DOI:
10.1145/3613904.3642449

Document Version
Peer reviewed version

SolarClub: Supporting Renewable Energy Communities through an Interactive Coordination System

GEORGIA PANAGIOTIDOU, King's College London, UK
ENRICO COSTANZA, University College London, UK
KYRILL POTAPOV, University College London, UK
SONIA NKATHA, University College London, UK
MICHAEL J. FELL, University College London, UK
FARHAN SAMANANI, University College London, UK
HANNAH KNOX, University College London, UK

Energy communities are a key focus for governments around the world in support of more sustainable energy practices. However, interactive systems for supporting energy communities to coordinate around renewable energy resources are still lacking. We present SolarClub, a demand-shifting visualization system that supported households in coordinating their energy usage by booking energy-hungry activities when solar energy was available. We deployed SolarClub with four groups of neighbors (N=15) for a month. SolarClub successfully enabled neighbors to coordinate, even when some of those participating households were less flexible. While participants reported that SolarClub did not foster a feeling of community, it helped them empathize with their neighbors. Our findings demonstrate the potential of sensor- and visualization-based technology to help understand the relation between everyday practices and resources consumption, beyond *individual* eco-feedback. This work thus contributes to the development of a next generation of practices and technologies that support collective action for environmental sustainability.

CCS Concepts: • **Human-centered computing** → **Empirical studies in HCI**; **Field studies**; **Empirical studies in ubiquitous and mobile computing**.

Additional Key Words and Phrases: energy communities, coordination, data visualization, demand-shifting, sensors

ACM Reference Format:
Georgia Panagiotidou, Enrico Costanza, Kyrill Potapov, Sonia Nkatha, Michael J. Fell, Farhan Samanani, and Hannah Knox. 2024. SolarClub: Supporting Renewable Energy Communities through an Interactive Coordination System. In *Proceedings of the CHI Conference on Human Factors in Computing Systems (CHI '24), May 11–16, 2024, Honolulu, HI, USA.* ACM, New York, NY, USA, 27 pages. https://doi.org/10.1145/3613904.3642449

1 INTRODUCTION

Within the current climate emergency, energy communities have emerged as a key element of many strategies for achieving transition to clean energy sources [8, 36]. These communities harness and store renewable energy, like solar or wind power, and seek ways to support local use of the power generated to help tackle challenges like decarbonization, grid management, and energy affordability. Energy communities take diverse forms, from neighbors sharing solar panels, to groups collectively switching energy suppliers, and are defined by collective forms of action and self-understanding that incorporate energy. Various governments, including the UK, are now also creating regulatory frameworks and initiating pilot projects to facilitate the growth of energy

CHI '24, May 11–16, 2024, Honolulu, HI, USA

communities [19]. Despite the potential and growing popularity of such communities, research on energy collaboration remains relatively limited within the field of HCI, especially regarding collective demand-shifting. Demand-shifting refers to the practice of adjusting energy consumption patterns, so as to align with the availability of renewable energy resources. For instance, it might involve modifying the timing of energy-intensive activities, such as using household appliances or charging electric vehicles, to coincide with periods when renewable energy, like from solar or wind sources, is available. In the context of energy communities, demand-shifting requires additional coordination across households so as to ensure that the total communal consumption still remains within the available renewable energy.

For HCI this coordination offers a number of interesting challenges for supporting the technical as well as the social expectations of these groups. For instance, the interfaces and applications such communities may need to coordinate might vary depending on the diversity of renewable sources and storage solutions, the community's size and social fabric as well as their energy and technical literacy. Preliminary, exploratory work on community demand-shifting has suggested that coordination can introduce complexities such as accountability, privacy, fairness, social harmony [39], as well as the necessity for cooperation [26, 27]. Nevertheless, such prior work has mostly examined coordination theoretically, outside the context of actual neighborhoods [27, 39] and has used off-the-shelf technologies rather than develop them in a user-centered way [26]. Since in-the-wild evaluation can help produce more ecologically valid insights on the use of domestic technology [52, 53], we build on existing research to design SolarClub, an energy community coordination system, and then evaluate it in-the-wild with real households.

Inspired by existing community energy pilots [35], we specifically designed for the situation in which a group of neighbors (which we refer to as a 'club') share the energy generated by a solar panel that is collectively owned. Following a user-centered process we propose SolarClub, an interactive tool through which households can indicate their intention to run high-consumption appliances. SolarClub serves both as an eco-feedback system to examine live group energy consumption, as well as a coordination tool for future energy use. We deployed SolarClub in-the-wild with four groups of neighboring households in the UK and investigated its reception. The solar generation from the shared panels was simulated using real live data.

Through a combination of interviews and interaction log data, our findings indicate that the design of SolarClub successfully enabled neighbors to demand-shift and coordinate their electricity consumption, even when some participating households were less flexible themselves. Nonetheless, despite feeling able to coordinate, participants expected a stronger *feeling* of community, which SolarClub did not offer. Finally, unlike previous studies, not conducted in-the-wild, we found that participants asked for less rather than more privacy within their clubs and saw how SolarClub encouraged a feeling of empathy to neighbors even if they didn't actively engage in-person throughout the deployment. We unpack these findings in the context of prior work, and present a series of considerations for designing demand-shifting systems among energy communities. This study makes a novel empirical contribution to demonstrate how HCI can support energy communities, while also broadening our understanding of the forms energy communities can take. These findings thus can support governments and other stakeholders work towards a renewable energy transition.

2 RELATED WORK

This work relates to energy communities, and specifically to how eco-feedback can inform collective demand-shifting. We thus first discuss research prototypes that are meant to support demand-shifting and then survey emerging work in HCI which examines eco-feeback for energy communities and similar collectives.

2.1 Supporting Energy Demand-shifting

The turn to renewable sources of energy also requires a shift from 'demand-based' energy consumption patterns, in which energy is available at any moment, to 'supply-based' patterns, in which availability is conditional on renewable sources such as wind or solar [9]. While fluctuations in supply can be smoothed out with the use of smart grids and battery storage [9, 48], such solutions nevertheless can be costly and even environmentally unsustainable [62]. Load or demand-shifting [12], i.e. the alignment of energy consumption to the generation of a renewable energy resource, is therefore potentially a more affordable, efficient and sustainable solution to the unpredictability of renewable sources. Demand-shifting usually entails shifting flexible, energy-intensive household activities, like laundry and EV-charging, to times when renewable power is available [45]. Which activities are considered 'flexible', however, varies significantly across households, and is influenced by lifestyle, values, and home specifics [30].

HCI research has long emphasized that energy is an abstract concept that can be difficult to understand [43] making tasks like demand-shifting challenging. To address this, researchers have developed different visualizations to represent energy data as part of eco-feedback systems [17]. These range from statistical representations to more ambient artistic physicalizations (see [6] for an overview). Jensen et al.[24], for instance, developed 'the Box', which signaled the presence of renewable energy prior to participants starting their laundry: effectively motivating families to conduct their laundry during periods of renewable availability. Bourgeois et al. [4] deployed a similar intervention for shifting laundry loads and found that engaging users with energy issues right in front of the washing machine, seems to align best with the activities that people use every day to organize their life. Collaborating with a remote island community in the UK, Simm et al. [57] created real-time visualizations to help synchronize individual households' energy consumption with a renewable energy supply. Costanza et al. [10] deployed an agent-based booking system that took into account the weather forecast to create dynamic pricing of the different laundry slots during the day. Rasmussen et al. proposed ClockCast [50], a clock-like device, that indicated optimal times for electricity usage (rather than avoidance) so as to support more sustainable behaviors. Using a traffic light system consisting of green, yellow, and red indicators to forecast green energy availability and grid status, Kluckner et al. [32] identified specific color 'zones' within which energy shifting tended to occur. Quintal et al. [47] *physicalised* information on renewable sources in Watt-I-see, summarizing the current state of the renewable energy in the grid within a glowing powersocket. Similarly to Watt-I-see, Morais et al. [38] proposed Lumiphys, a physicalisation on how energy is produced (e.g., solar, hydroelectric, wind) as ambient environmental displays to support more informed decisions.

The impact of deploying eco-feedback systems for supporting demand-shifting however goes beyond just changing energy habits, as people tend to also change their social practices around such interfaces. Previous work has shown for instance, how people started repeatedly consulting their energy status, or force-spending energy when there was an apparent excess [44]. As the next section discusses, these social practices are especially impactful in collective settings.

2.2 Eco-feedback for Collectives

Despite their popularity, eco-feedback systems have also been critiqued for their tendency to focus on individuals rather than collectives [60]. Accordingly, from public displays to personal apps, there is an emerging body of work aiming to facilitate collective discussion and reflection around energy. In some of this work the eco-feedback itself was public but action in response to eco-feedback remained up to individuals whereas in others, like in our case, the eco-feedback was meant to elicit coordinated action. We summarize these related studies here, focusing on considerations that have informed our design.

Community-level feedback through ambient and public displays has been used to help households compare and then lower their individual energy consumption patterns. In the neighborhood project Tidy Street [55] for instance, energy consumption of different households was drawn with chalk on the public streets, thus encouraging people to reflect on each other's consumption. Similarly, Vande Moere et al. [37] presented a household's energy consumption hand-drawn on their house façade prompting discussions in the wider community. Such normative comparisons among households have been shown to support more long-term change in energy consumption patterns [13].

Nevertheless, interfaces that encourage competitive comparison among households are also perceived as outside the spirit and values of energy communities [26, 27, 39]. The Lumen ambient display for instance aimed to support an energy community in shifting domestic energy-consuming practices to align with times of high availability of sustainable energy. They found that community dynamics played an active role in the adoption and appreciation of the system and that the system nevertheless provoked unwarranted competition [20]. The Community Energy Planner [26], an off-the-shelf eco-feedback app which helped a group of households collaborate and collectively shift around renewable energy similarly identified issues of competition because of viewing other's energy patterns even when that was outside in the designers' intentions.

Whether digital or in-person, communication seems to be key in collective energy systems. Wilkins et al. [61] surveyed household reactions to peer-to-peer energy trading, i.e. micro-grid collectives that trade energy among themselves, to derive design considerations for digital platforms that can support it. Crucially they found that such platforms should provide infrastructure to allow for interaction among groups. Moreover, they documented how peer-to-peer energy trading has ecological, economical as well as social benefits for communities. Scuri et al. [56] developed and tested PowerShare, a decentralized, peer-to-peer energy trading platform within a community of households, noting the crucial importance of trust in the mediating technology in enabling successful trading. Interestingly, they also highlighted the importance of personal relations, noting how pre-existing relationships among neighbors allowed them to cultivate trust. Learning from this work, we added various communication modalities to SolarClub such as notes on bookings and messaging as will be described in Section 3.2.

Specifically as it relates to collective demand-shifting, previous work used 'energy blocks' [39], physicalizations of the energy consumption of participant's activities, to uncover how people would coordinate using a shared solar panel. Participants were asked to place these energy blocks on a printed solar curve according to their schedules so that "they could easily compare when their collective consumption was going over the generation (out of the curve)"[39]. They found that participants expected different modes of energy coordination ranging from immediate, short- and long-term and uncovered issues of accountability and automation as core themes for system design for energy communities [39]. As the coordination activity made household consumption patterns visible by providing each participant with differently colored blocks, issues of privacy also entered the discussion. Participants suggested that a careful balance was necessary to sustain the already fragile relations among neighbors. Other similar work also found a need for real-time data to help individual households "adapt their activities to the needs of the community" as well as for flexible ways of indicating the use of various energy intensive devices among community members [42]. A limitation of such existing work on collective demand-shifting has been its speculative nature. Few studies to date have deployed technologies in real households to understand the actual behaviors and social relations arising from their use.

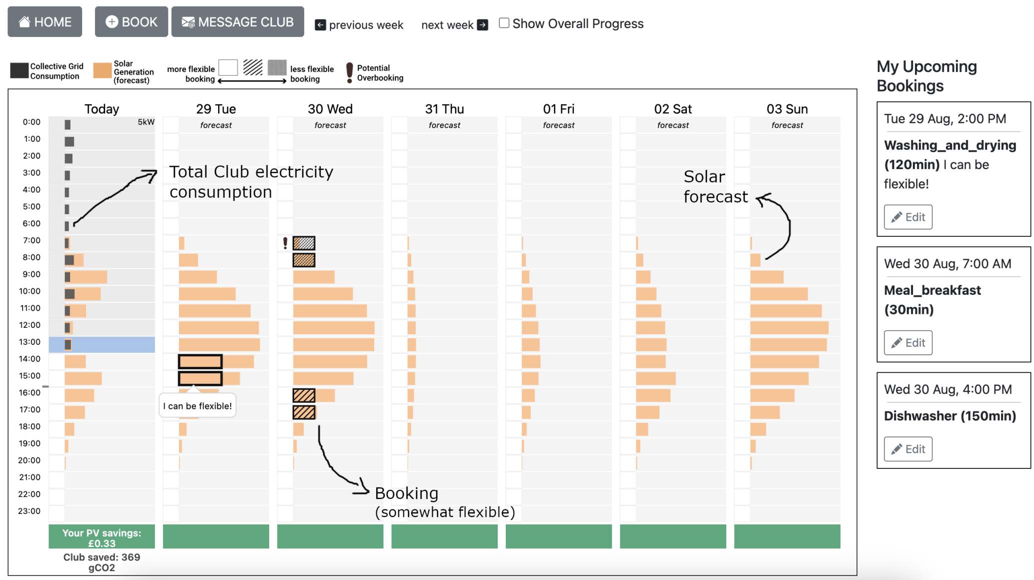

Fig. 1. The SolarClub coordination overview page. In dark gray is the total electricity consumed by the club collectively. In orange is the simulated actual solar generation (in the past) and the forecasted solar generation (in the future). This allows a quick comparison of whether the club has overshot the generation of their panels. Three bookings are also depicted: a 'flexible' one with a note (on Tuesday 29th), a 'somewhat flexible' one (on Wednesday at 4pm) and a 'non-flexible' one on Wednesday morning. The individual PV savings and collective gCO_2 emissions saved are depicted at the bottom of each day (in green).

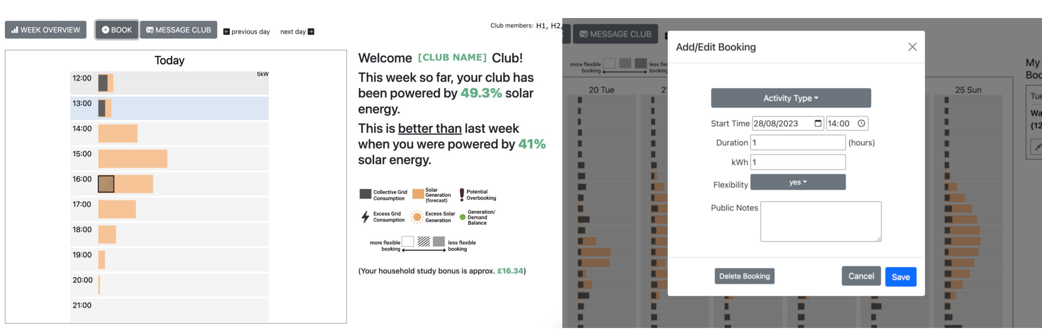

Fig. 2. The daily view page of the coordination interface (left) as well as its booking view (right). The daily view offered some summary statistics for the club as well as the household bonus incentive. In the booking interface, once an activity was selected, the values for the duration and kWh were populated based on the household's previous annotations (see Figure 3).

3 SOLARCLUB

3.1 Design Rationale

Based on the insights from the Related Work, we designed and developed SolarClub: an interactive tool to support energy communities in demand-shifting and coordination. Previous work exploring collective energy consumption has considered real-time feeds of energy generation [14, 20, 25]. For instance, Lumen [20] indicated whether electricity currently being used by any of the participating households was considered sustainable and the Ener-geyser [14] visualized peak times of high demand for energy as a community fountain. However, households in these studies were only given a momentary snapshot of solar-energy availability and the level of collective household consumption, without any indication as to how these would continue or vary over time. Such information is necessary for household decision making.

In contrast, SolarClub is based on the principle that in order to be able to efficiently and collectively use the limited resources of a shared photovoltaic (PV) installation, households need to be able to *see a forecast* of when renewable energy is expected to be available, and to *communicate* their intention to use energy at specific moments in time. Accordingly, SolarClub provides a visualization of the expected PV generation and allows households to book time-slots for their energy-consuming activities, which are shared with the other members of the community. To indicate the duration of the activity, we based our design on the "energy block" [39] concept, modeling our bookings and visualization with a similar modular aesthetic. SolarClub also builds on the AgentB user interface [10] in terms of the renewable energy forecast, and booking activities. However, while AgentB bookings were a tool to control an autonomous agent charging a battery, in SolarClub they are primarily for human-to-human communication, to signal one's intentions to other community members, while also serving as an expression of commitment [1] to consume when solar generation is available or even abundant. Together, these features were intended to enable intricate coordination though a simple, booking-oriented platform. SolarClub also displays the past collective energy consumption of the community, together with the historical solar generation data, to support retrospective reflection.

Moreover, we aimed to avoid previously reported pitfalls by promoting a cooperative rather than competitive approach among households. We did that by not using leaderboards or similar individualistic designs, but instead we emphasized the collective rather than individual savings (although both were depicted in the interface) and added group level information such as the CO_2 the group saved and their percentage of solar energy usage per week. Finally, informed by discussions on community privacy [39] we took a privacy-preserving approach removing identifiable information from the bookings and the historical energy consumption visualizations.

3.2 Coordination Interface

In SolarClub two web pages provide an interface for coordination: the overview (Figure 1) and the daily (Figure 2-left) pages. Both pages include a calendar-type visualization that is divided into hours. For each hour, the SolarClub depicts the forecasted solar energy production (in orange), the collective energy consumption of all club households (in dark gray) as well as the potential future bookings (in overlayed black blocks). Users also have the option to browse back in time to see previous weeks. The overview page presents 7 days worth of data, while the daily page, which is optimized for mobile view, only one day. The daily page also includes a summary message of the percentage of the club's solar energy use as well as a summary of the household's bonus incentive (Section 4.2).

Besides showing the energy forecast and generation, on the two pages participants could create *"bookings"* for their electricity consumption. Specifically, through a pop-up dialog box as seen in Figure 2-right, they could select the activity type they intended to do and schedule it for a time in the future. For ease, the kWh of each activity type was pre-populated from an earlier annotation phase (as will be further explained in Section 3.5). Bookings were visually presented on the visualization as overlayed black blocks that spanned across the different hours (averaging the activity's consumption over time). Figure 1 for instance, shows three such bookings of two hours each. Informed by previous work that captured shifting flexibility [39] when creating a booking, households could also indicate to their club members how flexible that activity was (the options were 'flexible', 'somewhat flexible', 'not flexible'). This flexibility indication would then appear as a different shading on the booking's overlayed black blocks in the visualization.

In addition to the shared bookings, SolarClub also offered two modes of communication among club members: the Message Club feature and the notes on the bookings. Continuing our privacy-preserving approach, we designed all of the means of communication to be anonymous. The Message Club feature opened a popup screen in which users could fill in a title and a message. Messages were reviewed by a moderator from the research team, before being sent as an email to all the members of the club. To achieve anonymity and to also support the moderation, messaging was set up as a mailing list for each group of participating households. Users could also leave optional notes when creating bookings to indicate any additional information. In the visualization these notes appeared when hovering (or tapping on a mobile device) over a booking as shown in Figure 1.

3.3 Email Messages

Each week participants received a summary email notifying them of their group's progress in number of bookings made, as well as amount of carbon emissions saved. To make the emissions saved more relatable in this email, they were additionally described as car driving distance in miles e.g. "Your energy club made a total of 16 bookings this week and saved 6.71 kg of CO_2 – that's the equivalent in emissions of driving an average gasoline-powered car 17.2 miles". Finally, if a booking was mentioned as 'flexible' or 'somewhat flexible', the SolarClub system sent automated notification email when other households might have overbooked for the same time. The email message informed that another household has also made a booking for the same time and that if the receiving participant was flexible they could go back to the interface and reschedule their own booking. In the interface this appeared as an exclamation mark next to the hour (as seen in Figure 1 on Wednesday at 7am).

3.4 The Sensor Kit

SolarClub depicted the live energy consumption of all the households together (in dark gray). To achieve this, we installed a dedicated sensor kit to each household. The sensor kit consisted of a Raspberry Pi and an electricity consumption sensor with a current clamp. The Raspberry Pi was connected to the household's WiFi so as to be able to upload the measure energy data to a secure university server. To sense electricity consumption sensors we used the Open Energy Monitor EmonTx device[1] with our own firmware, or custom hardware equivalent to the EmonTx[2], depending on availability. The current clamp connected to a cable of the participant's electricity meter so that the measured electricity voltage was sent via radio to the Raspberry Pi (using HopeRF RFM69 radio transceivers). These values were then uploaded from the Raspberry Pi to the aforementioned university server and stored in an time-series database (InfluxDB[3]).

3.5 Annotation Interface

In order to create the personalized list of 'bookable' entries for each household, SolarClub included an *annotation interface*. For this interface we re-implemented and extended FigureEnergy [11], an "interactive visualization that allows users to annotate and manipulate a graphical representation of their own electricity consumption data". The interface contained a live view of the household's energy consumption collected through the installed sensor kit. The consumption was shown as a bar chart over time averaged to 30-minute intervals blocks (Figure 3-left). Once identifying an

[1] https://guide.openenergymonitor.org/technical/emontx/
[2] https://learn.openenergymonitor.org/electricity-monitoring/ct-sensors/interface-with-arduino
[3] https://www.influxdata.com/products/influxdb-overview/

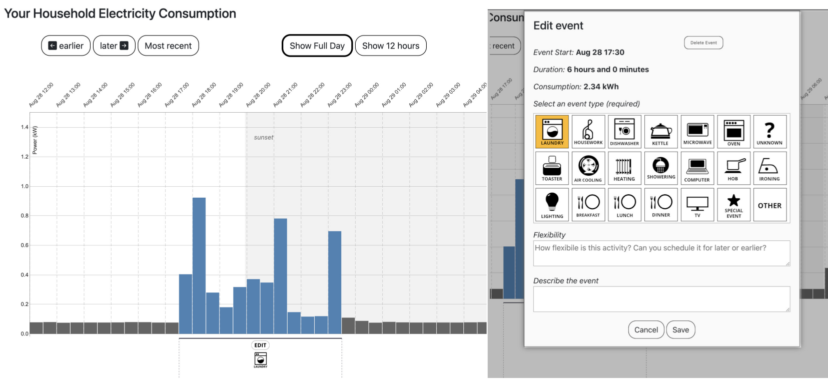

Fig. 3. Left: The Annotation interface. Here the x-axis indicates time while the y-axis is Power. In dark gray (or blue when annotated) is the live consumption of that household. Consumption peaks such as the one shown in blue can be selected and annotated with the pop-up interface shown on the right. Right: a series of pre-generated activities are presented to assist participants to annotate their consumption peaks. Note how the duration and total consumption values are populated for the corresponding activity. These are the values used by the SolarClub system for making bookings.

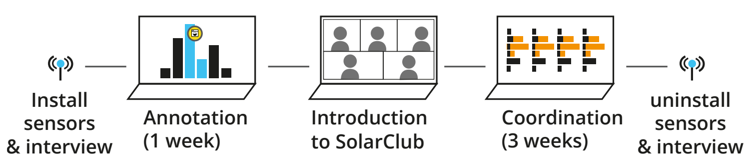

Fig. 4. Study design and process of deployment. The introduction to the SolarClub in some cases was done via a pre-recorded video tutorial.

area of increased consumption, participants could highlight and 'annotate' that area using a series of pre-generated options as icons (see Figure 3-right). The annotations were saved in a relational database on the same university server.

Besides allowing the creation of a 'catalogue' of the household energy-consuming activities, annotating enabled participants to better understand and reflect on their everyday habits and energy consumption patterns as was found in prior research [11, 22].

4 METHODS

In this section we describe the in-the-wild evaluation of SolarClub with four groups of neighbors in the UK. To give a brief overview, the process went as follows: first, households were fitted with the sensor kit that could measure their live electricity consumption (Section 3.4). They then spent one week annotating their activities (using the UI described in Section 3.5), and finally they coordinated their energy consumption with their neighbors for three weeks (using the UI described in Section 3.2, which was revealed to them only at the end of the annotation week). A visual overview of the process is presented in Figure 4. For the purpose of this study, SolarClub only *simulated* energy generation[4] because we wanted participants to be able to experience solar usage

[4]Received from the https://forecast.solar API assuming a total of 4KW panels facing South and with an inclination of 37 degrees (which is considered the the optimal orientation to maximize total electricity production).

even before deciding to purchase, and because the installation of real solar panels went against logistical, budgetary and current regulatory constraints. The work was approved by UCL's ethics commission (UCLIC_2022_004_Costanza).

4.1 Study Design

After getting consent, two researchers visited the participants' homes to install the sensor kit and to give a short demonstration of the annotation interface. During the installation visit, they also conducted an entry interview probing the household's relation to energy, climate change and sustainability as well as handed out a basic demographic survey. This process, which we refer to as 'onboarding', included any members of the household that were available at the time. Participants had the functionality of the SolarClub system explained to them, but were not told that they had to make use of this functionality in any particular way (besides providing annotations in the first week). Rather, they were simply told that an incentive payment would be proportional to their ability to shift electricity usage towards using solar instead of the grid during the coordination phase. Participants were then asked to spend one week using the annotation interface, highlighting the activities that appeared as peaks in the consumption graph (without doing any changes in their behavior yet). Participants did not have access to the coordination interface in this annotation phase, but only the annotation view.

Following the annotation week and whenever possible, the participants were introduced to the coordination interface as well as to each other via a 30-minute online workshop. Where the workshop was not organized, we sent participants a video tutorial of the SolarClub coordination features. The workshop (or video tutorial) officially signaled the kick off of the coordination phase that lasted 3 weeks, making the whole deployment a total of 4 weeks.

During the coordination phase participants could use the SolarClub coordination features (Figure 1, Sections 3.2 and 3.3) to do the following actions: (1) create or edit an energy booking, (2) check the availability of solar energy, (3) browse the historical patterns of the club's consumption/generation, (4) get feedback on their savings in carbon emissions, reward and monetary terms and (5) message the other members of their club. At the end of the coordination phase, two researchers uninstalled the sensors and conducted exit interviews. Participants were then interviewed on their experience of collectively coordinating with their club, on their interactions with the interface and on the impact of this deployment on their broader views around climate change, sustainability and community energy. All interview and workshop protocols can be found in the supplementary materials.

4.2 Recruitment

Since we were simulating an energy community, we wanted to test our system with actual neighbors as previous work has described how such relationships can be fundamental in the reception, adoption and use of such systems [39, 56]. As such, we set out to recruit groups of 3-5 neighbors wanting to go through the deployment simultaneously. Accordingly, we recruited through a variety of means. The first two groups were found by contacting two past research participants and asking them to forward our call to their neighbors. The last two groups were recruited by on-street leafleting and snowballing in a UK council estate. Incidentally, each group held some type of relation before this deployment even if the participants did not always know each other. Group 1 was part of a street book-club which met monthly. Group 2 was part of a common street which shared its own email list. Groups 3 and 4 (located in a different neighborhood) were part of a council estate that has a lively local community as well as an active tenants and residents association, which meets monthly for discussing common affairs. From the 15 households that participated, 13 completed the full study, one household (H14) partially completed the study (participants went on vacations) and one household (H15) withdrew after some initial interest due to lack of time.

For their participation, households were given £50 as well as an additional bonus of up to £50 depending on their energy shifting. The bonus, calculated based on their relative solar consumption, was visible at all times on the daily page. To calculate the bonus, we compared what percentage of their consumption was solar-powered during the annotation phase (our baseline) and then compared it to the coordination phase. We assumed that the relative difference among the two constituted their shift towards hours of solar energy as they were not instructed (or encouraged) to change patterns until the coordination phase. Importantly, we did not explain the details of the incentive calculation (or that it was being compared to the first week "baseline") but only informed them of being rewarded for shifting their activities to solar generated power during the coordination phase. This choice was intended to avoid participants strategizing around the incentives structure itself, or focusing excessively on the individual reward.

4.3 Data Collection & Analysis

All introductory and exit interviews were audio recorded, transcribed verbatim and analyzed through thematic analysis [5] by the first author, together with the notes of the booking interface and the messages exchanged between participants. The first pass identified 261 relevant quotes, grouped into 55 codes and four themes after discussion with the other authors. Adhering to the reflexive nature of the methodology, no inter-coder reliability was calculated [7, p. 237]. The consumption data, the bookings, and the annotations were analyzed quantitatively to examine how participant's perceptions of their behavior translated in practice.

5 FINDINGS

We first present our quantitative analysis of data collected by the SolarClub systems, tracking patterns of booking and consumption. We then discuss four themes emerging from the semi-structured interviews, that relate to observed patterns of engagement with the system and interaction within groups. These themes explore different scalar understandings of coordination emerging from the study. Participants framed coordination as unfolding within the household, among neighbours, within an energy community, and through imagination and empathy.

5.1 Engagement

Overall, the intervention elicited a variety of reactions from the participants. Participants like P11 who were generally flexible and self-described as doing quite well in the intervention, mentioned how "it was lovely to dip a toe in the water of that [community energy], [..] it was nice to do something about that, because it's something which I very much believe in." (P11). Others similarly found it "empowering to participate" (P1) and a positive exercise to bring you closer to your neighbors (P3, P9, P14). P16 also made concrete action points for the future to bring alternative solutions to their local council. Yet, the deployment also made some participants feel 'restricted' in their actions (P4) or 'odd' (P2) for needing to plan things in advance.

In line with the findings of previous work on people's experiences with annotating their household's electricity usage e.g. [11, 21, 39]. participants enjoyed and learned from the annotating process, making an average of 28.9 annotations (min:11,max:53,SD:13.2) over one week[5]. Unlike these previous studies, however, in this case households were instructed to focus on annotating their larger appliances, potentially affecting the quantity of annotations and limiting comparability.

In total, each of the 14 active households made between 4 and 61 bookings (mean: 19, SD:15.8), for a total of 268. The amount of bookings, on average, seemed to be quite stable with a small peak

[5]This data excludes P16 who was especially motivated and continued to annotate 175 peaks throughout the 4 weeks of annotation and coordination phases.

Group	Household	Participant	Gender	Age	Occupation
1	H1	P1	f (f,f)	56, (61,15)	Gardener, (Retired,Pupil)
1	H2	P2 P3	f m	73 77	Retired Retired
1	H3	P4 P5	m f	67 64	Retired (Osteopath) Retired (Teacher)
1	H4	P6 P7	f m	69 73	Retired Retired
2	H5	P8	f	54	Art buyer
2	H6	P9	m (f,f)	65 (67,27)	Retired, (Judge, Student)
2	H7	P10	m	55	Strategy and Marketing Director
2	H8	P11	f	63	Operations & Partnerships Lead
3	H9	P12	f	71	Retired
3	H10	P13	m	54 (55,21,17,14,14)	Self employed, (Housewife, Student, Pupilsx3)
3	H11	P15	f	66 (70)	School admin, (-)
4	H12	P16	m	74	Architect/Translator
4	H13	P17	f	65+	Retired
4	H14	P18	f	40+	Designer
4	H15	P19	f	45	Artist

Table 1. Participant breakdown. Mentioned in brackets are other household members that were not interviewed.

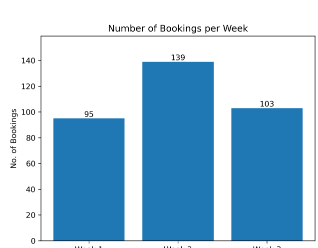

Fig. 5. The total bookings across the three weeks where relatively stable. Further breakdown is provided as supplementary material.

on the second of the three weeks of coordination (Figure 5). This finding is in line with previous work that noticed that a drop in eco-feedback engagement only occurred after approximately four weeks [3, 41]. The majority of bookings (38%) were made 1-2 hours in advance of the booking start

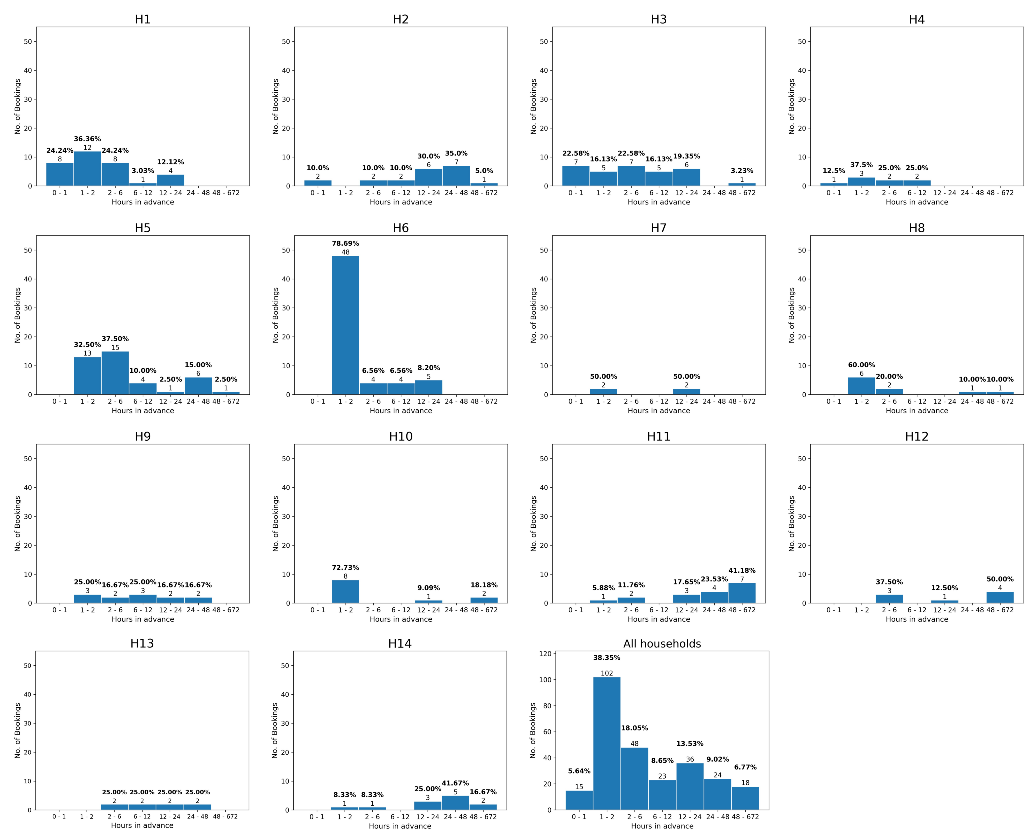

Fig. 6. The charts indicate how far in advance bookings were made (measured in hours) per household as well as total. The y-axis represents the number of bookings.

time, but in general bookings were made from less than a minute to 5 days in advance (mean: 12.5, SD:22 hours). The amount of time between making the booking and running the activity changed across participants as well as throughout the deployment. Figure 6 summarizes the bookings by household indicating the variation in household patterns. For instance, some people booked last minute "Generally four minutes before I wanted to use it"(P1, H1). H6 who made the most bookings overall also seemed to make these mostly the hour before the actual activity. Others planned only in the morning for the same day:

> P4 (H3): Our planning was more done in discussion between her and I, [..] overnight to plan the day.
> P5 (H3): Yeah. Yeah. We tended to book the night before or early that morning. So we were planning ahead.

For P11 (H8) the booking behavior evolved with the realization that the forecast accuracy is lower the longer in advance it is consulted, so that early bookings would be more likely to overshoot the actual solar availability (at the time they were run).

Moreover, as shown in Table 2, all groups but the last one, were 'successful' in shifting their energy consumption towards hours when there was solar. The last group included two households which engaged in energy shifting, but the other two (H15 and H14) were not actively participating.

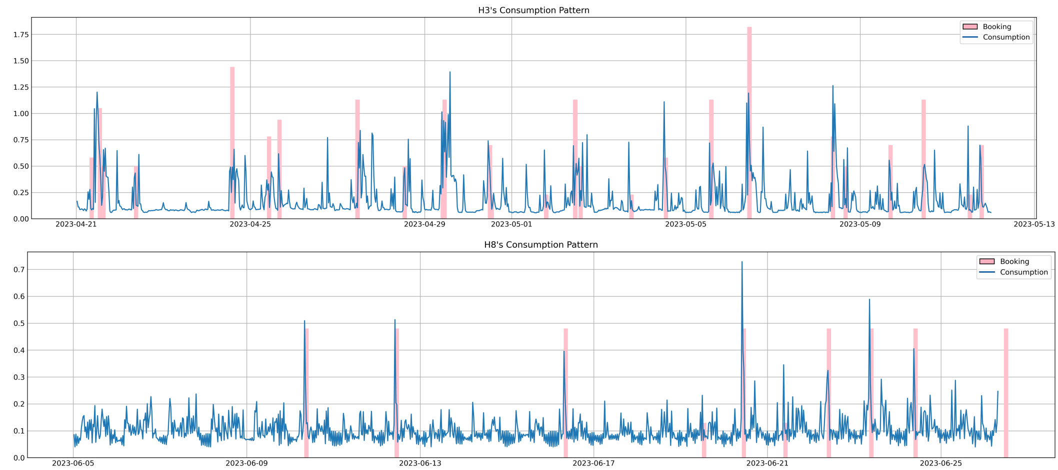

Fig. 7. The consumption graph for two households, overlayed with the bookings made (in pink). H3(top) booked during the daytime but not outside solar hours. H8 booked their large devices consistently and the last week of the deployment, they had visitors who also participated in the SolarClub system by booking.

Interestingly, when comparing the last two columns of Table 2 we find that the amount of bookings does not seem to imply higher shift percentage. H7 which consisted of P10 who worked until late during the week, only booked 4 times. Nevertheless they still seemed to shift their overall consumption to more solar hours. On the other hand H5 did not manage to shift (their energy was already 47% covered by solar), yet they nevertheless signaled their activities by making 40 bookings.

Table 3 reports the solar generation for each of the groups. This data suggests that for three groups (1, 2, and 4) the solar generation was higher during the coordination weeks, on average, than during the annotation week. However, there seems to be no pattern of higher solar consumption being explained by higher solar generation: for groups 1 and 3 the percentage of solar consumption (as a share of solar generation) went up during the coordination phase, while for the other two groups it went down. This makes sense since where availability of solar generation is relatively plentiful and doesn't act as a limiter on consumption (i.e. where participants' energy needs are already being met), we wouldn't necessarily expect a strong association between the two.

In all cases but one (P15) participants booked only to indicate their intention of using the available solar energy (i.e. made bookings only for times when solar generation was expected) as shown in Figure 8. P15 instead also booked their dishwasher outside the available solar hours in four bookings (out of their 17 in total, perhaps due to their inflexibility as detailed below). Participants understood booking as a strategy for solar coordination hence making sense only during solar generation times. As Figure 7 demonstrates, households booked when they wanted to consume during the day (i.e. there is coherence between the blue peaks and the pink bookings), and still consumed without booking outside the solar hours when they needed to.

Overall, only seven messages to other club members were sent through the MessageClub feature, whereas almost 25% of bookings included a note (67 out of the 268 total). Finally, we analyzed the flexibility data for the 101 bookings that were made at least 6 hours in advance. We focused on this subset of bookings because participants mentioned that when they booked their slots last-minute they were not flexible at that point anymore. Of these 101 bookings, 18 were marked as 'no' flexibility, 23 as 'somewhat' flexible and the remaining 60 as 'flexible' (which was also the

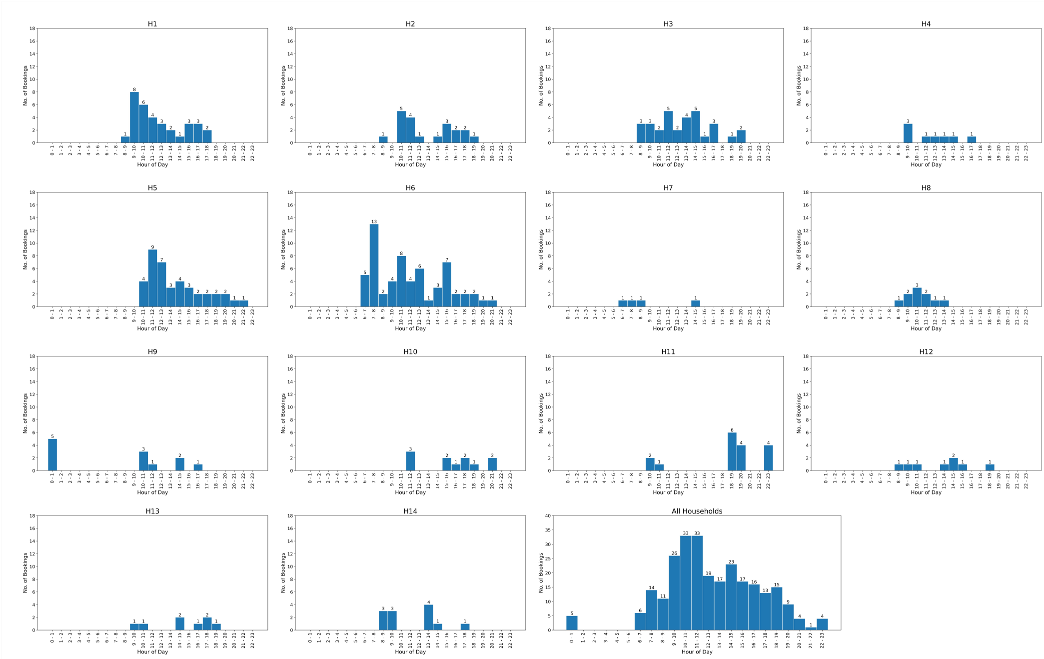

Fig. 8. Time of booking by household. Most participants have booked slots during the daytime except H11 who has also booked their dishwasher at 10pm. Based on the accompanying note, we believe that midnight booking of H9 was meant for midday. The histogram of all households together (the last one) resembles that of the solar distribution during daytime.

default, pre-selected option in the dropdown). We analyze these flexibility indicators qualitatively in Section 5.3.

5.2 Using and Coordinating with SolarClub as a Household

Participants mentioned that the SolarClub graph was 'simple' (P7), 'clear' (P9, P17), 'intuitive' (P10, P11) even 'satisfying' (P12) to read and interact with. "I think the display works well in terms of understanding the resource and understanding what other people are doing."(P1). The annotation drop-down selection however was described as 'clunky'(P1) and hard to understand (P16) even if all participants managed to use it. Further analysis revealed this to be the case because of a bug where the labels used for the annotations did not match the ones in the coordination interface (e.g. 'washing and drying' became 'laundry').

The interviews highlighted how, the coordination phase required substantial within household discussion and that, at times, could create friction. For instance, P9 and their daughter were engaged with coordinating whereas the other parent was not: "I [..] just liked doing the project, booking in the time, and – it's about putting order into your life, and I quite liked that bit of it, and that's what irritated my wife a lot, I think because she doesn't want to have to deal with that."(P9). P13 who is a working father of four, shared the responsibility of how to use the booking system with his son (and to an extent with the younger daughters), making him responsible for coordinating with family members on their bookings. Moreover, unexpectedly, P11 had guests and P8 a new tenant half way through the coordination phase. While this meant that the households would have

	Annotation (Baseline)		Coordination			
	Solar C.	Total C.	Solar C. (avg)	Total C. (avg)	Shift of Solar to Total ratio	Booking#
H1	8	33.2	10.7	29.9	11.32%	32
H2	5.76	19.7	7.9	20.8	8.57%	15
H3	6.97	39.5	8.4	30.2	10.01%	28
H4	6.75	21	10.6	27.2	6.95%	8
Group 1	27.5	113.8	37.5	108.2	10.4%	83
H5	10.54	22	12.5	26.5	**-0.40%**	40
H6	13	31	10	20.5	6.78%	61
H7	10.35	21.8	9	17.1	5.41%	4
H8	10.1	18.8	10	18	1.91%	10
Group 2	44.1	93.7	41.7	82.1	3.7%	115
H9	5.33	11.4	6	10.6	10.13%	12
H10	11.8	33.6	13.7	26	17.65%	11
H11	9	23.7	13.5	34.6	0.04%	17
Group 3	26.2	68.32	33.2	71.2	8.3%	40
H12	5.3	11.3	8	15.7	4.28%	10
H13	2.73	4.9	4.7	8.5	0.15%	8
H14	11	26.6	6.6	16.7	**-2.16%**	12
H15	-	-	-	-	-	-
Group 4	17.5	39.3	27.5	67.8	**-4%**	30

Table 2. Consumption during the coordination and annotation phases as well as the relative shift of activities towards solar hours. For easier comparisons, the coordination phase is shown as weekly averages (the coordination phase lasted 3 weeks). All values are in kWh. In bold are the instances were in fact households spent less solar energy proportionally.

	Annotation (Baseline)			Coordination		
	Solar Gen.	Solar Con.	% Consumed	Solar Gen. (avg)	Solar Con. (avg)	% Consumed
Group 1	59.7	27.5	46%	73.6	37.5	50.9%
Group 2	114.3	44.1	39%	125	41.7	33%
Group 3	124.9	26.2	21%	90.74	33.2	37%
Group 4	52.6	17.5	33%	95	27.5	29%

Table 3. Solar generation during the coordination and annotation phases as well as the ratio of solar generation used by the groups in total. The solar consumption values are the same as those on Table 2, but are repeated here for easier reading. In most cases the coordination phases were more sunny than the annotation phases. Solar generation and consumption values are in kWh and reported as weekly averages in the case of the coordination phase.

increasing energy consumption, they also found how these new members also became engaged in the coordination themselves finding it easy to understand the SolarClub system.

It should be noted that our intervention and study were not explicitly designed to account for coordination within the households. So, for example, while where possible we onboarded all householders, this was not always the case due to participants' availability or intrinsic motivation to take part. Moreover, we did not provide dedicated resources that could be used to onboard those not present. Therefore, serendipitous variations in how many household members were onboarded, brought to light different dynamics within the households. In H2 and H4, for instance, we onboarded both members of the household in the introductory session. These two households went on to share the tasks of planning and filling in the booking among themselves. On the contrary, in households H1 and H3 we only onboarded a single participant which meant that they had to then explain the system to the other family members which required understanding and verbalizing the aim of the study. In the case of household H3, this was a point of tension as P5 signed up for participating yet only P4 was present for the initial onboarding. Perhaps exactly because they were the ones onboarded, P4 took the research seriously, wanting to 'do it properly' and to communicate that buy-in to their partner (P5) who seemed to take a more casual approach. Indeed P5 told us about their partner P4: "P4 likes taking things very, very seriously. So when I hadn't quite embraced the system, P4 would tell me off that, no, you haven't booked to do that. You need to book to do that."

On the other hand, P1 did not seem to get the same resistance in participation but still originally struggled in explaining the functionality and purpose to the rest of the family.

> So [PARTNER'S NAME] would say to me, is it alright for me to put the washing machine on? Should I do that tonight? And I had to kind of keep wracking my brain about, okay, what is it we're trying to achieve here? I'm trying to achieve using energy during daylight, and communicating that. So it doesn't matter whether I booked it, if it's sunny outside, you can do what you like. If I'm not around, we haven't booked it. It doesn't matter, but if it's sunny outside, go for it. [..]
> It sounds stupid now, but at the start of the project, that felt like a conversation that we kept having, and I kept failing to find the language to just say, if it's sunny, put the washing machine on. Those were the words I needed, I think, I think three weeks to find them. (P1)

As described P1's quote above, households tended to find simple rules, such as in this case just checking if there is sunshine or not, to understand how to interact with the SolarClub system and to explain this to those they lived with. Such rules demonstrated each household's distinctive understanding of (simulated) solar energy in the context of the intervention and the actions required. For example, P9 and P12 similarly used the principle of "do stuff when there's power available"(P9) or "look outside and see what the weather is" (P12). Interestingly, participants often used terms that reflected the visual language used in our UI: "the main focus was on, how can we change what we did to make it more in the middle?" (P4, referring to the visualization showing the distribution of solar throughout the day) or "And then, yes, [we] are not making the most of the sun at all, really. The gray should be more equal to the orange."(P8).

5.3 Coordinating as Neighbors

When asked about the process of booking, participants mentioned that booking was not *necessary* to use solar energy, but was *helpful* to ensure that others are not using the power at the same time. In fact, some participants deemed the booking system entirely sufficient for the purpose of communication, avoiding the notes and messaging features. "I tried not to overutilize, so I just moved my own things, rather than go and talk to somebody else about doing something different." (P9).

Participants explicitly mentioned they were not only booking their activities to match the solar generation, but even adjusting their plans to take into account the collective consumption e.g. "I had booked for 9 but could see the usage was high so moved to 13:00" (note on a booking by P4). Similarly, others expressed their availability to change plan through the booking system: "going to put on the dishwasher when I go out so let me know if you need the slot urgently [P12 NAME]" (signed note of P12). Overbooking, however, was not that common. Although the SolarClub system sent automated notification emails in the case that people did overbook, participants reported that they would only notice and read emails when it was too late to act. "And the trouble was that [..] didn't check my emails over my phone. So the time had gone... [..] If I'd said, oh, yeah, of course I can be flexible. The time had gone by then. Anyway, so it made no difference."(P4). The SolarClub design, however, was not sufficiently oriented towards immediacy; with reminders for the bookings being one of the common features mentioned for a future iteration. "Then ideally you'd have it on an app, and everybody would have the app. And then the app would ping to say, actually 'P6 and P7 [are] doing a three-beans casserole', and 'could you turn your van off', you know, or 'it's not going to be as sunny as we thought, turn it all down', or whatever." (P1).

Moreover, P15 who was working full time and taking care of grandchildren in the evenings and weekends mentioned how for them, the the SolarClub system does not seem to make sense when compared to the annotation interface as they do not have almost any flexibility in their daily life. "And because I was slightly defeatist, I suppose, because I thought, 'Well, I can't do my washing at 10 o'clock in the morning when there's all that sunshine on a Monday. So what's the point?'" (P15).

The interviews also provided more context for how participants *signaled* their flexibility: "Yes, again, initially I was always saying it's flexible, and then as it went, as time went on, I kind of realized we were all doing the same thing, which was doing it [the booking] at the last minute." (P11). For P16, making a booking implied that all the maneuvering that was possible has already been done. "I've already been flexible because I was choosing that time."(P16) so that they would often (in 6 of their 10 bookings) indicate their bookings as 'not flexible'. There seemed to be also a reciprocal relationship with indicating flexibility as participants did not seem to pay attention to other people's stated flexibility (i.e. the booking shading) . As P9 mentioned "I did a bit at the beginning, thinking that it would be more polite if I was more flexible, but actually, [..] – nobody came back to me and said, 'Can you change this?'". As most participants understood bookings as 'fixed' and immutable after being made, the indication of flexibility as a shading on the booking representation seemed to be superfluous information.

All participants but one (P10) claimed that they felt like they were collaborating rather than competing with the other club members. P10 mentioned that it felt a bit like 'coopetition' (competition alongside cooperation) and they argued that 'a bit of gamification doesn't hurt' among neighbors to make them more motivated. P8 and P7 also mentioned experiencing some 'self-competition', in which they challenged themselves to keep their incentive (P8) or energy consumption (P7) at higher or lower levels accordingly.

As per our design approach, the SolarClub interface did not not reveal how much each individual household was consuming, nor did it by default include the author of messages, notes or bookings. As such, almost all participants felt the system was privacy preserving. "It felt, to me it felt very private in that if you, when you saw someone else's booking, if you clicked on it, you didn't see who it was or what it was." (P11). While P11 and P17 felt that this was sufficient and did not want more information, all the others claimed that they would like more transparency even when that meant that they would show more data about their household. "If anybody wants to know when I'm doing my laundry, they're really welcome." (P10). This feeling was supported by the observation that one participant also explicitly added their house number to their note and three more added their name, thus breaking anonymity.

Perhaps because of this lack of transparency, the graph provoked inferences about what the other Club members were doing although to a lesser extent than we anticipated. "There were a couple of early morning big power surges, actually, we were wondering what they were doing. "(P5). In other instances this kind of guesswork was triggered by the messaging and notes function:

> Because I just know P12 and I just felt it was her. "Oh, I can do that," or, "I'm going to try and do that," or, "I'm going to try and engage with that." I know that P13 or his son wouldn't talk like that – little messages – these few messages that came through. Maybe I'm wrong. (P15)

Moreover, discussions about accountability were quite minimal as participants mentioned they did not go back to check if people had actually followed through with their booking (P2). In fact, participants suggested that this kind of feature would be relevant to have in future iterations.

5.4 Building an Energy Community

A core recurring theme across interviews was the notion of community and collectivity. Participants had some preconceived ideas of what constitutes a community that went, in this case, far beyond the idea of sharing renewable solar energy. For P10 for instance, "a community *communicates*" either in person or through tools like WhatsApp. For P17 a community was the council estate in which they lived on and less a group of people sharing energy. Community was also associated with feelings of motivation and accountability as "[communal living] probably would be quite a good basis for chat and improvement and getting together on things, and saying, 'Now look, come on Number 54, you can do a whole lot better than this. What's the problem? Why can't you use the stuff when it's daylight? Can we help?'"(P12).

Despite their 'success' (as summarized in Table 2), participants mentioned that it was hard to judge how well their energy community was performing. "So I don't know. I mean, it's difficult when you're one household sitting in front of a terminal, to know – to judge how well the whole thing has done. You're probably in a better position to judge that than we are." (P7). This lack of intuition was also related to the amount of communication that took place among households.

> I'm not sure we did very well on the trading, because maybe we could've done a whole lot of messages. [..] I think individual people made choices. We did. I'm assuming others did. But I don't know to what degree, if at all, we corporately made choices. (P7)

As mentioned in the quote, participants overall felt like they were working as individual households while keeping in mind what other households are doing somewhat redefining what collaboration could look like. "I think we probably approached it in an individual way, knowing that other people were doing – assuming that other people were doing the same thing." (P9). "Well, I knew there were others because I looked on the scheduling tool, but we never spoke." (P10). "I was a bit selfish about it. I tended to look at what I wanted and whether other people have booked it rather than looking at the whole team. I kind of thought oh wow this is blocked I won't use it but I suppose that's still working as a team in a way." (P17).

For most, these experiences contrasted with their existing understanding of what 'community' entails, and even with what they were expecting from an energy community experiment such as the one they participated in. "It wasn't too much about the community. We were very autonomous and self-sufficient" (P8). This lack of friction during the household coordination even left some feeling as if the other participants were non-existent. "If I book those times and somebody else also wanted to put those time then there would need to be an agreement between us, but I would move to a different time or a different day but that never happened so I was able to do everything I wanted to on the day I wanted at the time I wanted. I didn't see anybody trying to book anything at the same time. [..] There was no friction at all, because I couldn't see that anybody was trying to book any." (P16).

This notion of community as interpersonal connection was also reflected in how participants used the communication features within the SolarClub coordination interface. Booking notes were the most popular option, seemingly related to their personal nature ("I like the notes. I found that... That made it quite personal, you know." (P5)) and they ranged from brief explanations of the activity to longer argumentation of why it will take place (e.g. "I can watch the TV Later in the day but my favorite show is on can't miss that"(H10)).

On the other hand, the Message Club feature wasn't felt to be as useful as participants "never felt [they] needed to [message]"(P11). P1 and P7 attributed this lack of usefulness to the perceived importance of the message received: "Well, I saw the odd message pop up, but then you just thought, 'Oh, why? Oh.' And some of them [..] – when you read them, they weren't like the world's going to end kind of " (P7). For P17 the dislike of the messaging tool related to the lack of response by the other participants indicating the importance of two-way communication. " [..] that was the only message I sent and so for me that was like I didn't use it again when I thought I hadn't got a reply I thought well they can't be bothered so I won't." (P17). P15 also mentioned their saturation on the modes of communication and not needing a new one "about cooking or washing"(P15).

During the first group deployment, all four households mentioned separately they would have liked an initial workshop so as to get a 'shared understanding' (P1). However, even when we organized a brief workshop for the subsequent two groups (online, to simplify participants' attendance), it still did not seem to fulfill the expectations and desires of some for collective discussion "When we were doing the Zoom, I thought we were going to discuss that more, and I was up for really – I thought we were going to have to do an agenda. Do you know what I mean? Or [take out] a calendar and say, 'OK, does anyone want this?'"(P8).

5.5 Simulation, Imagination and Empathy

Related to the desire among many participants to know more about who was making bookings and why, participants frequently imagined how they might respond towards under particular circumstances – from their neighbors hosting a dinner party, to neighbors living with a disability. In some cases, these imagined scenarios prompted empathy and a desire to be accommodating, but in other cases, they were envisioned as occasions where energy communities could break down.

The simulation aspects in our study, seemed to have helped some of our participants reflect about what it would mean to live with only renewable energy and how their practices would need to change, sometimes radically. P4 and P8 ran-through a scenario in which renewables such as solar were the only source of energy available. "And then I was like – it was slowly dawning, well, how am I going to eat my dinner? [..] So I would even have considered, there's different ways, perhaps lunch would be my main meal or… Do you know what I mean?" (P8). P4 who had mentioned how they found this experiment 'restrictive' equally explained how they considered such kind of restriction necessary in order to change society. "I think that, you know, if we were in a situation where, as I said earlier, where this wind and solar were the only things available, then yeah, I would accept that that is restrictive and that would mean even, I suppose we would as a society, society then have to change. And I'd be accepting of those things and engage with them in order to make it work." (P4).

Practices of imagination not only pertained to 'extreme' scenarios, but also to the changes required in daily life. For instance a common reflection was considering the effect of trying to coordinate during the winter months when there is less solar. Daily activities such as an immediate need of electricity or then simply a dinner party were also presented as occasions were energy communities could break down "I was only thinking, if you had a dinner party, it's bad enough trying to find a date for when everybody can come together for a dinner party. Then working out and then having to communicate between people maybe too - well, you wouldn't necessarily know how much energy there was." (P2).

Besides making participants reflect on alternative personal scenarios, the deployment also seemed to generate more empathy towards others, within and beyond the club, either through direct knowledge of others' circumstances was based on hypotheses. "Families of four must be really going through it. And it's reminded me – living here on my own – what a low-energy user I am compared with people who've got multiple people under the same roof." (P10).

6 DISCUSSION

Our study exposed groups of neighbors to a simulated future energy system, SolarClub. During three weeks, participating households used SolarClub to see their energy consumption, assess the solar forecast and create bookings as if they formed an energy community. Overall, we found that SolarClub enabled our participants to demand-shift and coordinate; with most participants shifting their energy consumption and reducing their simulated carbon emissions by using more solar energy as shown in Tables 2 and 3. Still, our findings have also raised several questions with regards to the role of the system in forming communities, household and group flexibility, as well as group privacy and empathy.

6.1 Bookings as a Means for Collective Demand-Shifting

Our findings indicate that the booking system functioned well as a medium for communicating intention, as participants actively changed their consumption patterns based on the existing bookings. Our interviews also suggest that at least partially, the lack of overbooking was a result of the visibility of other households' bookings (i.e. people saw others' intentions and changed their schedules). Bookings were even used as a social signal or as a more general communicative act. For instance, P15 booked outside solar times to signal their inflexibility to their fellow members.

Interestingly, participants were also able to organize collectively through bookings, even though they did not *feel* that they were a community. There is perhaps a tension here between what has been called an "energy community" in prior work and expectations about "community" in more general terms that tends to refer to the immediate, direct, local relationships among individuals with something in common [31]. We argue that our participants indeed acted as an *energy* community, i.e. a collective organizing around renewable energy consumption: they took into account the sun generation and their club members by making bookings and also took into account other's bookings when consuming. Nevertheless, participants claimed they did not feel like they were part of a community as they had imagined it. Perhaps, this was also further exacerbated by not experiencing any severe moment of infrastructural friction [18, 33], for instance a full week without solar power or excessive power-usage by an individual household that would require negotiation and further dialogue [18].

As participants seemed to experience the coordination without communication as strange or unfamiliar, an **implication** for future work is to investigate, besides bookings, features or contextual additions that can **support different feelings of 'community' among cohorts of participants**. Based on our study this could be achieved by conducting in-person onboarding workshops where participants are introduced to each other and come to an agreement on basic coordination rules; by adding more immediate response alerts of clashes and overbookings so as to have more immediacy to an activity as shown in previous work [24]; and by providing better (visualised) connections between the individual and the collective, for example, by displaying public notes on the shared visualization. Although participants were able to successfully coordinate and shift electricity usage without feelings of community, cultivating such feelings may help increase efficacy and the sustainability of coordination platforms; participants often linked their expressed desire for a greater sense of community to the pragmatic goals of wanting to account for the needs of others and ensuring ongoing collective buy-in.

6.2 Individual, Group and Within-Household Flexibility

In this research flexibility can be conceptualized at at least two levels: more narrowly in terms of bookings, and more broadly in terms of routine. At the booking level, flexibility is conceptualized as the possibility for shifting bookings to accommodate other members' needs. We explicitly represented that flexibility by visualizing the bookings with different shading. There were relatively few cases in which such an overlap among club member bookings was necessary. However, during the research, flexibility came to signify more broadly, the capacity of participants to rearrange their daily routines to maximize the use of solar energy, or to reschedule at short notice, for instance to accommodate for solar energy unavailability. Powells and Fell [46] have defined that capacity to responsively change interaction patterns as *flexibility capital*. We found that our representations of booking-flexibility were not utilized as much as we had expected because the act of making a booking *itself* was an expression of flexibility at the broader level, resulting from having such capital. For instance P17 claimed that they already had been flexible for booking during solar energy hours while P15 claimed they were not flexible exactly because they could not shift activities to earlier hours. This indicates how acts of booking directly *embodied* the flexibility of the participants. Thus, our participants did not need their visualized bookings to represent additional, more granular flexibility. Bookings were therefore most useful for and utilized by participants who had higher flexibility capital. This raises the question as to whether community coordination systems such as SolarClub are still beneficial even in settings of low energy flexibility capital. We argue that they can be because of the group's *total* capital.

Just as in individual settings [29], household circumstances and general routine flexibility are important in communal settings. Nevertheless, we also saw how diverse households together have more capacity to leverage solar than it may be possible individually, in virtue of their aggregate flexibility. Homogeneous groups such as Group 1 mostly consisting of people with higher flexibility capital (e.g., because most were retired), were most successful in terms of shifting load (see Table 2). Nevertheless, even Groups 2 and 3 still managed to shift overall, even though P10 was only available for shifting in the weekends due to work obligations and P15, as they self-described, was inflexible. As a consequence, purely in terms of environmental and community benefit, it may be sufficient for some households to be more analytical and flexible in their energy usage, while others with less flexibility capital due to family, work, disability or other situational constraints were less so. This would be especially relevant to recognise in cases in which such communities might not be self-selected and homogeneous but 'forced' through policy and circumstance (e.g. because of living arrangements). This finding demonstrates how shared solar has the potential to build *collective* flexibility capital, especially when operated to support and motivate coordination, in a way that is likely to be more affordable than individual solar installations.

An **implication** for future work therefore is to make this property of energy clubs visible in systems such as SolarClub to avoid defeatism due to perceived lack of agency from those who are less flexible. Practically, this can be achieved by **emphasizing indicators of collective success or progress** such as the number of bookings or the collective's percentage of consumption coming from renewable energy sources. While we have used some of these indicators in SolarClub, we find they were not enough to avoid the defeatism of some of our participants.

Finally, our findings show how internal coordination within the household is another important factor in supporting collective demand-shifting. P9 engaged his daughter to add and check bookings, P1 and P13 engaged their families as well. Research has identified how home systems often fall short in engaging the household but are targeted to technical 'gurus' [59]. Our system was mostly reported as intuitive and easy to use but the fact that some household members were not onboarded, and the uneven diffusion of understandings as to what the system was 'for' still left some members feeling excluded. These findings thus reinforce the understanding that smart home systems need less 'digital housekeeping', i.e. maintenance and tinkering with smart devices, and to become generally more welcoming places [59]. As previous work with families has found, [54], such an approach can lead to greater collaboration within the household. We suggest **future work** learn from these findings and **provide vocabulary or other heuristic resources to explain collective demand-shifting systems to households of children and adults**, rather than assuming the task should be offloaded to individual household members. Our previous suggestion for an onboarding session could also help such engagement.

6.3 Privacy, Perspective-taking and Cooperation

In contrast to prior, exploratory work [23, 28, 39, 49, 51, 58], our in-the-wild deployment found that participants seemed to want more, rather than less information about their neighbors. Additional contextual information about neighbors was not *needed* for coordination, as mentioned above, but it was reportedly preferred; perhaps for 'mutual understanding of needs' (P17) (i.e. perspective-taking) or for allowing them to make better inferences regarding their neighbors and be more 'amenable'(P10) in cases of friction. Our decision to design for more privacy therefore seemed to work against cultivating feelings of community, in which some exposure was in fact expected to build deeper relations. This is especially interesting given that unlike previous work [26, 39], we deployed SolarClub with groups of existing neighbors who already had some familiarity with their fellow members (and therefore did not require additional information about them). We suggest that **future interfaces** for collaborative demand-shifting should include **opt-in privacy settings at the group or household level**. Such settings could be collectively agreed upon before launching their energy community for instance during an onboarding workshop as we suggest in Section 6.1. Such an approach would permit both privacy as well as accountability and empathy-building, depending on how each specific energy club decides.

Our findings also show how *collective* experiences of data sensing and visualization can encourage empathy and perspective-taking towards fellow neighbors. In Section 5.5 we saw how new perspectives on others' energy needs and patterns, could be based on understanding actual conditions (as discovered in the initial workshop with Groups 2 and 3) or on imaginative assumptions about others, when personal circumstances were unknown. The intervention overall was also described as a 'positive thing to share with your neighbors' (P9). This further reinforces how even though participants lamented that they did not communicate enough and did not feel like a community, they nevertheless acted as one.

Interestingly, collective action emerged even without direct comparisons between households, as in previous 'social' or 'normative' comparison studies [16]. In fact, perhaps because participants were not directly comparing consumption and shifting behaviours, or because our groups already formed a type of collective, our simulation resulted in feelings collaboration, in contrast to previous studies of energy communities that described more competitive stances [20, 26]. Previous research has also documented how, through data, participants could reconstruct behavior and expose the sensitive personal data of others [34]. Our work extends these findings, demonstrating how data, when enacted, i.e. when experienced live and simultaneously, can also be pro-social and build towards communities.

6.4 From Simulation to Practice

Given the success that SolarClub demonstrated in supporting coordination of energy use, what might be the prospects of applying this kind of solution in practice? The first important question is the extent to which this kind of manual coordination is necessary compared to more automated approaches. Automation is widely expected to play a significant role in energy demand coordination

[2, 15]. This is for reasons including increased convenience, responsiveness, and reliability of response. The SolarClub coordination interface did not offer the capacity to automate any aspects of appliance use. Nevertheless, there is still an important role for the manual form of coordination it enabled. This partly derives from the potential to support empathy and a sense of the collective (albeit somewhat limited), which can help justify and motivate interest in demand-shifting and build flexibility capital for it. We know for instance, that people's energy-intensive activities are versatile and need to account for external factors beyond resource availability. Laundry may be scheduled based on factors such as home planning, children, vacations, sunshine and noise considerations. Alongside these multiple considerations, there are often multiple possible 'solutions' as to how to schedule and coordinate. By seeing each other's live consumption and even future intentions, SolarClub demonstrates one way around more rigid automation-driven approaches. In addition to this, there are a range of power-intensive activities which are much harder to automate, such as cooking. While households' ability to shift such activities is likely to be quite constrained, having a manual option for coordination provides at least the opportunity for some flexibility to occur.

Moreover, systems such as SolarClub that make users externalize their usage and flexibility through bookings, can provide training data for automation algorithms on how to operate most acceptably and effectively. Given these considerations, we see potential real-world applications for SolarClub-like solutions either as a complement to more automated approaches, or where automation is impractical. It helps promote the agentive coordination of energy-using activities, cultivates active commitment to underlying goals of demand shifting and sustainability, and may have potential to act as a focal object for more thoroughgoing community-building. Most likely contexts for deployment are those where shared assets are more common, such as multiple occupancy buildings. Further research is needed to understand the extent to which the coordination behaviors SolarClub helped develop could act as a basis for habit formation, which is likely to be necessary if it is to act as a longer-term solution.

6.5 Limitations

Our group of self-selected participants was potentially biased towards people with ecological sensitivities and higher flexibility capital so that our results maybe reflective of early-adopters of such systems. Our interventions were conducted during the spring and summer, when there was more solar that might otherwise be there during the year. Moreover, the probe diverged from reality as it still only offered a simulation. Therefore the results might be different depending on whether the participants had actually invested in the shared solar; on the fact that the generation was simulated; on that the incentive was probably rather large and in a different form to bill savings; and that it was a rather short-term intervention when compared to living with solar panels. Especially as relating to the duration of the study, a more extended study may well provide deeper insights into longitudinal user behavior, especially in light of previous research indicating potential relapsing effects [3, 40, 41]. Finally, we intentionally de-emphasized the monetary incentive on our system, except as an indicator of 'success' in shifting, whereas in real life, people might be more conscious of the costs associated with energy consumption. Future work can make incentive models more transparent and even experiment with different possibilities, for instance penalizing non-solar consumption.

7 CONCLUSION

This work examined how a community of households might plan and coordinate their electricity use to make the most of a shared renewable energy source, specifically a solar panel installation. We presented SolarClub, a custom demand-shifting system which we deployed with 15 households over a period of a month. We found that an interface such as SolarClub can successfully enable neighbors to coordinate their electricity consumption, even when some of those participating households were less flexible themselves. We also saw how SolarClub, while still a simulation, could encourage empathy towards neighbors. Nevertheless, even though neighbors were able to coordinate effectively, SolarClub fell short of delivering a *sense* of community. Using our rich findings, we propose a set of additional design considerations for mediating solar energy coordination among energy communities. Hence, we contribute to the development of the next generation of practices and technologies that can support collective action for environmental sustainability.

ACKNOWLEDGMENTS

This work was supported by the Engineering and Physical Sciences Research Council BIP project (EP/V042327/1) and approved by the Ethics Committee of UCLIC (UCLIC_2022_004_Costanza). The authors would like to thank all the participants. We are also grateful to the anonymous reviewers for their comments and suggestions that improved the quality of the paper. Data URI: 10.5522/04/25213640.

REFERENCES

[1] Wokje Abrahamse, Linda Steg, Charles Vlek, and Talib Rothengatter. 2005. A review of intervention studies aimed at household energy conservation. *Journal of environmental psychology* 25, 3 (2005), 273–291.

[2] International Energy Agency. 2017. Digitalization and Energy. https://iea.blob.core.windows.net/assets/b1e6600c-4e40-4d9c-809d-1d1724c763d5/DigitalizationandEnergy3.pdf

[3] Mary Barreto, Evangelos Karapanos, and Nuno Nunes. 2013-09-16. Why don't families get along with eco-feedback technologies?: a longitudinal inquiry. In *Proceedings of the Biannual Conference of the Italian Chapter of SIGCHI* (Trento Italy). ACM, 1–4. https://doi.org/10.1145/2499149.2499164

[4] Jacky Bourgeois, Janet van der Linden, Gerd Kortuem, Blaine A. Price, and Christopher Rimmer. 2014. Conversations with my washing machine: an in-the-wild study of demand shifting with self-generated energy. In *Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing* (Seattle Washington). ACM, 459–470. https://doi.org/10.1145/2632048.2632106

[5] Virginia Braun and Victoria Clarke. 2006. Using Thematic Analysis in Psychology. *Qualitative Research in Psychology* 3, 2 (2006), 77–101. https://doi.org/10.1191/1478088706qp063oa

[6] M.L. Chalal, B. Medjdoub, N. Bezai, R. Bull, and M. Zune. 2022. Visualisation in energy eco-feedback systems: A systematic review of good practice. *Renewable and Sustainable Energy Reviews* 162 (2022). https://doi.org/10.1016/j.rser.2022.112447

[7] Victoria Clarke. 2021. *Thematic Analysis : A Practical Guide*. SAGE Publications Ltd. http://digital.casalini.it/9781526417305

[8] European Comission. 2022. *Energy Communities*. https://energy-communities-repository.ec.europa.eu/energy-communities_en

[9] European Commission, Directorate-General for Research, and Innovation. 2006. *European SmartGrids Technology Platform – Vision and strategy for Europe's electricity networks of the future*. Publications Office.

[10] Enrico Costanza, Joel E. Fischer, James A. Colley, Tom Rodden, Sarvapali D. Ramchurn, and Nicholas R. Jennings. 2014. 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* (Toronto Ontario Canada). ACM, 813–822. https://doi.org/10.1145/2556288.2557167

[11] Enrico Costanza, Sarvapali D Ramchurn, and Nicholas R Jennings. 2012. Understanding domestic energy consumption through interactive visualisation: a field study. In *Proceedings of the 2012 ACM Conference on Ubiquitous Computing (UbiComp '12)*. 216–225.

[12] Brandon Davito, Humayun Tai, and Robert Uhlaner. 2010. The smart grid and the promise of demand-side management. *McKinsey on Smart Grid* 3 (2010), 8–44.

[13] Stefano De Dominicis, Rebecca Sokoloski, Christine M. Jaeger, and P. Wesley Schultz. 2019. Making the smart meter social promotes long-term energy conservation. *Palgrave Communications* 5, 1 (2019), 51. https://doi.org/10.1057/s41599-019-0254-5

[14] Martijn de Waal, Tara Karpinski, Gabriele Ferri, Nazli Cila, Inte Gloerich, Wouter Meys, Dolinde van Beek, Angella Mackey, Karel Millenaar, and Vava Stojadinovic. 2021. Circulate: Ener-geyser: situated design in energy resources communities.

[15] Department for Business, Energy and Industrial Strategy and Ofgem. 2021. Transitioning to a net zero energy system: Smart Systems and Flexibility Plan 2021. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1003778/smart-systems-and-flexibility-plan-2021.pdf

[16] Tawanna R. Dillahunt and Jennifer Mankoff. 2014. Understanding factors of successful engagement around energy consumption between and among households. In *Proceedings of the 17th ACM conference on Computer supported cooperative work & social computing*. ACM, Baltimore Maryland USA, 1246–1257. https://doi.org/10.1145/2531602.2531626

[17] Jon Froehlich, Leah Findlater, and James Landay. 2010. The design of eco-feedback technology. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Atlanta Georgia USA, 2010-04-10). ACM, 1999–2008. https://doi.org/10.1145/1753326.1753629

[18] René Glas, Sybille Lammes, Michiel Lange, Joost Raessens, Imar Vries, Jeroen Jansz, Joyce Neys, Stefan Werning, William Uricchio, Joost Raessens, Anne-Marie Schleiner, Ingrid Hoofd, Liz Barry, Don Blair, Jessica Breen, Shannon Dosemagen, Jennifer Gabrys, Stephanie De, René Glas, Sybille Lammes, Daniel Harmsen, Ben Schouten, Erik Van Der, Anne Dippel, Sonia Fizek, Mercedes Bunz, Sam Hind, Eric Gordon, Stephen Walter, Douglas Rushkoff, Michiel De, Mark Deuze, Lindsay Ems, Alex Gekker, and Imar Vries. 2019. *The Playful Citizen: Civic Engagement in a Mediatized Culture*. Amsterdam University Press. https://doi.org/10.5117/9789462984523

[19] UK Goverment. 2023. *Community Energy*. https://www.gov.uk/guidance/community-energy

[20] Anders Høgh Hansen, Rikke Hagensby Jensen, Lasse Stausgaard Jensen, Emil Kongsgaard Guldager, Andreas Winkel Sigsgaard, Frederik Moroder, Dimitrios Raptis, Laurynas Siksnys, Torben Pedersen, and Mikael B. Skov. 2020. Lumen: A Case Study of Designing for Sustainable Energy Communities through Ambient Feedback. In *32nd Australian Conference on Human-Computer Interaction* (Sydney NSW Australia). ACM, 724–729. https://doi.org/10.1145/3441000.3441001

[21] Melanie R. Herrmann, Duncan P. Brumby, Tadj Oreszczyn, and Xavier M. P. Gilbert. 2018. Does data visualization affect users' understanding of electricity consumption? *Building Research & Information* 46, 3 (2018), 238–250. https://doi.org/10.1080/09613218.2017.1356164

[22] Melanie R Herrmann, Enrico Costanza, Duncan P Brumby, Tim Harries, Maria das Graças Brightwell, Sarvapali Ramchurn, and Nicholas R Jennings. 2021. Exploring domestic energy consumption feedback through interactive annotation. *Energy Efficiency* 14 (2021), 1–20.

[23] Timo Jakobi, Gunnar Stevens, Nico Castelli, Corinna Ogonowski, Florian Schaub, Nils Vindice, Dave Randall, Peter Tolmie, and Volker Wulf. 2018. Evolving Needs in IoT Control and Accountability: A Longitudinal Study on Smart Home Intelligibility. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* 2, 4 (Dec. 2018), 1–28. https://doi.org/10.1145/3287049

[24] Rikke Hagensby Jensen, Dimitrios Raptis, Jesper Kjeldskov, and Mikael B. Skov. 2018. Washing with the Wind: A Study of Scripting towards Sustainability. In *Proceedings of the 2018 Designing Interactive Systems Conference* (Hong Kong China). ACM, 1387–1400. https://doi.org/10.1145/3196709.3196779

[25] Rikke Hagensby Jensen, Yolande Strengers, Jesper Kjeldskov, Larissa Nicholls, and Mikael B. Skov. 2018. Designing the Desirable Smart Home: A Study of Household Experiences and Energy Consumption Impacts. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. Association for Computing Machinery, New York, NY, USA, 1–14. https://doi.org/10.1145/3173574.3173578

[26] Rikke Hagensby Jensen, Maurizio Teli, Simon Bjerre Jensen, Mikkel Gram, and Mikkel Harboe Sørensen. 2021. Designing Eco-Feedback Systems for Communities: Interrogating a Techno-solutionist Vision for Sustainable Communal Energy. In *C&T '21: Proceedings of the 10th International Conference on Communities & Technologies - Wicked Problems in the Age of Tech* (Seattle WA USA). ACM, 245–257. https://doi.org/10.1145/3461564.3461581

[27] Victor Vadmand Jensen and Rikke Hagensby Jensen. 2023. Exploring Values of Energy Justice: A Case Study of a Burgeoning Energy Community. In *Extended Abstracts of the 2023 CHI Conference on Human Factors in Computing Systems*. ACM, Hamburg Germany, 1–9. https://doi.org/10.1145/3544549.3573864

[28] Haojian Jin, Boyuan Guo, Rituparna Roychoudhury, Yaxing Yao, Swarun Kumar, Yuvraj Agarwal, and Jason I. Hong. 2022. Exploring the Needs of Users for Supporting Privacy-Protective Behaviors in Smart Homes. In *CHI Conference on Human Factors in Computing Systems* (New Orleans LA USA). ACM, 1–19. https://doi.org/10.1145/3491102.3517602

[29] Charlotte Johnson. 2020. Is demand side response a woman's work? Domestic labour and electricity shifting in low income homes in the United Kingdom. *Energy Research & Social Science* 68 (2020), 101558. https://doi.org/10.1016/j.erss.2020.101558

[30] Charlotte Johnson, Sarah Bell, Aiduan Borrion, and Rob Comber. 2021. Working with Infrastructural Communities: A Material Participation Approach to Urban Retrofit. *Science, Technology, & Human Values* 46, 2 (2021), 320–345. https://doi.org/10.1177/0162243920916235

[31] Miranda Joseph. 2020. Community. In *Keywords for American cultural studies*, Bruce Burgett and Glenn Hendler (Eds.). Vol. 11. NYU Press.

[32] Patricia M. Kluckner, Astrid Weiss, Johann Schrammel, and Manfred Tscheligi. 2013. Exploring Persuasion in the Home: Results of a Long-Term Study on Energy Consumption Behavior. In *Ambient Intelligence*, Juan Carlos Augusto, Reiner Wichert, Rem Collier, David Keyson, Albert Ali Salah, and Ah-Hwee Tan (Eds.). Vol. 8309. Springer International Publishing, 150–165. https://doi.org/10.1007/978-3-319-03647-2_11 Series Title: Lecture Notes in Computer Science.

[33] Matthias Korn and Amy Voida. 2015. Creating Friction: Infrastructuring Civic Engagement in Everyday Life. *Aarhus Series on Human Centered Computing* 1, 1 (2015), 12. https://doi.org/10.7146/aahcc.v1i1.21198

[34] Albrecht Kurze, Andreas Bischof, Sören Totzauer, Michael Storz, Maximilian Eibl, Margot Brereton, and Arne Berger. 2020. Guess the Data: Data Work to Understand How People Make Sense of and Use Simple Sensor Data from Homes. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*. ACM, Honolulu HI USA, 1–12. https://doi.org/10.1145/3313831.3376273

[35] Energy Local. 2023. Energy Local: Making Energy Work for You. https://energylocal.org.uk

[36] J. Lowitzsch, C. E. Hoicka, and F. J. van Tulder. 2020. Renewable energy communities under the 2019 European Clean Energy Package – Governance model for the energy clusters of the future? *Renewable and Sustainable Energy Reviews* 122 (2020), 109489. https://doi.org/10.1016/j.rser.2019.109489

[37] Andrew Vande Moere, Martin Tomitsch, Monika Hoinkis, Elmar Trefz, Silje Johansen, and Allison Jones. 2011. Comparative Feedback in the Street: Exposing Residential Energy Consumption on House Façades. In *Human-Computer Interaction – INTERACT 2011*, Pedro Campos, Nicholas Graham, Joaquim Jorge, Nuno Nunes, Philippe Palanque, and Marco Winckler (Eds.). Vol. 6946. Springer Berlin Heidelberg, 470–488. https://doi.org/10.1007/978-3-642-23774-4_39 Series Title: Lecture Notes in Computer Science.

[38] Luiz Morais, Lívia Sampaio, Gibran Yásser, and Andrey Brito. 2021. Lumiphys: Designing a Long-Term Energy Physicalization to Democratize Smart Campus Data. In *Proceedings of the Twelfth ACM International Conference on Future Energy Systems* (Virtual Event Italy). ACM, 362–366. https://doi.org/10.1145/3447555.3466596

[39] Georgia Panagiotidou, Enrico Costanza, Michael J. Fell, Farhan Samanani, and Hannah Knox. 2023. Supporting Solar Energy Coordination among Communities. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* 7, 2 (June 2023), 1–23. https://doi.org/10.1145/3596243

[40] Lucas Pereira, Filipe Quintal, Mary Barreto, and Nuno J. Nunes. 2013. Understanding the Limitations of Eco-feedback: A One-Year Long-Term Study. In *Human-Computer Interaction and Knowledge Discovery in Complex, Unstructured, Big Data*, Andreas Holzinger and Gabriella Pasi (Eds.). Vol. 7947. Springer Berlin Heidelberg, 237–255. http://link.springer.com/10.1007/978-3-642-39146-0_21 Series Title: Lecture Notes in Computer Science.

[41] Lucas Pereira, Filipe Quintal, Nuno Nunes, and Mario Bergés. 2012. The design of a hardware-software platform for long-term energy eco-feedback research. In *Proceedings of the 4th ACM SIGCHI symposium on Engineering interactive computing systems* (Copenhagen Denmark, 2012-06-25). ACM, 221–230. https://doi.org/10.1145/2305484.2305521

[42] Èlia Gil Peña and Rikke Hagensby Jensen. 2023. The Character of Eco-feedback Systems for Energy Communities. In *The 11th International Conference on Communities and Technologies (C&T)*. ACM, Lahti Finland, 203–214. https://doi.org/10.1145/3593743.3593783

[43] James Pierce and Eric Paulos. 2010. Materializing energy. In *Proceedings of the 8th ACM Conference on Designing Interactive Systems - DIS '10* (Aarhus, Denmark). ACM Press, 113. https://doi.org/10.1145/1858171.1858193

[44] James Pierce and Eric Paulos. 2012. Beyond energy monitors: interaction, energy, and emerging energy systems. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, Austin Texas USA, 665–674. https://doi.org/10.1145/2207676.2207771

[45] James Pierce and Eric Paulos. 2012. The local energy indicator: designing for wind and solar energy systems in the home. In *Proceedings of the Designing Interactive Systems Conference on - DIS '12* (Newcastle Upon Tyne, United Kingdom). ACM Press, 631. https://doi.org/10.1145/2317956.2318050

[46] Gareth Powells and Michael J. Fell. 2019. Flexibility capital and flexibility justice in smart energy systems. *Energy Research & Social Science* 54 (2019), 56–59. https://doi.org/10.1016/j.erss.2019.03.015

[47] Filipe Quintal, Clinton Jorge, Valentina Nisi, and Nuno Nunes. 2016. Watt-I-See: A Tangible Visualization of Energy. In *Proceedings of the International Working Conference on Advanced Visual Interfaces* (Bari Italy). ACM, 120–127. https://doi.org/10.1145/2909132.2909270

[48] Sarvapali D. Ramchurn, Perukrishnen Vytelingum, Alex Rogers, and Nicholas R. Jennings. 2012. Putting the 'smarts' into the smart grid: a grand challenge for artificial intelligence. *Commun. ACM* 55, 4 (2012), 86–97. https://doi.org/10.1145/2133806.2133825

[49] Kopo Marvin Ramokapane, Caroline Bird, Awais Rashid, and Ruzanna Chitchyan. 2022. Privacy Design Strategies for Home Energy Management Systems (HEMS). In *CHI Conference on Human Factors in Computing Systems* (New Orleans LA USA). ACM, 1–15. https://doi.org/10.1145/3491102.3517515

[50] Majken K. Rasmussen, Mia Kruse Rasmussen, Nervo Verdezoto, Robert Brewer, Laura L. Nielsen, and Niels Olof Bouvin. 2017. Exploring the flexibility of everyday practices for shifting energy consumption through clockcast. In *Proceedings of the 29th Australian Conference on Computer-Human Interaction* (Brisbane Queensland Australia). ACM, 296–306.

https://doi.org/10.1145/3152771.3152803

[51] Tom A. Rodden, Joel E. Fischer, Nadia Pantidi, Khaled Bachour, and Stuart Moran. 2013. At home with agents: exploring attitudes towards future smart energy infrastructures. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Paris France). ACM, 1173–1182. https://doi.org/10.1145/2470654.2466152

[52] Yvonne Rogers. 2011. Interaction design gone wild: striving for wild theory. *Interactions* 18, 4 (July 2011), 58–62. https://doi.org/10.1145/1978822.1978834

[53] Yvonne Rogers, Kay Connelly, Lenore Tedesco, William Hazlewood, Andrew Kurtz, Robert E. Hall, Josh Hursey, and Tammy Toscos. 2007. Why It's Worth the Hassle: The Value of In-Situ Studies When Designing Ubicomp. In *UbiComp 2007: Ubiquitous Computing*, John Krumm, Gregory D. Abowd, Aruna Seneviratne, and Thomas Strang (Eds.). Springer Berlin Heidelberg, Berlin, Heidelberg, 336–353.

[54] Antti Salovaara, Andrea Bellucci, Andrea Vianello, and Giulio Jacucci. 2021. Programmable Smart Home Toolkits Should Better Address Households Social Needs. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems* (Yokohama Japan). ACM, 1–14. https://doi.org/10.1145/3411764.3445770

[55] Johannes Schöning, Yvonne Rogers, Jon Bird, Licia Capra, Julie A. McCann, David Prendergast, and Charles Sheridan. 2012. Intel Collaborative Research Institute - Sustainable Connected Cities. In *Ambient Intelligence*, David Hutchison, Takeo Kanade, Josef Kittler, Jon M. Kleinberg, Friedemann Mattern, John C. Mitchell, Moni Naor, Oscar Nierstrasz, C. Pandu Rangan, Bernhard Steffen, Madhu Sudan, Demetri Terzopoulos, Doug Tygar, Moshe Y. Vardi, Gerhard Weikum, Fabio Paternò, Boris de Ruyter, Panos Markopoulos, Carmen Santoro, Evert van Loenen, and Kris Luyten (Eds.). Vol. 7683. Springer Berlin Heidelberg, Berlin, Heidelberg, 364–372. https://doi.org/10.1007/978-3-642-34898-3_28 Series Title: Lecture Notes in Computer Science.

[56] Sabrina Scuri, Gergana Tasheva, Luísa Barros, and Nuno Jardim Nunes. 2019. An HCI Perspective on Distributed Ledger Technologies for Peer-to-Peer Energy Trading. In *Human-Computer Interaction – INTERACT 2019*, David Lamas, Fernando Loizides, Lennart Nacke, Helen Petrie, Marco Winckler, and Panayiotis Zaphiris (Eds.). Vol. 11748. Springer International Publishing, Cham, 91–111. https://doi.org/10.1007/978-3-030-29387-1_6 Series Title: Lecture Notes in Computer Science.

[57] Will Simm, Maria Angela Ferrario, Adrian Friday, Peter Newman, Stephen Forshaw, Mike Hazas, and Alan Dix. 2015. Tiree Energy Pulse: Exploring Renewable Energy Forecasts on the Edge of the Grid. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (CHI '15)*. Association for Computing Machinery, New York, NY, USA, 1965–1974. https://doi.org/10.1145/2702123.2702285

[58] Stephen Snow, Awais Hameed Khan, Mashhuda Glencross, and Neil Horrocks. 2021. Neighbourhood Wattch: Using Speculative Design to Explore Values Around Curtailment and Consent in Household Energy Interactions. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems* (Yokohama Japan). ACM, 1–12. https://doi.org/10.1145/3411764.3445095

[59] Yolande Strengers, Jenny Kennedy, Paula Arcari, Larissa Nicholls, and Melissa Gregg. 2019. Protection, Productivity and Pleasure in the Smart Home: Emerging Expectations and Gendered Insights from Australian Early Adopters. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow Scotland Uk, 2019-05-02). ACM, 1–13. https://doi.org/10.1145/3290605.3300875

[60] Yolande A.A. Strengers. 2011. Designing eco-feedback systems for everyday life. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Vancouver BC Canada). ACM, 2135–2144. https://doi.org/10.1145/1978942.1979252

[61] Denise J. Wilkins, Ruzanna Chitchyan, and Mark Levine. 2020. Peer-to-Peer Energy Markets: Understanding the Values of Collective and Community Trading. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu HI USA). ACM, 1–14. https://doi.org/10.1145/3313831.3376135

[62] Yue Yang, Emenike G. Okonkwo, Guoyong Huang, Shengming Xu, Wei Sun, and Yinghe He. 2021. On the sustainability of lithium ion battery industry – A review and perspective. *Energy Storage Materials* 36 (2021), 186–212. https://doi.org/10.1016/j.ensm.2020.12.019