Lumen

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ABSTRACT

Within sustainable HCI research, we see a growing interest to study how designing interactive technology can improve the utilisation of renewable energy resources. In this case study, we explore the concept of energy communities and how technology can be designed to support people to cooperate around transitioning to a more sustainable use of electricity. To do so, we designed the Lumen prototype, which aims to support a small energy community in shifting domestic energy-consuming practices to align with times of high availability of sustainable energy. By creating awareness of current and future sustainable energy availability through an ambient feedback display, the Lumen prototype informs households about the community's consumption patterns. To obtain insights into how people understand and experience an energy community, we conducted a qualitative field study with three Danish households. Through our study, we found sustainable awareness and incentives materialised in the ambient display were amplified by the dynamics of the community. We conclude by discussing future directions for exploring how to design technology for energy communities.

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CCS CONCEPTS

• **Human-centered computing → Empirical studies in interaction design**.

KEYWORDS

Energy communities, ambient design, sustainable energy, SDG, case studies

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1 INTRODUCTION

Sustainability is currently one of the most debated topics on the global scene, because of climate change. To help build a plan of action, the United Nations has defined the Sustainable Development Goals (SDG) [20], which comprises a set of 17 goals for sustainable development. Some of these goals focus on climate action, renewable energy consumption and sustainable communities. In this case study, we explore these in combination.

One way to combat increasing carbon emission is to consume electricity from renewable resources like wind and solar power. In most Western societies, electricity has become a resource people are accustomed to always have access to, no matter time or place. Yet, the place and, in particular, time at which electricity is consumed can greatly influence the impact electricity production has on the environment. Depending on the availability of sustainable energy

sources, the emission of greenhouse gasses can be significantly larger at certain times of the day. Matching supply and demand for electricity is a challenging task, doing so with sustainability in mind is an even greater challenge. As electricity is far more intangible than sorting trash or eating less meat, HCI scholars have investigated how to raise awareness about energy consumption and its sustainability implications.

To address the challenge of raising awareness of energy consumption habits, HCI research has explored various forms e.g. digitalised visualisations [17, 26] and physical forms [13, 16, 24] to support individuals in 'shifting' energy-consuming practices in time and place [21–23]. Examples include eco-feedback (e.g. [7, 22]), lighting (e.g. Watt-Lite [15]), ambient feedback (e.g. [8, 25]) as well as a street-sized graph visualisation showing energy use within a community-based street in Brighton [2].

We have lately witnessed different projects investigating how technological-driven solutions (e.g. smart-grid infrastructures and smart home technology) can address various problems related to sustainability and energy [3, 12]. However, while the overall aim of these software infrastructures and services is to monitor and control energy consumption in people's home, these also offer support for groups of people to gather in renewable energy communities. Such communities could prove an efficient way of hastening the transition to more sustainable energy consumption, providing an incentive for people to enter the energy market and become advocates for using energy from renewable sources [29]. Today, we see different examples of what energy-communities are and could be, ranging from self-defined to pre-defined and from geographically dependent proximity communities to interconnected wide-spread communities [9, 29, 30]. In Brooklyn, NY, the Brooklyn Microgrid Energy Marketplace seeks to connect solar panel owners and environmentally conscious local consumers, to create a community sustained by locally produced electricity [18]. Another example is the Danish concept called Eco-Village [5], which is a self-sustained community. The concept relies on house-sharing and utilises modern energy-, water- and heat-saving technologies to maximise the sustainable aspects of living together.

In HCI, the concept of energy communities has only sparsely been explored. Simm et al. [26] co-developed a forecast display with an energy community located on a remote island, while Dillahunt et al. [4] studied a community-focused eco-feedback app among two localised communities. Both studies found that changing energy-consuming habits can be influenced by social engagement in a community. Other studies have worked with designs that take private data, like energy data, and make it publicly available. For instance, Valkanova et al. [28] designed and evaluated the prototype 'Reveal-it', a public, interactive social visualisation that facilitates citizens to compare energy data both as individuals and communities. The authors found that while abstract visualisation techniques can evoke curiosity, such techniques also have an impact on how people understand and trust such information. Similarly, Moere et al. [19] evaluated a custom-made chalkboard designed to convey different visualisations of household energy usage to purposely encourage local support of more effective energy conservation.

In this case study, we seek to explore how to design for an energy community that looks beyond geographical limitations. We aim to investigate how technology can be designed to support households to gather in an energy community across greater physical distances, by allowing socially connected groups to cooperate around transitioning to a more sustainable use of electricity. To do so, we designed the Lumen prototype system that provides social knowledge about the community's consumption patterns through ambient feedback. With the participation of three households (six participants) in one of Denmark's larger cities, we evaluated how a small energy-community can inspire each other to shift a larger percentage of their electricity consumption to electricity made from renewable sources. From this, we gained knowledge on how to design to increase awareness, inspire sustainable behaviour and create a sense of community around electricity use.

2 THE LUMEN PROTOTYPE

To explore the concept of an energy community aiming to shift electricity consumption to times where it is sustainably favourable, we designed the Lumen prototype. The main purpose of the Lumen prototype is to provide ambient feedback on shifting at a community level. To support this, the Lumen prototype was built as a two-part system: One part designed as a physical ambient light display (see Figure 1) giving households immediate feedback on the collective electricity usage of the community, and a second part designed as a digital application (see Figure 2) aiming to encourage households to explore both individual and community consumption data in more detail.

The system is supported by smart plugs that can monitor electricity use of individual household appliances e.g., vacuum cleaners, charging devices, lamps, and dishwashers. To determine what are the most and least sustainably favourable times of the day to consume electricity for the next 12 hours, the Lumen prototype determines if electricity is sustainable, by utilising data from an external energy data service provider [6].

2.1 The Physical Ambient Feedback Display

The physical ambient feedback display of the Lumen prototype was designed as a set of physical wall-mounted hexagon light covers (see Figure 1). We chose to design an ambient feedback display as other research has indicated that ambient feedback can be an intuitive means for households to better understanding energy consumption [8]. At the same time, we opted for a wall-mounted design that embeds aesthetic and ambient design qualities because introducing such feedback devices into the home requires thoughtfulness to the surrounding domestic context [25]. Besides aiming to provide information on the status of electricity consumption, the physical presence of the Lumen light display was purposely designed to be a continuous reminder of a households' relation to the community and their common goal to consume electricity sustainably.

To design feedback for the collective electricity usage, we conceptualised an energy community as a set of hexagon covers. This same setup is represented in every household of the community. Each household within the community is represented with a light cover surrounding the centre hexagon cover (see Figure 1). The centre cover represents possible sustainable consumption and turns on if the current electricity is considered sustainable (see Figure 1.1). If the currently available electricity is not considered sustainable, none of the lights will turn on. This means if a household

Figure 1: The Lumen physical ambient light displayed in a participating household. 1) The centre hexagon cover lights up to display that the current electricity is considered sustainable. 2) This cover illustrates that the current household is using electricity. 3) These two covers show, which other households in the community are using electricity sustainably.

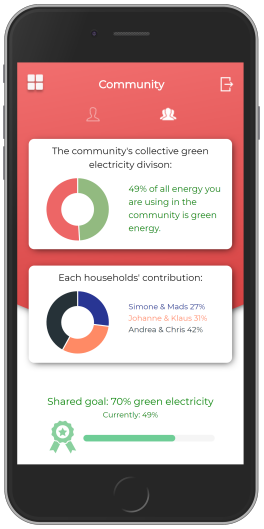

Figure 2: The Lumen digital application displaying the community page. The red background colour illustrates that currently, electricity usage is considered unsustainable.

consumes non-sustainable electricity, this will not be visible to the community. Thus, a household's respective light cover will only turn on if they are currently consuming electricity that is considered to be sustainable (Figure 1.2). Likewise, other lights in the set of hexagon covers will turn on if other households in the community are consuming electricity sustainably (Figure 1.3). This means the wall-mounted lights in Figure 1 represents three households in an energy community, whereof all are currently using energy that is considered sustainable.

2.2 The Lumen Digital Application

The digital application of Lumen was designed to support households with exploring consumption data. This app provides a simple overview of each households' use of electricity and how much of it is sustainable. The background colour of the app is specific to the state of the available electricity (Figure 2). If the current electricity is considered sustainable, the background colour is green and red if not. The information in the app can be viewed either as accumulative consumption data or specified for each electric product used. As not all devices can be plugged into a smart plug, the app has features allowing households to manually log usage of electronic devices.

Additionally, the app provides a forecast of the status of electricity for the next 12 hours supporting households in shifting their consumption. Lastly, the app gives access to information on the community's collective electricity consumption.

The community page displays energy information contextually relevant to the community (Figure 2). The shared goal is designed to give a common incentive in the community to use sustainable energy. With this, members of the community can see the percentage of sustainable energy consumed by the community, as well as a breakdown of how much each household contributed to that percentage.

3 QUALITATIVE FIELD STUDY

As the main purpose of our case study was to obtain initial insights into how people experience technology designed to support households to gather in energy communities across physical distances, we conducted a field study with three households. Each household lived with the Lumen system for a two-week period and thus, the prototype itself acted as a technological probe [11]. In an effort to maximise visibility, awareness, and engagement with the prototype, the Lumen physical ambient light display was mounted in the participants' living rooms (see Figure 1), while the digital application was installed on all participants' mobile phones.

3.1 Participants

In this study, we conceptualise closely acquainted people as a form of a virtual energy community [29]. Therefore, we required that recruited participants were already familiar and comfortable with each other, as we wanted to explore what happens if an existing community become aware of sustainably consuming electricity as a collective. We recruited participants through our social networks by snowball sampling. Six people (three couples) in three households participated in our field study. Five of the participants were aged 25 and students at university level, while one was aged 26 and working full-time. All participants were conscious of sustainability issues and incorporated various sustainable routines into their daily lives, e.g. sorting their waste. Before the study, none of the participants contemplated the carbon footprint of their electricity consumption, or that shifting electricity can be considered a sustainable practice.

3.2 Data Collection and Analysis

We conducted two semi-structured interviews with all three households. Firstly, we collected data through an initial interview when

the study began. The purpose of this interview was to gather insights on participants' motivation for participating, how their community currently functioned, and their thoughts on sustainability and electricity consumption. In this interview, we also introduced the Lumen system to the participants, where they were able to ask clarifying questions about the concept. The second interview was conducted at the end of the study, and questions were focused around participants' experiences and behaviour during the study period, reflections on values regarding the Lumen system, and the added component to their community. Two and a half hours of audio recordings were transcribed and divided into singular statements for the data analysis. Five authors took part in thematically analysing statements by dividing them into named categories and using affinity diagramming to collect the categories in themes [1]. In the next section, we present two themes that emerged from this analysis; collective awareness in an energy community, and reflections of ambient feedback.

4 FINDINGS

4.1 Collective Awareness in an Energy Community

Our first theme illustrates how designing ambient feedback at a community level can create awareness of energy consumption that is extended beyond individual households. Our findings demonstrate different aspects of this. One aspect is related to how such a design can foster a feeling of being part of a community that collectively attempts to act upon sustainable challenges. P5 from H3, for example, reflected that; *"to do it joined with the others [trying to be more sustainable] has been the greatest factor, with sustainability being the second factor"* suggesting that, for some participants, feeling being part of a community was a greater motivator than acting sustainably in itself. This feeling of being part of a collective meant participants started to update themselves about their energy consumption patterns in relation to other households in the community during our study. P6 from H3, for instance, built into his daily morning routine to update himself on community data through the Lumen prototype. He explained this routine as follows; *"when I get up, I look at how everything is [the data], how we are matched in relation to the others and how the forecast is for green electricity"*.

The presence of the Lumen prototype also made participants aware of the community's view and opinion of themselves in varying degree. When asked how the presence of the Lumen prototype influenced participants decisions to actively shift electricity use to a more sustainable time, some participants reflected that decisions revolved around how others in the community saw them. A participant explained this as; *"because you would like to show the others that you're 'green' and that you think about when you use things [electronic appliances]"* (P5, H3). However, because Lumen integrates various data graphs allowing participants to compare themselves to others in the community, the feeling of community belonging also sparked competitiveness between community members. Because of this, we found participants becoming more focused on being 'the best' in their community, thus moving the focus away from the collective feeling of 'being in it together'. P1 from H1 explained this dilemma; *"It is an environmental thing, but I can't get around the competition"*, while P6 from H3 saw it as; *"for me, it has been that you want to win over the others"*. This comparison aspect of the feedback design appeared to cause a particular dynamic in the community leading to participants expressing a clear wish to be aware of consumption patterns in the community as consuming felt like a competition. P4 from H2, for instance, reflected; *"I have looked more at the shared front [data], but that is probably because of the competition, so that I could quickly see the score"*, while P6 from H3 most frequently used data to tell him *"who was leading in green energy and who was last"*.

Lastly, our findings indicate that having access to collective consumption data also meant participants started to monitor each other. P1 from H1 explained this aspect as; *"We have been afraid that [P6] might cheat, so we [P1, P2] have been looking over him"*. Interestingly, because the participants in our study were already very familiar with each other, they saw this behaviour as a friendly competition among friends and not a violation of privacy concerns. Even though data on electricity can reveal sensitive issues, e.g. how much a household consumes, when the household consumes, and when inhabitants are home, we found limited aspects of privacy concerns of sharing data in the participating community. P3 from H2 noted that *"I think it is because we know each other so well because it is kind of monitoring each other"*. P1 from H1 further elaborated on this stating that; *"this is not something I have had problems with"*. However, this is not to say that this would not be the case in larger communities with people who are not immediately familiar with each other.

4.2 Reflections of Ambient Feedback

Our study further showed that the feedback from the ambient displays in Lumen served as a physical reminder for the participants, in the ways of how they were using electricity, being part of the community, and participating in the study. We saw examples of the lights inspiring participants to shift their electricity consumption with P1 from H1 remarking *"The light has been a good way of reminding us that 'green' electricity was available, and then you just think if there is anything that could use electricity right now"*. P1 also reflected that; *"I think 'do we have a phone that needs power' when I see the [Lumen] lights on"*. P1 also noted that the lack of a reminder in other spaces caused missing reflections on sustainable electricity availability saying *"At Uni I have not looked at whether there was green energy when I have charged. At home, I'm reminded by the light."*. P3 from H2 supported that physical presence of the lights saying, *"We have both [P3, P4] been good at being attentive to whether the light was on"*.

Along with this, a general theme of the colour choice for the lights emerged; *"I think it was a good choice to not use green light whenever 'green' electricity was available - that would be annoying"* (P3, H2). As a general rule, the participants thought that the ambient feedback should be subtle and non-intrusive, whilst remaining visible for the participants to reflect on their energy consumption at a given time. P1 from H1 commented that; *"she [P2] has always asked me when there is a green light, 'can we use the dishwasher now?'"*, showing that the Lumen lights prompted the participant to reflect on shifting their electricity consumption. Some participants noted that the physical part of the Lumen prototype also sparked

interest from visitors; *"when people have visited us, they ask what those lights are and then you have a nice talk about it. You try to explain why it's a good idea and then you reflect a little on it yourself as well."* (P3, H2).

5 DISCUSSION & CONCLUSION

Although designing energy feedback directly targeted at an energy community has only sparsely been researched in the HCI community, our case study illustrates that introducing such a design to a community can bring different facets with it. As discussed by others [2, 4, 26], designing energy feedback at a community level can help raise awareness on individual household's consumption patterns. While our case study illustrates that designing for the collective can be a driving motivator for people to engage with sustainability issues, our findings also bring other aspects of using such energy data that goes beyond the desire of increasing awareness of sustainable electricity use. Although we designed Lumen with the purpose to unite an energy community around a common cause, our findings showed it quickly became a question of who could be "the best" at being sustainable.

Others studies show that learning and competing with others can be beneficial to raise awareness of sustainability issues [2, 10, 13, 19, 28]. However, our study highlights that such aspects of communal feedback can lead to consumption patterns unintended by designers as competition becomes a driving incentive. In this case study, Lumen was not purposely designed to be used for a competition, but in hindsight, it is easy to see how it might be. The competitive dynamics of the community changed the course of the planned field study and provided interesting findings that differentiate from the design vision of the authors. Other studies highlight that the design vision, including sustainability, which designers embed into the design artefact does not necessarily align with the desires that shape energy-consuming practice [14, 27]. Thus, in the future, we believe it is important to conduct real-life, longitudinal studies, to better investigate how the effects of designing for an energy community can be maintained, but also to see how such designs may shape energy consumption over time.

Despite this misalignment between our design vision and how our design was experienced and used by participants, our work provides new findings towards understanding how designing feedback at a community level can influence energy consumption practices. Through the implementation of the Lumen system, we facilitated an existing community of three households, to focus on their awareness of sustainable electricity consumption. Our results show that leveraging the effect of a community can be a driver for creating sustainability awareness. We saw this especially in how the community members took energy consumption and sustainability challenges and incorporated it in other activities such as discussing it in the community throughout the study. These activities have strengthened the reflection on sustainable electricity consumption and might not be found in situations where a community was not a part of the practice.

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