the ways of how they consume and start to reflect on how they use electricity to change and influence these routines. It is not a problem to move consumption the first few times when being conscious about the change. However, moving usage continuously quickly becomes difficult and time consuming. Participants were more likely to move consumption during the evening routines which indicates that morning routines are more strictly planned.

The use of appliances is highly dependent on everyday life routines. We argue that the use of some appliances can potentially be moved. We found that appliances which do not dependent heavily on routines and which usage can be planned were more likely to be postponed. An example could be an iPad charger or a dishwasher. Because the iPad is battery-powered, consumers can postpone the need for electricity consumption. The dishwasher can often be postponed as the activity which the dishwasher is a part of is highly independent from other activities. On the other hand, appliances which usage was the result of a sudden need, were not likely to be postponed. Examples of such appliances are coffee makers and toasters. We argue that electricity suppliers should focus on making consumers move consumption on appliances that could be planned.

Engaging Users in Moving Electricity Consumption

To get users to move electricity consumption requires a strong motivation. We found that the reason to why users were not moving consumption was the lack of information and a missing financial incentive. Our participants mentioned that electricity suppliers should increase the general public awareness towards the problem of peak demand periods. This would in turn make users more likely to reflect upon electricity usage. Even though FlexiViz provided real price data, the users knew that it would not have any direct impact on their electricity bill. We found that the financial incentive should be considerable if users were to move consumption. We suggest that dynamic pricing should be considered to make users move electricity consumption. Price of electricity do not have any influence on peak demand periods as pricing is currently fixed. We argue that by making the price depend on either the availability of green energy, the load on infrastructure or both, we can change electricity consumption behaviour.

It can be discussed if it is the right decision to involve the users to take an active part in moving electricity consumption. After all, we have learned that most families have little time for moving electricity consumption activities due to busy schedules and strict routines. In contrast to users making the choice themselves, we find automation to be another possible solution. However, our findings suggest that not all appliances can or should be automated. We suggest that future technologies should support automation while still enabling consumers to make an active choice to move electricity consumption.

Visualizing Data and Information Capacity

FlexiViz consists of six views that visualize information in various forms. The first three views, Price, Load, and Environment, are created with the purpose of giving as minimum spatial information about electricity consumption as possible within a domestic household. Furthermore each view only contains one additional line representing either price of electricity, the load on infrastructure or the availability of green energy. By simplifying the data within the view we strived to make the designs as simple as possible, but still with context related information. These views was implemented using pragmatic visualizations, which should make the information presented easily understandable.

Some of the focus group participants mentioned that the first three designs were close to being oversimplified and that the information capacity within these views was too low. This made it difficult to interconnect the various pieces of information presented by the system. To overcome this the Overview design was implemented with the purpose of supporting this missing link by allowing the users to interconnect the various data. The three pieces of flexibility related information were incorporated within the Overview, which resulted in a view containing a large amount of information. The focus group participants stated that the large amount of information in contrast to the first three views could make it difficult to decide when to consume.

Another problem that occurred was, that it was difficult to make a connection between the different pieces of information. The line indicating the availability of green energy indicates that the consumer would benefit the most from consuming when the line is near the top edge. Whereas the other two lines, price of electricity and the load on infrastructure, indicate that the consumer should use electricity when they are close to the bottom edge. This led to some confusion among the participants. It made it difficult to interpret when it would be most favourable to consume. We argue, that the different lines could be designed to have the same meaning. The lines should indicate that it is non-favourable to consume when the line is near the top edge and vice versa.

The Joint Effort for a Sustainable Future

Solving the problem of peak demands is a national challenge. We have studied consumption in domestic households only, as domestic consumption account for one third of the total national electricity consumption. To solve the problem requires a joint effort.

A general attitude that we encountered, was that participants considered their part of the total consumption as insignificant, and that it is the responsibility of the electricity suppliers to solve all problems related to energy supply. During our study we attempted to inform participants of their role in relation to the consumption of the entire society. To make users aware of the fact that it makes a difference if they move their consumption away from peak demand periods, is not a trivial task.

7 Conclusions

In the last decade the concern for the environment has increased. A major focus has been on conserving energy to limit environmental impact. While conserving energy is still of importance, it is not possible to completely eliminate domestic electricity consumption. This however does not solve the problem of peak demand periods. To solve this problem it is necessary to move electricity consumption to more favourable times of the day. We refer to this as being *flexible*. In this report we presented two articles that relates to flexibility, but with a different focus.

In the first article we built a system that visualised electricity related information to the user. We called this system FlexiViz. The purpose of FlexiViz was to facilitate a discussion that could explore users' motivation, understanding and interests concerning moving their electricity consumption. We implemented FlexiViz as a flexibility-enabling eco-feedback display which consists of six views. We designed the views based on Riche et al.'s first and second stage to accomplish a more sustainable behaviour. These stages are *raise awareness* and *informing complex changes*. To raise awareness we visualized electricity consumption in the display. To inform complex changes we visualized electricity price, the load on infrastructure and the availability of green energy. Furthermore we introduced the concept of prognosis and flex points so that users could see where to move consumption and how much they have moved usage.

In the second article we describe the study of exploring electricity consumers motivation, understanding and interests towards moving consumption. We used FlexiViz as a technology probe to facilitate discussions about flexibility. A total of 12 semi-structured, in-home interviews were conducted with the three participating households. We found that it was difficult for users to understand the necessity of moving electricity consumption, primarily because they had not been confronted with the problem of peak demands before. To make users move electricity consumption proved to be a difficult task, because it requires a large amount of continuous planning. The planning disrupts routines, forcing users to rethink and reflect on their electricity consumption behaviour. Therefore a strong motivation is required. Users stated such a motivation to be the price of electricity. Besides motivation we also found several obstacles for moving electricity consumption. Examples of such obstacles were the lack of information about the problem and the absence of technologies notifying users of when to consume.

Lastly we discussed how routines should be changed to make electricity consumers reflect on when and how they consume electricity. Making the users reflect and determine how they can become flexible consumers is difficult. To ask users to move consumption requires a strong motivation, which we argue consists of both information related to the problem and an economic incentive. To effectively enable users to move electricity consumption, they should furthermore be supported by appliances with built-in flexibility-enabling technology.

8 Limitations

Through our study we have observed certain limitations towards moving electricity consumption. Several of the participants in our study mentioned that FlexiViz had certain limitations. The price of electricity visualised in FlexiViz were based on real data. However, the households were well aware that if they acted according to those data nothing would happen to their electricity bill. We argue that a limitation towards our study was that the actual electricity price did not change according to data in the system. This would probably have enabled us to go further into detail of motivations towards moving electricity consumption.

Another possible limitation in FlexiViz was that we could only measure on appliances that were connected to the ZenseHome system. During the interviews focus were on heavy electricity consuming appliances such as the stove and the washing machine. A drawback was that we could not measure the consumption of such appliances, because they were not connected to the ZenseHome system. This meant that we could not verify using our quantitative data if participants had actually succeeded in moving any electricity consumption. Measuring these appliances would probably have enabled us to verify several statements from participants as well as showing more precise information in FlexiViz.

9 Further Work

In this project we have presented our work in two articles. In the first article we introduced FlexiViz, a flexibility-enabling eco-feedback display that visualizes information related to moving electricity consumption. In the second article we used FlexiViz to explore the human factors in moving electricity consumption. We see the following possibilities for further work.

Designing Systems for Flexibility

We developed FlexiViz based on the two first stages of behaviour change described by Riche et al. The designs underwent early evaluation to ensure that users would understand the designs. While the participants did understand the designs, we did notice certain suggestions for changes. We used FlexiViz as a technology probe, but instead of focusing on human factors we suggest that further work could go more in depth concerning design implications. Furthermore we suggest an approach where participants should be the center of design.

Measuring Behaviour

During our study we did not see any persistent change in user behaviour from our quantitative data. The purpose of FlexiViz was to supply us with topics for discussions during our interviews. We suggest a redesign of FlexiViz if the purpose is to measure changes in electricity consumption behaviour. We suggest that users should interact with the system whenever they move electricity consumption, making it possible to observe specific behaviour changes. Another way to address the problem towards measuring behaviour change could be by getting the participants to keep a diary of when and why they decided to move electricity consumption. This would give further discussion topics to the semi-structured interviews, and it would allow for more in-depth questions. For example it would be possible to ask about specific occasions where electricity consumption had been moved.

Maintaining Sustainable Routines

In the first article we presented the design for FlexiViz. Another idea for further work could be to explore the last step suggested by Riche et al. which is maintaining sustainable routines. This step requires the design to evolve with the users needs which requires that the study continues for a longer period of time to be able to observe the effects of such a redesign. We therefore suggest that the study in this report continues and that the design evolves to fit the users.

Bibliography

[1] Kirsten Gram-Hanssen. Husholdningers elforbrug-hvem bruger hvor meget, til hvad og hvorfor? 2005.

[2] Department of Energy and Climate Change. Demand Side Response in the domestic sector - a literature review of major trails, 2012.

[3] Sophie Nyborg and Inge Røpke. Constructing users in the smart grid - insights from the Danish eFlex project. *Energy Efficiency*, 6(6):655–670, May 2013.

[4] Danmark må nu importere el hver eneste uge. `http://www.dr.dk/Nyheder/Indland/2014/05/28/0528082848.htm`, Online; accessed 28. May 2014.

[5] Craig Morris. Reforming the Renewable Energy Sources Act (EEG) – Market solutions for market failures. *energytransition*, 2013. `http://energytransition.de/2013/10/market-solutions-for-market-failures/`, Online; accessed 2. May 2014.

[6] Michael Hogan. Aligning power markets to deliver value. *The Electricity Journal*, 26(8):23 – 34, 2013.

[7] Aditya Mishra, David Irwin, Prashant Shenoy, and Ting Zhu. Scaling distributed energy storage for grid peak reduction. In *Proceedings of the Fourth International Conference on Future Energy Systems*, e-Energy '13, pages 3–14. ACM, 2013.

[8] Matthew P. Johnson, Amotz Bar-Noy, Ou Liu, and Yi Feng. Energy peak shaving with local storage. *Sustainable Computing: Informatics and Systems*, 1(3):177 – 188, 2011.

[9] Ea Energy Analyses. *Intelligent energy systems. A white paper with Danish perspectives*. Ea, 2010.

[10] TotalFlex. `http://www.totalflex.dk/`, Online; accessed 2. May 2014.

[11] Dennis Lund, Michael Kvist Nielsen, and Tue Hald Hald. Powerviz: Investigating the impact of an always-on eco-feedback display for appliance level consumption. January 2014. (2014).

[12] Yann Riche, Jonathan Dodge, and Ronald A. Metoyer. Studying always-on electricity feedback in the home. In *Proc. of the SIGCHI Conference on Human Factors in Computing Systems*, pages 1995–1998. ACM, 2010.