Exploring Renewable Energy Futures through Household Energy Resilience

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Hanna Hasselqvist
Design and Human Factors, Chalmers University of Technology
hanna.hasselqvist@chalmers.se

Sara Renström
Digital Systems, Prototyping Societies, RISE Research Institutes of Sweden
sara.renstrom@ri.se

Maria Håkansson
Built Environment, Energy and Circular Economy, RISE Research Institutes of Sweden
maria.hakansson@ri.se

Helena Strömberg
Design and Human Factors, Chalmers University of Technology
helena.stromberg@chalmers.se

ABSTRACT

A transition to renewable energy increases the risks of disruptions when electricity supply does not meet demand. HCI has explored how digital technologies can mitigate such problems in households through support for reducing or shifting electricity use. However, faster transitions may be possible if some disturbances can be acceptable and households are supported in adapting to them. In this paper, we present a study of 21 Swedish households and their experiences of and ideas on how to manage disruptions in electricity supply. We call this perspective *household energy resilience* and identify three strategies for resilience: (1) *response diversity*, i.e., diversity in ways of carrying out normally electricity-dependent practices, (2) creating *opportunities to develop resilience*, and (3) building *community energy resilience*. Furthermore, we suggest how HCI can support these strategies, both by providing tools to increase resilience and by carefully designing technology and services to be more resilient in themselves.

CCS CONCEPTS

• **Human-centered computing** → Human computer interaction (HCI); Empirical studies in HCI; • **Social and professional topics** → Professional topics; Computing industry; Sustainability.

KEYWORDS

Sustainable HCI, Energy resilience, Renewable energy, Energy futures, Households

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1 INTRODUCTION

A transition to renewable energy is necessary to meet climate goals. However, production of renewable energy such as solar and wind power vary with the weather and the season, and the production is thus harder to control than fossil-based production. At the same time, the demand for and dependency on electricity is expected to rise due to electrification of for example transport [34] and increased digitalisation [2], which adds to the strain on often aging and undersized electricity grids [54, 60, 87]. Hence, the world is becoming more dependent on electricity at the same time as electricity supply is becoming less reliable.

Digital technologies are considered important for managing energy systems and securing electricity supply [34]. In the field of Human-Computer Interaction (HCI), opportunities for digital technologies to support reduction and shifting of electricity use have been explored, as well as the energy use and environmental impact of ICT devices and services themselves [27]. Such research contributes to the goal of securing electricity supply in renewable energy systems and reducing the risk of disruptions. However, risks of actually having to face disruptions are increasing in affluent societies currently used to stable power systems, due to the aforementioned push for renewable electricity production, electrification, insufficient grid capacity, as well as due to extreme weather events causing blackouts [35]. An energy future with more frequent disruptions is less investigated in HCI, although we can draw from ideas of collapse informatics [82], computing within limits [50], historical understandings of resource use and disruptions [e.g., 83] as well as qualitative studies of communities that have different experiences of unreliable power supply [68, 75, 87].

While unreliable access to electricity is a reality in many parts of the world today, imagining or supporting a future with less reliable electricity supply might be difficult for affluent households that are used to constant and unlimited access to electricity. Promises of effortless comfort and convenience through energy-demanding smart home technologies [e.g., 74] further clashes with such ideas. In this paper, we explore how affluent households think they would manage in a future with more frequent power cuts and power shortages that limit electricity use at a household level. Compared to research exploring voluntary reductions in energy use or load shifting through price signalling, we explore the question of *how* households would adapt to limitations, rather than *if* households would adapt their electricity use.

As a starting point for our exploration, we use a concept we call *household energy resilience* [29], which is a combination of *energy resilience* and *household preparedness*. Resilience can generally be described as an entity (e.g., a household) with a function (e.g., living a good life) that can persist or be fulfilled despite disturbances (e.g., power outages) [26]. Energy resilience typically focuses on securing the function energy supply and views infrastructure as the entity that should be resilient to disturbances such as power shortages and outages [10, 55]. In household preparedness, on the other hand, the concern is instead the resilience of everyday practices in relation to *rare* and *severe* disturbances, such as large blackouts [1, 30]. With household energy resilience, we combine these understandings of resilience by focusing on households as the entity, and how they can fulfil a good everyday life despite disturbances that can be expected in a renewable energy future. These disturbances range from brief shortages and planned outages to unexpected and long-lasting blackouts.

Understanding possibilities for living a good life despite intermittent power supply is important to open for more ways to reach a renewable energy future, and to reach it faster. Rapid reductions in carbon emissions are needed to limit future climate change [47] and striving for a completely secure power supply, where households never experience disruptions, may slow down the transition from fossil fuels, as well as lead to counterproductive practices [75] and unrealistic expectations of technological systems and services [83]. This paper makes the following contributions: First, it introduces household energy resilience as a useful concept for HCI to explore renewable energy futures – specifically because it acknowledges disruptions as a likely part of our future, and shifts focus to different efforts required in adapting to disruptions in electricity supply. We situate the concept in relation to research from several disciplines and ground the argument why electricity-related disruptions and adaptations need to be addressed from a household perspective. Second, the paper contributes to building an empirical understanding of household energy resilience, based on an interview study with speculative elements of 21 households in Sweden that are energy resilient to different extents and in different ways. This provides insights into what life without constant access to electricity may be like and whether it could be considered a good life. Third, the paper presents three strategies for household energy resilience based on the participants' previous experiences of limited availability of electricity and their ideas of how they would act in a renewable energy future. Finally, we suggest implications for HCI, including how HCI can support household energy resilience and how digital technologies can be more resilient in themselves, rather than contributing to increased dependency on constant access to electricity.

2 RELATED WORK

In this paper, we explore what might happen in the future when a developed, resource-rich country goes from reliable, unlimited energy supply to a new normal of intermittent power supply. We report below on how past research in HCI and neighbouring fields have explored questions around households' roles in the energy system, limitations of consumption, and resilience in varying energy contexts.

In efforts related to energy, past Sustainable HCI research has looked both at how to lower the environmental impact of digital systems in and of themselves [e.g., 3, 58, 61, 62], and how to design digital services to facilitate new solutions and social changes [7], such as automated energy-efficient home systems [36] and peer-to-peer energy markets [91] which are components in the larger concept *smart grids* [see e.g., 69].

Together with other technical solutions such as energy storage, *flexibility* – or *demand-side response* (DSR) – is anticipated to help balance supply and demand in smart grids [34]. The idea is that households (and other larger stakeholders, e.g., industries) participate more actively in the energy system by 'providing flexibility', which means moving energy-consuming activities to less constrained hours to better balance the demand and supply from intermittent renewable sources. In HCI, past work exploring flexibility includes a smart digital agent designed to help households to shift demand [14], a smart system developed to better align one's own micro-produced electricity with the use of household appliances [9], and insights into how energy conservation programs could be designed to motivate people to reduce demand during peaks [78]. While a large part of flexibility research across disciplines is technology-driven and based on the assumption that households will voluntarily and rationally become flexible based on financial incentives, scholars in social science and HCI are arguing that such assumptions often match poorly with households' everyday life of social practices and routines, for example because some practices are more flexible than others, which in turn impact the 'success' of price tariffs and peak-pricing [8, 52, 60, 73, 79].

In design-oriented research on flexibility, deliberately provocative scenarios and interventions have been used to explore households' relation to electricity, questioning a taken-for-granted constant supply by suggesting electricity independent activities during electricity peak times [39], making a washing machine that only functions when electricity from renewable sources is available [37], providing a solar-powered, low-tech website available only when the sun shines [65], and exploring values around smart energy systems, including privacy and voluntary curtailment [71]. Similarly, social and design-oriented research on smart home technologies more generally highlights concerns regarding dominant industry visions promoting 'pleasance', which risks increasing energy consumption rather than reducing demand [74]. Low-energy alternatives of creating pleasance and 'hygge' are suggested as a constructive path for HCI to explore in striving for a more sustainable energy system [38, 74].

In our work, we build on similar ideas of questioning constant supply (and, implicitly, energy-intensive versions of pleasance) in affluent communities. Assuming shifting supply and disruptions as a likely new normal in the future, we turn to explore people's different abilities and prerequisites for adapting to such a future. However, disruptions in various forms can be experienced already today. Trentmann [83] argues that disruptions such as power cuts, traffic jams, and digital system breakdowns are not "freak accidents" but a normal part of everyday life, which we are likely to experience more frequently as technological systems become more and more complex. He suggests that "disruptions reveal the flexible side of habits and routines so often imagined as stable and stubborn" [83:68] and that they "raise questions about accountability (who

is to blame), entitlement and social justice (who should get what), and, most profoundly, about 'normality' (how can or should members of a society live)" [83:69]. Hence, by focusing on disruptions, household energy resilience has the potential to explore questions of accountability, social justice and normality related to energy use.

Related work is further concerned with how to limit overall consumption, including energy, in affluent countries and communities. *Sufficiency* is an emerging concept in social science-oriented energy research, focusing on people's needs versus wants, while also considering planetary limits and societal justice [20]. Although not using the term sufficiency, previous HCI work exploring how different resource-rich groups can balance needs and wants, what the benefits might be, and how such practices could inspire tech design include studies of 'car free' households [28], 'green' households [92], simple living families [23], and limiting internet use [89, 90]. These examples both show how limitations in consumption can increase some aspects of quality of life, and the efforts and learning required to live in ways outside mainstream norms. Limiting technology, and use of technology for various reasons, including environmental sustainability and wellbeing, has previously been explored in design, such as Pierce's work on undesign [59].

Motivated by climate urgency, some HCI researchers argue more strongly that we need to consider planetary limits as hard boundaries to our work in HCI [e.g. 42, 50, 56]. This includes questioning the premise of constant economic growth, often presupposed in development and design, as it limits our ideas of alternative futures. Prior to *computing within limits* [see e.g. 20], the related concept of *collapse informatics* [82] outlined HCI's role in exploring an unknown future impacted by scarcity and climate change, and the need to learn, in an abundant today, to design for a future in scarcity. Tomlinson et al. [82] argue that there is a need in HCI to address both *mitigation* (i.e., efforts to reduce the negative impact of climate change) and *adaptation* (i.e., efforts to adapt to the changes that climate change might bring), because if/when mitigation attempts are not enough, or fail, adaptation is necessary.

In some Western communities, adaptation to energy-related limits and resilience to manage unplanned energy events like blackouts are already part of everyday life, sometimes because of an 'edge-of-grid' location where investing in innovative renewable energy technologies makes more sense than strengthening the traditional grid [45]. Watts' [87] ethnographic work on the Orkney Islands describes a community that is both at the margin of infrastructure because of its isolated location, and right at the centre of renewable energy production. The islanders have adapted to living with intermittent power supply, meaning limited supply and sudden energy events are part of the normal. As Watts describes "[w]hen the infrastructures considered essential to modern living fail, the Energy Islands carry on with their modern lives, just wearing an extra jumper" [87:76]. Similarly, Simm et al. [68] worked together with the community at the Isle of Tiree, also at the margin of infrastructure and exposed to breaks in power supply, to explore ways digital technologies could support the islanders in managing shifts in supply, for example by renewable energy forecasts. As Lovell et al. [45] point out, the social, geographical, and technological contexts in these locations are important to consider (e.g., island communities with strong social bonds), as they set the frame for new energy practices which do not necessarily transfer well to other contexts. Some Western households voluntarily make the decision to go completely off-grid, for example because of environmental concerns, and manage instead on self-produced renewable energy and modest batteries for storage, in combination with fundamentally modified practices and rhythms that need to be sensitive to seasonal changes [84]. As Vannini and Taggart show, "batteries are not magic wands" [84:638] and it takes significant effort and adaptiveness from households to adjust their practices during periods of low energy production.

Furthermore, there are additional insights and lessons to be learnt from how resource-limited regions and communities live with, and have adapted to, energy-related limits such as unreliable energy infrastructure. As highlighted by for example [15:2220], greater HCI, and particularly research on sustainability, can "learn from the constraints dictated by low-resource settings and how they are navigated". Past research provides insights both from resource-limited communities in affluent contexts, and studies of communities in developing regions. To low-economic-status communities in Australia, everyday resilience involves having a basic "know-how" how to deal with hardship in a resourceful, creative, and diverse way [85]. As Dillahunt et al. [16] show, low-income households in the US might lack satisfactory and efficient energy technologies due to structural inefficiencies, as well as feedback on energy consumption, but still draw on values and practices about energy conservation learnt during childhood, and a range of creative low-tech solutions to save energy. In a similar way, Strengers and Maller [75] show how migrants bring practices grounded in resource scarcity and visibility to a new affluent country, Australia, and how these practices continue to shape resource use in everyday life. It suggests that past experiences of scarcity and the visibility of resources (e.g., using firewood to make a fire for heat and light) can help limiting future demand, an insight that Strengers and Maller propose should impact new supply systems [75]. Notably, however, other research into low-resource practices at music festivals in the UK (i.e., experiences clearly limited in space and time) show that although visitors voluntarily change their normal hygiene and cleanliness practices during the festival, e.g., showering less, they do not necessarily bring these low-resource practices into everyday life [32].

Turning to communities in developing regions, Chen [11, 12] has pointed to the overlaps between computing within limits and ICT for development (ICTD), where ICTD offers valuable design principles to strengthen resilience, such as designing for simplicity and modularity. Patterson's [57] report on how the Haitian people adapted to an intermittent infrastructure in the aftermath of a natural disaster includes several examples of social changes that may also be required in a future of intermittent renewable energy as explored in this paper. One example is that electricity in the home came from different sources of varying capacity and reliability, which had to be managed on a daily basis, and living with an intermittent infrastructure meant learning new rhythms and routines for when things could be done, that in turn shaped social interaction. Another highly relevant study explored how Kenyan households navigate frequent and unexpected blackouts, and sensor-based technology to monitor blackouts and get notifications about when the power would go off and restore was found to support households in better dealing with disturbances [13]. This

Table 1: Types of disturbances and potential consequences of disturbances that were presented to and discussed with the study participants.

Types of disturbances	
Extent of limitation	From complete power outages to power shortages where the household has a cap on power use.
Timing & frequency	Likely during peak times, i.e., mornings and evenings, and during cold winters in Sweden. Shorter or planned outages and shortages more frequently (a few times per month during winters) and more extensive outages once per year or less often.
Duration	From an hour to a couple of weeks.
Geographical extent	If everyone in the neighbourhood is affected or not.
Planned vs. unplanned	Knowing or not knowing about the disturbance and its duration in advance.
Consequences of disturbances	
Electrical appliances	Not working during power outages, unless they have battery, and potentially limits in number of appliances or total power that can be used during power shortages.
Electricity-dependent transport	Not possible to charge during power outages and likely affected by power shortages.
Internet connection	Wi-Fi or network at home immediately affected by power outages while mobile networks may work for some hours.
Heating	Affected by power outages and likely by power shortage during the heating season, although it takes some time before it is noticeable.
Water	Hot water immediately affected by power outages (if the distributor or building heat exchange is affected) while cold water may last longer depending on the distribution system.

points to the value of reliable communication as a way to anticipate and respond to coming events.

Bringing with us these insights, we now return to the importance of addressing both mitigation and adaptation in HCI [82] – and to mentally shift from 'if' to 'how'. If we are to adopt more progressive energy scenarios to have a chance to meet climate goals – fundamental changes are to be required from affluent communities like the one studied in this paper. It is time to explore alternative ways – the 'how' – to live a resilient and good life in a changing energy system where "disruption is normal" [83], as well as to learn from other communities how to develop resilience in the case of both expected and unexpected disturbances in power supply. Next, we begin to explore empirically what household energy resilience might involve and how HCI could support it in different ways.

3 STUDY SETUP

The purpose of the study was to learn from experiences and to explore expectations of life with disruptions in power supply to identify possibilities for supporting household energy resilience. Insights of interest were thus both of a design ethnographic character (experiences) and of a speculative character (expectations), cf. design ethnography vs. design fiction in [44]. The study was set up to capture both types of insights.

In the autumn of 2020 21 households with varying experience of variable availability of electricity (1) received a workbook describing a possible renewable energy scenario (see 3.1), (2) were interviewed about experiences and expectations in relation to the scenario, where one adult member per household participated in the interview, and (3) received situated speculative follow-up questions via text message, a form of experience sampling. Insights from the study were then analysed to identify existing and potential future strategies for household energy resilience, and to concretise the roles HCI could play in supporting household energy resilience in a renewable energy future.

3.1 Renewable energy scenario

As a starting point for our research, we used a future energy scenario (called 'Legato') from the Swedish Energy Agency [80]. In this scenario, which explores what energy use could look like in 2050 in Sweden, electricity production is nearly 100% renewable and, although storage options exist, there will be times when supply does not meet demand. For households, this could result in complete power outages as well as power shortages with a cap on power use and limitations in which electrical appliances can be used. Based on the brief descriptions in the scenario, we concretised potential types of disturbances and their consequences for households, see Table 1. These examples formed the basis for describing the scenario in the workbook, in the interviews, and for the questions in the speculative experience sampling. Notably, the climate in this study involves dark and cold winters, which both limits solar energy production and creates a general peak demand for space heating and light, creating large seasonal changes in needs and potentially practices, similar to those in Vannini and Taggart's work [84].

3.2 User study participants

We intentionally sought participants from different types of households: households with significant experience of variable availability of electricity, such as people living off-grid or in some parts of the countryside; households with experience of temporary limitations of availability of electricity, for example from holiday cabins or camping trips; and households that rarely experience power cuts or limitations. We recruited people from experienced households primarily through online forums for off-grid living, self-sufficiency, and camping in the wild. In addition, we recruited

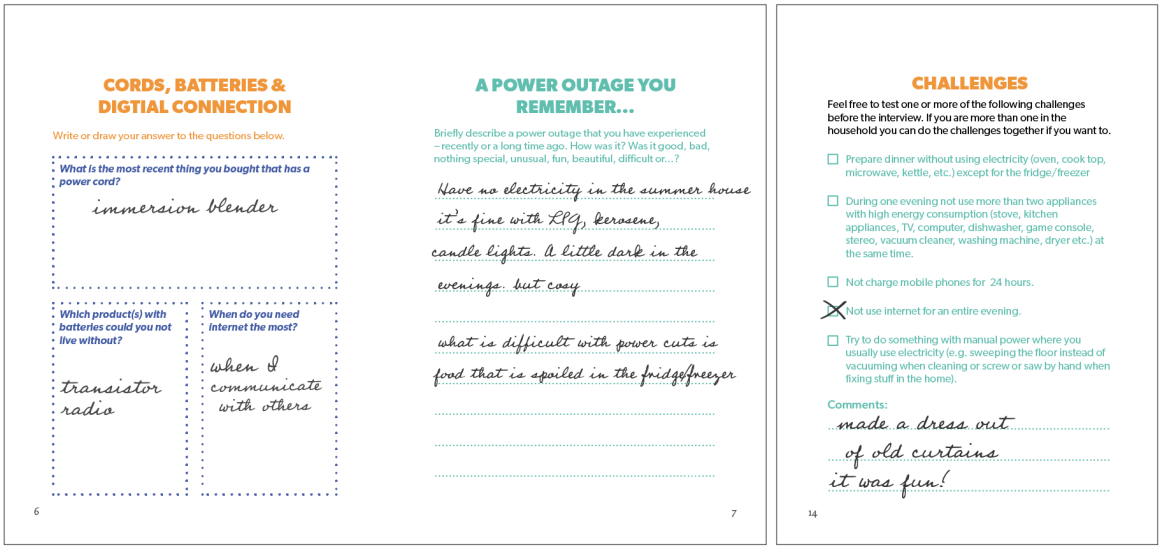

Figure 1: Workbook exercises exploring current and past energy needs and experiences (left) and with speculative challenges (right) completed by the adult who was not interviewed in the household of P11.

participants from a living lab apartment building. The living lab has been touted as the future of housing and incorporates several innovative energy-related solutions and renewable energy production. Finally, we recruited participants through a large housing association's newsletter, i.e., households living in regular apartments and attached houses. Participation in the study was compensated with a gift card (20 EUR/24 USD).

People who were interested in participating filled in an application form with questions about themselves and their households. We selected 21 households for the study, from different parts of Sweden, aiming to get a mix of households in terms of demographics, type of home (apartment/house, rural/urban), experience of relevant technologies such as PV panels or electric cars, and their perceived preparedness for power outages (see Table 2 for an overview of the participants).

3.3 User study and analysis

Before the interview, a workbook was sent out to all members of the participating households. The main purpose of the workbook was to *sensitise* the participants in preparation for the interviews, i.e., make them reflect on current and past experiences in the context of their everyday lives [70] and in relation to a renewable energy future, as well as to spark discussion within the household. The workbook briefly introduced the energy scenario, framing it as a potential way to speed up the shift from fossil to renewable energy, and provided examples of what such a shift could mean in everyday life. It also included several exercises for the participants to reflect on current and past energy practices and to speculate on how future disturbances may affect their lives. Additionally, we included optional challenges inviting the participating households to act out this speculative future, for example by preparing dinner without electricity, cf. *speculative enactments* [18]. Although the workbook described variable energy supply as a potential consequence of a faster shift to renewable energy, it did not frame situations with limited electricity supply as either positive or negative; variable energy supply was described as potentially influencing everyday life. However, one exercise explicitly invited the participants to reflect on situations that might become better without electricity or internet connection.

Three versions of the workbook were created, adapted to adults, teenagers aged 13-17, and children aged 5-12 respectively. The participants brought the filled-in workbooks to the interviews, and we asked about their answers and reflections. After the interview the participants were encouraged to return the workbooks to us in a prepaid envelope. In total, we received 27 workbooks from 4 children, 2 teenagers, and 21 adults. Examples of completed workbooks are presented in Figure 1 and Figure 2. The contents of the workbooks have been translated to English and transferred to the English version of the workbook by the authors.

We conducted online interviews with one adult from each participating household. The interviews were carried out as online video meetings (due to the Covid-19 pandemic), except for two interviews which were voice only. All interviews were recorded, and detailed notes were taken. The interviews were semi-structured and included four sections. The first section covered the households' lives today and what they think is important in everyday life. Then, we asked about experiences of variable availability of electricity. Third, the participants were asked to imagine that they, in a near future, would face one day and one week respectively with variable electricity supply and (as a consequence) limited internet connection. We asked how the households would handle such disturbances and experience that day and week.

The final section covered ways in which the households are already, or could be, prepared for disturbances. As in the workbook, we did not frame situations with limited electricity supply as either

Table 2: Overview of the participating households based on the application forms. Perceived preparedness was in relation to a potential 24-hour power outage. *Information regarding the household member who participated in the interview.

Code	*Type of home (location)*	*No of adults in the household (age of any children)*	*Gender **	*Age span **	*PVs, solar water heating or electric car (EV)*	*Comment*	*Perceived preparedness*
P01	Farm (rural)	2 (0, 5, 7, 11, 12)	Man	35-44			Very prepared
P02	House (rural)	2	Woman	65-74			Can adapt
P03	House (urban)	2	Woman	55-64	Solar water heating, EV	Planning for PVs	Somewhat prepared
P04	Apt (urban)	1	Non-binary	45-54			Somewhat prepared
P05	Farm (rural)	3	Man	55-64	Solar water heating		Very prepared
P06	House (rural)	2	Woman	35-44	PVs in future home	Previously lived in and about to move to off-grid house	Very prepared
P07	Attached house (urban)	3 (17)	Woman	45-54	PVs in holiday home		Very prepared
P08	Attached house (urban)	2 (5, 10)	Man	25-34			Somewhat prepared
P09	House (rural)	1	Man	35-44	PVs	Off-grid house	Very prepared
P10	House (semi-urban)	1	Man	65-74	EV		Somewhat prepared
P11	House (urban)	2	Man	65-74	PVs in holiday home	Off-grid holiday home	Can adapt
P12	Apt (urban)	1	Woman	18-24	EV		Somewhat prepared
P13	Apt (urban)	2 (10, 12, 14)	Woman	45-54			Somewhat prepared
P14	Apt (urban)	1 (15, 17)	Woman	45-54			Not at all prepared
P15	Apt (urban)	1 (9, 12)	Woman	35-44			Somewhat prepared
P16	Apt (urban)	2 (2, 7)	Man	35-44	PVs on apt building	Living lab building	Not at all prepared
P17	Apt (urban)	1	Woman	18-24	PVs on apt building & holiday home	Living lab building	Somewhat prepared
P18	Apt (urban)	1	Man	18-24	PVs on apt building	Living lab building	Unsure
P19	Apt (urban)	1	Man	18-24	PVs on apt building	Living lab building	Somewhat prepared
P20	Apt (urban)	1	Woman	18-24	PVs on apt building	Living lab building	Unsure
P21	Apt (urban)	1	Man	25-34	PVs on apt building	Living lab building	Can adapt

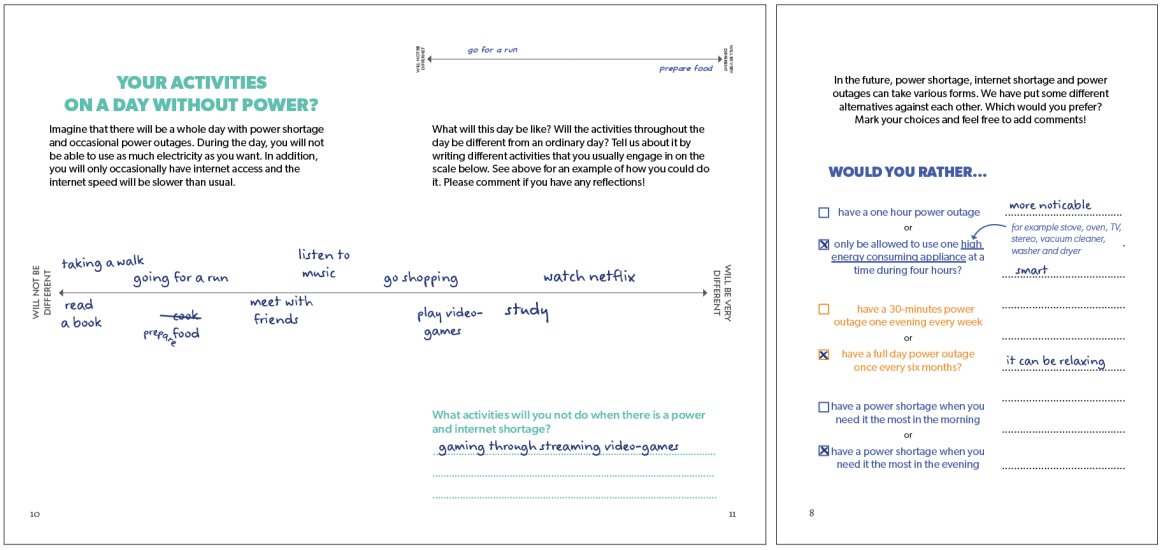

Figure 2: Two speculative exercises from the workbook for adults completed by P19.

positive or negative, as we wished to collect any insights the participants wanted to share. However, we did invite the participants to speculate whether a more intermittent supply is compatible with a good life, and this may have resulted in some participants reflecting more about potential positive aspects than they would normally have done.

After the interview, the interview participants received four questions via text message over two weeks, as a form of *speculative experience sampling about* everyday life in a future predicted by the renewable energy scenario. The intention was to engage the participants in speculations about performances and experiences in a future [cf. 43], but to strengthen the empirical character by situating the future and the speculations in the participants' everyday lives through experience sampling [5]. Each text message included a different example of power outages or shortages, followed by questions about expected experiences and actions, for instance: *If you would be informed now (Sunday 10 am) that there will be a power cut for four hours tomorrow at this time, would you do something differently today?* The participants replied via text message, with 19 participants responding to all questions and two participants responding to three and one respectively.

For the analysis, interview notes and transcripts along with the text messages were analysed thematically using both predetermined codes and inductive (sub-)coding. The returned workbooks served as memory aides and provided complementary data during the analysis. We present the results from the analysis in two parts: first, the participants' reflections on their experiences of and expectations on limited availability of electricity with related challenges and positive aspects (section 4), and second, identified strategies for household energy resilience (section 5). The strategies were identified through inductive coding of the participants' examples of what they previously had done, currently do, and in the future could do to manage situations with limited availability of electricity. Based on the identified strategies for resilience and links to previous work, we developed suggestions for how energy resilience can be supported by HCI (see section 5.1.1-5.3.1).

4 PARTICIPANTS' REFLECTIONS ON LIMITED AVAILABILITY OF ELECTRICITY

Below, we describe the participants' and their households' experiences of situations with limited electricity supply, expectations on what intermittent supply might involve in the future, challenges and concerns regarding the energy resilience of current practices, as well as envisioned positive aspects of situations with limited availability of electricity. In section 5, we move on to present the participants' strategies for household energy resilience and how this could be supported by HCI.

4.1 Experiences and expectations

Rather than fitting into either category of experienced or inexperienced with regards to energy resilience, the participants all had different types of experiences of variable energy supply, enriching our understanding of energy resilience. We highlight their respective experiences when relevant below.

All participants had earlier experiences of being temporarily without electricity access, for example when camping, hiking, or sailing, yet only a few of them had recently experienced a blackout at home, that is, managing without electricity in everyday life. However, for some rural participants power cuts happen several times per year and they already talked about energy resilience as a necessity. Three participants had experiences of living off-grid, in a holiday home or because of interests in self-sufficiency and simple living. Other reasons for developing energy resilience were interests in 'prepping' (proactively preparing for different types of emergencies) and outdoor life. Finally, the households who already consider themselves to be more energy resilient explained that they are less dependent on constant electricity supply because they have developed practices such as not using appliances simultaneously,

showering less often, having cold meals with non-refrigerated ingredients, and being flexible with what is done or when and how. These practices resemble those in past research, including everyday resilience [85], off-grid living [84], practices impacted by resource scarcity [75], and simple living [23].

All participants believed that it would be rather unproblematic with shorter power outages, lasting from an hour to a day, if they could catch up on important electricity-reliant chores after. One of the participants with experience of frequent power outages routinely waited one to two hours before connecting their back-up generator – for shorter outages it was not needed. Short outages might still be annoying or time-consuming, especially if they are frequent or unexpected. Timing is also important, as exemplified by a participant who had previously experienced short, reoccurring outages:

> "Since they [forty-minutes outages] usually took place on weekend mornings in the summer, it was not particularly difficult. We boiled water on the balcony on the gas camping stove to make coffee and that saved the situation. The children thought it was fun, at least the first two times." (P08)

Only a few participants had experience of power shortages in the form of a cap on power use, limiting which or how many electrical appliances could be used simultaneously. These participants lived off-grid with solar panels and batteries limiting available power or had a holiday home with a poor electricity system causing fuses to blow easily. When speculating, most participants thought that they would prefer power shortages over power outages but acknowledged that there could be potential social challenges related to negotiating and coordinating limited supply. For example, as the participant below illustrates, it could be difficult to coordinate energy use in a large household in which housework and paid work are combined with children's hobbies and entertainment:

> "I have no idea how things are used. Someone might be doing the laundry right now, someone might be cooking, anyone might be doing anything right now; I have no idea. Should I try to coordinate so no one does anything at the same time as someone else? That's difficult!" (P01)

In addition, if there is a shortage, the limited supply needs to be negotiated among household members and activities. One participating parent thought that this would be problematic:

> "If it is not available at all, it will be more like, 'yeah okay, this is how it is, we have to adapt and rethink completely'. But if you can, in some sense, continue as usual but with limitations then there will be quite a lot of frustration and conflicts around it, who gets to go first and who should be prioritised and so on." (P14)

4.2 Challenges and concerns in the everyday

While shorter disruptions were viewed as relatively unproblematic, reflecting on household energy resilience as a way to transition to a renewable energy future raised new questions and concerns among the participants. The idea that electricity supply might become limited in the future was new to many of the participants, perhaps partly because such scenarios were not part of the public debate at the time of the study, or voluntarily and transparently discussed among energy actors. In addition, some participants did not consider future power shortage likely – they trust that supply will be secured through, for example, increased energy production and large-scale energy storage. Yet, the majority of the participants, irrespective of experience of variable energy supply claimed that they would accept more frequent power disturbances if deemed necessary for a renewable energy future. Regarding such a future, some of the households raised personal concerns related to the wellbeing of their household, friends, and family. Several participants also raised large societal concerns, such as the impact on economic growth and future jobs if grid capacity would hinder establishment of energy-intensive business; the stability of digitalised and electrified infrastructures (such as digital payment, electrified modes of transport, and mobile communication); food provision; and energy provision to hospitals. About half of the participants suggested that any limitations in electricity provision should affect all households equally, as this was considered to be most fair and needed to increase acceptance, facilitate norm shifts, or prevent negative social effects. A couple of the participants would prefer voluntary limitations, with or without economic incentives. Finally, several participants pointed out that critical societal functions, such as hospitals and mobile communication infrastructures, should be prioritised and some that fairness also should include households' different preconditions for developing energy resilience.

The challenges that participants had experienced and speculated that they would experience in a future with more frequent power shortages and outages covered a wide spectrum of practices performed at home – such as hygiene, cleaning, renovation, exercise, and entertainment – and outside of the home – such as shopping or work. As the study was carried out during the Covid-19 pandemic, some practices previously performed elsewhere were now performed at home, such as paid work or studies. Additionally, some practices were performed less or not at all, such as commuting, travelling, and inviting guests. The participants brought up both practice-specific and general challenges and concerns. One general concern was poor timing of power disturbances. All participants, regardless of previous experiences of variable electricity supply thought that there would be specific occasions or tasks when power disturbances would become very problematic, such as highly critical and urgent tasks including calling the emergency services; external deadlines including online exams or work deadlines; planned tasks that are undesirable to postpone such as showering after exercise; in the middle of tasks such as food preparation; and when having guests. A second concern, particularly among participants living alone, was a fear of feeling lonely without the social life that digital technologies enable. Thirdly, the participants were worried that life would be less enjoyable without internet and connected devices.

Regarding practice-specific challenges, practices related to food were considered both important for maintaining a good life and highly electricity dependent – for both more and less experienced participants. Several participants considered warm food necessary to make the meal pleasant, but lacked knowledge and ideas for meals that require no or little energy to prepare:

> "I often use the oven to prepare food. That's difficult to change. What do you do if you don't have an oven? What can you do instead?" (P04)

Another concern was food storage. Almost all participants worried about refrigerated or frozen food going bad during longer power outages. The stored food was in some cases grown, hunted, or gathered by the householders, meaning that the time and effort spent would go to waste. Unlike the energy resilient off-grid households in Vannini & Taggart's study [84] who had installed energy-independent food storage, or even changed their diet to manage without constant access to cold storage, only a few of the participating households in our study were using some kind of alternative storage.

Work or studies performed at home due to the Covid-19 pandemic was another concern for the participants. This concern was rooted in a desire to get things done and not "waste" time or stemmed from a worry of getting behind with tasks piling up. As such practices typically relied on equipment with built-in batteries, such as laptops, internet access was often considered more critical than electricity. As shown in Mark et al's study of information workers who did not have access to email, it takes planning and effort both from the individuals and from the organisation to manage modern work without email [46], and most likely significantly more without any access to internet. Again, it raises questions about our societies.

A majority of the participants thought that power disturbances would be significantly easier to live with if they are planned or announced in advance, preferably with expected length and indication of their cause. If disturbances were announced in advance, households could prepare. For example, participant P05 had the habit of checking the weather forecast for storms or snow so he could prepare for electricity outage by activating the fast freeze function on his freezer to keep it cold for longer.

4.3 Positive aspects

Based on related previous experiences, the participants also envisioned possible positive aspects of power disturbances. First, a power shortage or outage could encourage people to try out new things – being flexible and creative in finding alternatives in the situation [e.g., 81] – and to prioritise and reflect on what is important in life. Alternative ways of doing, such as using a wood stove, could be experienced as rewarding. Some urban participants speculated that power outages could become a good excuse for treating oneself, for example ordering take out (as long as restaurants are still in service). For one younger adult, notifications about an upcoming power disturbance could be a reason for prioritising electricity-reliant leisure activities before the outage. Being without internet access could to some extent also be considered a positive experience:

> "I would say, the hard thing would be to not know when the connection resumes, or you hope that it won't be gone for too long. But other than that, I think it would be nice, you know, to not have to be connected [. . .] It's nice sometimes to live a simpler life. . . like, how would I solve this without electricity?" (P12, about shorter outages)

Social life may also be positively affected by power disturbances. While some participants living alone feared that it might get lonely without access to digital social networks, they imagined that they would instead spend more time with friends in person, which was perceived as positive. In families with children, some parents viewed power disturbances as an opportunity to focus on each other, similar to values expressed by simple living families who limit ICT for this reason [23]:

> "Personally, I think it would be positive if our daughters were forced to spend more time with us, instead of spending all their time in their rooms, with their devices, socialising online. . . They would have to spend time with us instead, and to go back to like when they were young, when we could play a boardgame and such things." (P07, speculating on what a day with electricity limitations would be like)

While managing everyday life during power disturbances can be time consuming [84], the participants also expected they would "save" time during disturbances as they would spend less time browsing the internet and social media on digital devices. In addition, they imagined that they would spend their time on what they considered to be more meaningful activities that they would like to do more of, such as reading books, spending time with friends, and handicraft. This relates to how information workers felt that they could concentrate more easily on their core tasks, and that work became less stressful, during an experiment where their work e-mail was turned off [46]. Energy resilient ways of doing could in themselves be time well spent, a 'slower way' of living [84], as P06 reflected on:

> "Everything takes much longer when you're off-grid, that's just a fact. You have to boil water. You cannot just say that you fancy a cake or a biscuit, you have to bake it. You have to fire up the oven and prepare everything. So it's like a slower way of life so you have less time to be bored and irritated and, like, 'oh let's put a film on for three hours'."

5 STRATEGIES FOR HOUSEHOLD ENERGY RESILIENCE

The participants provided a variety of examples of what they previously had done, currently do, and in the future could do to be more energy resilient. Below, we present these examples and ideas related to three identified strategies for household energy resilience: (1) *response diversity*, i.e., diversity in ways of carrying out normally electricity-dependent practices, (2) creating *opportunities to develop resilience*, and (3) building *community energy resilience*. In addition, we consider the implications of these strategies for HCI and provide suggestions for how HCI could support resilience within each strategy, drawing, when possible, on past research. Although we present the strategies one by one, they are in reality overlapping – response diversity is for example easier to achieve in a community where households can contribute with different energy sources or competences needed for performing practices in alternative ways. Furthermore, the proposed strategies correspond to three components or *attributes* of resilient systems [86] and should consequently

be regarded as complementary ways of strengthening household energy resilience.

5.1 Response diversity

Response diversity, that is, having different ways of responding to disturbances, is an important attribute of resilient systems [86]. Among the participants who experienced power cuts more frequently or lived off-grid, common ways of achieving response diversity were to have *backup electricity sources*, such as diesel generators, PV panels and product-specific batteries, to power important appliances, or to have alternative energy sources, such as wood stoves and fireplaces, for cooking and heating. This resembles how off-grid households set up an ecology of technologies to manage life without connection to the grid [84], and how households in Haiti needed to secure electricity through a range of diverse solutions, particularly energy storage, to make up for an intermittent energy infrastructure [57]. However, the participants in our study who used these types of alternative electricity or energy sources mainly live in rural detached houses and it may not be possible or desirable to scale up solutions such as fossil fuelled generators or firewood stoves more generally. Importantly, response diversity does not only mean a diverse set of materials or objects, such as having alternative technologies, but also the diverse knowledge and skills to use them when needed.

A more broadly applicable strategy was to *carry out important or urgent activities outside of the home*. However, the context still matters for how this strategy could be used and for whom. For example, in a close-knit community [45] strong social bonds make it easier to rely on other people for support. In our study, some rural participants illustrated this with examples of doing laundry and storing food at relatives' and neighbours' homes. Some urban participants speculated instead that they would eat out during power outages or shortages if possibilities to cook food as usual were affected. This strategy in turn assumes that power shortages or outages would be geographically limited or that there would be prioritised places with access to electricity and other resources. Furthermore, in addition to participants wanting to know the timing, duration, and cause of the disturbance, they would also want to know the geographical extent of the disturbance, or which specific places have access to electricity.

Many participants referred to *old ways of doing things*, including using low-tech products, as their current or speculated ways of being more resilient. This relates to how other communities stay resilient through re-adopting both old technology and skills for social change, and simply relying less on electric appliances [24] Some participants in our study live in homes with a naturally cooled pantry for storing food, which is common in older houses and apartments in Sweden, and some stored food outdoors, particularly during winter:

> "After cooking I often put the food outside on the stairs to cool down, and then in the fridge, and in the winter the soup can stay there for a while. [. . .] So I know how to use the cold outside as a fridge." (P03)

This requires access to an outdoor space, and depends on outdoor temperatures suitable for storing food, but can in Sweden be an option during winter (which coincides with the highest risk of power shortage). Other traditional ways of doing things included reading news in newspapers instead of on the internet or tv, reading books, communicating through telephone land lines, letters or in person, cleaning the home with manual power, using hand-powered kitchen tools, and doing things with the family instead of everyone on their own devices. Interestingly, such practices were many times associated with nostalgia, rather than suggesting that they are currently a part of everyday life:

> "I'm thinking about the short period when my mobile phone broke. It felt pretty good to not be available all the time. [. . .] I might be romanticising the past, I didn't live in the past, but perhaps we would socialise in different ways without internet and devices – we might be talking more." (P17)

However, the thought of a future including a (temporarily) more low-tech lifestyle was also regarded as negative, yet again triggering complex questions about our societies, energy demand, and what it means to live a good life:

> "Honestly, it is still a bit scary [...]. It feels like... as we [society] are not progressing but rather regressing." (P12)

Nevertheless, having *non-electric alternative activities*, and offline options, were considered important for resilience, both among those with more and those with less experience of limitations in availability of electricity. Some participants thought that they would need to make backup plans to always have alternative, electricity-independent activities or, for expected power outages or shortages, they might take a day off from work. For those with more experience, for example P09 who was living off-grid, such planning was already a part of everyday life:

> "There is always something to do that does not require electricity". (P09)

There were also ideas on how study or work practices could become more energy resilient. One participant drew parallels to digital practices when travelling:

> "But it is possible to download videos. If there is a time during the day when internet works well, then I can download it [pre-recorded lecture] and watch it downloaded. [...] I have done that for example when travelling by train." (P17)

Participants commonly mentioned having information available offline and having devices charged as important, but also reflected on, for example, that deadlines may need to be more flexible in a future with more power outages and shortages. If energy-related disruptions were to happen more frequently in the future, organisations would have to support workers in new ways, and plan tasks accordingly, similar to the implications provided in Mark et al.'s [46] study of work without email.

Some energy resilient practices require *changes in one's own expectations and in societal norms*. The example of having offline work tasks available and more flexible deadlines would require new workplace or study norms. Other examples include one participant who thought that knocking on a friend's door without calling or texting first would be socially unacceptable today, but perhaps more normal in a future with more power outages, and a few participants

talked about showering less often. There are already different expectations and norms in different situations, and a participant with a holiday home gave that as an example of a place where it would be easier to be energy resilient:

> "The conditions there are different for sure. I feel like we would manage there much easier than in the city. Because we are a bit more prepared and don't have the same requirements on everything being perfect." (P13)

Similarly, P21 commented on the different hygiene norms that apply when hiking. A renewable energy future with more electricity disturbances would provide a new context for energy-dependent practices, and other ways of doing things may consequently be more acceptable.

5.1.1 Implications for HCI in supporting response diversity. What roles could HCI take and what could HCI do to support household energy resilience through response diversity? We understand response diversity as adapting to a disturbance through doing something people need or wish to do in a different way. As suggested previously in Sustainable HCI, *exploring low-tech alternatives* is one way to address and mitigate an increasing dependency on electricity and internet, and expand opportunities for response diversity. Examples include Strengers et al.'s low-energy practices for achieving 'pleasance' [74], Blevis' principles of sustainable interaction design such as 'finding wholesome alternatives to use' [7], and Pierce's concept of restoration – "(re)introducing a displaced or foreclosed technology" [59:962]. Essentially, these ideas promote low-energy alternatives to energy-intensive practices which are likely to be increasingly needed in the future, and we encourage HCI to continue this path. Adding the perspective of energy resilience to these suggestions would highlight not only the need to strive for low-energy solutions in general but to also *provide solutions that can adapt their energy use to current availability of power* and move between various degrees of high- and low-tech. At times of complete power outages, perhaps only some core functionality is provided while at times of energy surplus more energy-intensive features are available. Here, HCI could for example explore how to design technologies in such a way, and what people in different contexts consider core functionality.

Another way HCI could contribute to response diversity is *powering devices with alternative energy sources.* Solar- or human-powered chargers are today primarily targeted for use in development contexts [see e.g. 93], for outdoor life, or for preppers. Integrating these also into products for a wider audience would increase household energy resilience. Another possibility is to allow devices to share battery power with each other. Yet another path to explore is *developing services for low-energy and offline use situations* for currently highly digitalised societies. Many ICT services already have features to reduce data usage and save battery, which would be useful in situations of power shortage or outage [see e.g. 8]. There are also possibilities in using ICT to support low-energy or offline practices in other ways, for example by suggesting what information may be useful to have offline and to communicate to others when someone is not available online due to lack of power. In developing contexts [see e.g. 30], simpler versions of services like Facebook are already crucial for communicating. As part of a future energy system, it might be considered important for digital services of all kinds to communicate and visualise risks for energy-related disruptions, and if possible suggesting ways to prepare for them in advance, rather than claiming 'disruption free' services.

As with low-tech and low-energy solutions, a non-trivial design challenge for HCI is likely to *make energy resilient solutions acceptable and desirable*, instead of perceived as old-fashioned and undesirable backup options.

Importantly, we believe a path forward is to explore designs that move away from 'doom' and dystopia [cf. 22]. However, just like industries are now moving away from fossil fuel, integrating aspects of energy resilience into digital services and products might be a necessary way to stay competitive and relevant in a future where shifting electricity supply is more frequent. Finally, building on past work in Sustainable HCI and computing within limits, HCI continue to have a valuable role in exploring what energy resilience, response diversity, and vulnerability connected to disturbances might look like in other social and geographical contexts.

5.2 Opportunities to develop resilience

To be exposed to disturbances is important for maintaining resilience [86]. People learn to manage without electricity from experiencing blackouts and similar disturbances [88] whether it is voluntarily [84], or from experiencing hardship or scarcity [75, 85]. Disruptions "offer a snapshot of rhythms as they unravel and are braided back together again, capturing the work that is needed to keep them going" [83:69]. Similarly, in our study, the participants who had experienced power outages more regularly were also better prepared. Still, power outages are currently rare for most people in Sweden and opportunities to *learn from actual power cuts* are consequently few. The participants suggested other strategies that could contribute to learning energy resilience.

One way to develop energy resilience, despite lack of disturbances, is to *integrate energy resilience products and practices into everyday life.* A participant from one of the more prepared households described his preparedness equipment:

> "The reason why I have it [a combined power bank and inverter] here [in the office] is that I regularly use the things. If I don't use them, I won't know how to use them the day something happens." (P01)

In addition to providing opportunities for learning, when the products are used in everyday life it is more likely that they function and are ready for use also in a situation of power outage or shortage. P07 had bought a container for storing water for emergencies but when there was a sudden power cut, and water could not be pumped up from the well, the container had never been filled with water. Similarly, other products that can contribute to resilience may need to be charged or depend on having fuels at home.

Another opportunity for developing resilience is to *learn from other low-energy or electricity-independent experiences.* P04 commented that they should have a camping stove to be better prepared for power outages, but they did not identify as a 'camping person' and were a bit scared to use it. On the contrary, P08, who regularly went camping with his family, felt confident using a camping stove

during power outages. Through camping without access to electricity, the family naturally got opportunities to learn something that could be valuable also for energy resilience in everyday life.

Many practices that the participants considered energy resilient were also expressed as potentially being fun 'out of the ordinary' experiences, such as spending time outdoors, cooking over an open fire, having a cold 'refreshing' shower (as opposed to warm showers), and spending time with family and friends without distractions from devices. This resembles findings in Hitchings et al.'s study of music festivals, where low-resource cleanliness practices could be considered a part of a holistic festival experience [32]. Even if such practices do not seem to naturally transfer to or impact everyday life after the special event [32], they nonetheless add to building up skills and knowledge about dealing temporarily with a low-resource situation. Furthermore, some participants expressed that occasional power cuts could be positive for personal development and perceived as opportunities to break habits, be creative and reflect on what is important:

> "Well, it forces you to reflect. It forces you to make decisions about things that otherwise would go by unnoticed. Now you're forced to ask yourself 'Do I need this, do I need that, and do I have enough of this, and so on?' And that kind of thinking would impact life in general, you would learn how to be more prepared." (P10)

As P21 recognises below, this is a highly privileged perspective:

> "I'm privileged to be able to say this, but it could even be nice and cosy with a blackout sometimes. It could be an opportunity to change habits or to focus on something else." (P21)

It was also suggested that a power outage may be considered an exciting experience only if it does not complicate life too much. Power outages that are frequent, unexpected or have bad timing would likely have a low chance of being perceived as positive events and opportunities for learning. We believe that the positive nature of the statements and examples above illustrate both the affluent reality of our participants, where past experiences are voluntary rather than stemming from hardship and regularly dealing with scarcity, and their current situation where energy-related disruptions are rare, making it hard to imagine the full range of potential consequences, positive and negative, and the respective efforts to adapt to them.

5.2.1 Implications for HCI in supporting opportunities to develop resilience. An overall, non-trivial challenge regarding energy resilience is how to *communicate a need to learn and build up energy resilience* to affluent groups who currently do not experience disruptions, limitations or vulnerability related to resources. Still, this is a core aspect of resilience and adaptation – the insight that we must not wait until the day we face a crisis, but to foresee needs, skills, knowledge, etc that could be useful in a different situation, society, or future. We encourage others in HCI to experiment with the concept of household energy resilience to speculate, provoke, and reflect together with different groups of people in order to develop further strategies related to communicating resilience to households.

HCI could also continue the work to study what skills and knowledge people in different contexts consider important and relevant for a changing future. As our participants have shown, disruptions could be valuable because they make you question your needs. Therefore, we believe it is key to draw further on sufficiency [20] in order to *explore how different people would understand 'wants' vs. 'needs'* in situations where energy-related disruptions and limitations would be more frequent. Again, just like technologies in the future might need to 'switch' between handling no electricity and abundant electricity, what would similar shifts in supply mean for people and their practices? As Vannini and Taggart [84] show, in dark winter seasons, off-grid households fundamentally change their rhythms to live according to when electricity is produced. While grid-connected households might not be as impacted, their rhythms might still need to change more with seasonal or other external changes impacting the production of renewable electricity.

Energy resilience does not concern households in isolation but would require engagement and new collaborations between actors in the energy system, as Powells et al. have argued is needed for flexibility [60]. Utility and energy companies most likely need to work on their communication toward households around resilience, and to find ways they themselves could be more transparent about shortages and disruptions and see these as 'invitations' to collaborate. We believe that HCI could support this process, for example by helping energy actors *utilise existing disturbances to develop resilience.* Planned power, water, or internet outages, that are required for maintenance or similar purposes, could be framed as proactive opportunities for developing energy resilience in affluent contexts. HCI could help energy actors in taking on a new role, as well as support reflection during outages, for example by making use of principles of 'slow technology' [25, 53]. Related to this, HCI could draw on the concept of household energy resilience to analyse more widely different energy futures, as done by [77], as a way to move beyond technology-driven visions that are currently strong in the energy sector, and to visualise future social practices to actors in the energy sectors.

Furthermore, we believe that HCI could support people in developing resilience by exploring ways to *integrate energy resilient devices and features into everyday life,* rather than positioning them as intended only for crises. One familiar example is how most mobile phones are equipped with a flashlight, which is naturally incorporated in everyday life compared to a torch stored in a drawer somewhere in the home. Previously, it was also common that mobile phones had an FM radio, which could be used during power outages independently of internet access, provided that the phone was charged.

Finally, we encourage HCI to explore how to *build on other experiences that contribute to energy resilience* to integrate learning into current practices. Digital technologies are already used to support experiences such as outdoor life [31] and cooking [81]. These could include or build on features that are important also for energy resilience. Recipe or cooking services, for example, could highlight aspects such as energy resilient storage of food or alternative ways of preparing a meal with limited use of electricity.

5.3 Community energy resilience

Resilient systems should neither be over- nor underconnected, but modular [86]. With overconnected systems (e.g., people relying on the same infrastructure or doing things in the same way) disturbances affect the whole system, while underconnected systems miss opportunities for people to, for example, learn from each other. Hence, while a certain degree of independence might be beneficial, household energy resilience is likely to be strengthened by connections to other households, community organisations, as well as public and private organisations. This is supported by study findings of everyday resilience in a low-economic-status community, where not only relying on one's social network was key for support and sharing resources, but also valuing and cherishing the social community was central [85]. As Solnit [72] describes in her work on how communities respond to natural disasters, strong examples of community resilience and joy emerge among the chaos and hardship. However, the belief that we can help each other is weakened in strongly individualistic societies where we are fed with messages that we must fend for ourselves, and so this strategy might be of extra importance.

As already mentioned, *making use of the electricity at neighbours and family* during power outages was practiced by some of the rural participants who had experience of power outages. This might, however, be more acceptable at times considered 'crises', for certain practices, and in some contexts. P09, who lives off-grid and relies on PV panels for electricity, describes going to his neighbours to shower once a week but he would rather "turn on the generator or wait until there is sun" for charging his devices than to bring them to his neighbour.

Another way to become more resilient with the help of others was by *learning from other people*. It included learning from how older relatives did things, learning from neighbours with skills that you do not have yourself, and learning from online communities. Previous work in Sustainable HCI has emphasised the value of learning together as a way to strengthen resilience in a community [6, 24] and supporting 'deep learning' about sustainable practices [92]. Other people were also considered valuable in this study as potential *sources of information* about the disturbances, as *emotional support* during times of crises and, for people living alone, as *company*:

> "It would matter if I knew beforehand [that there would be a week-long power outage]. Then I would probably prepare. Perhaps spend time with a friend or so. I would be bored in the beginning of the week otherwise." (P18)

Furthermore, *doing things together* with neighbours, family, and friends during power outages or shortages can be more efficient. The participants gave examples such as cooking and watching tv together, and staying with another family to only have to heat one house. However, a feeling of independence can still be important:

> "Like in a co-living house where you cook together. There is a large kitchen that accommodates for many and then everyone can take their food and eat at their own table if they want. [...] Although I'm not... I would still want to be very autonomous; I would still want to manage on my own." (P04)

People living close by were by many participants considered important, both related to past experiences of power outages and in speculations about a future with more power outages and shortages. Getting help from and doing things together with your neighbours was however perceived as difficult if you do not know your neighbours. It was suggested that for example housing associations and workplaces could have a role to play during power outages and shortages, to support their members or employees.

5.3.1 Implications for HCI in supporting community energy resilience. We believe there are at least two relevant paths for HCI to support community energy resilience. The first is to *use the concept of household energy resilience to explore complex questions* about for instance energy justice, disruptions, a good life, and constant supply as a 'right' in relation to a transition to a fully renewable energy system. We believe that this is a discussion to be held at multiple levels of society, that involves foregrounding and questioning rules and norms of the community. This is likely to be an important learning process in itself, if, like in this study, affluent people have not paid these questions and possible futures much attention.

The second path is already central in HCI, and it is to support ways to *strengthen the interconnection between people*. However, applying this to energy resilience emphasises the need to support the interconnection between people *beyond the digital* as well as *encouraging collaboration rather than individualism*. One way this could be done is to explore ways to *anchor digital communities in local communities*. Purely digital communities may be useful for sharing experiences and developing resilience. At the same time, they depend on electricity and would consequently provide a better support during power outages and shortages if they were also anchored in local communities. In addition, face-to-face meetings are invaluable for learning, joy and trust building in communities [6].

A related strategy is to *utilise shared facilities*, both as a potential hub for resources and for anchoring a community to a local place. Already shared facilities such as laundry rooms, gyms, community centres, libraries, or coworking spaces could be designed as places for people to carry out important and urgent activities requiring electricity, such as charging devices or using the internet. These could also be places for using or borrowing energy resilient products that not everyone may need or can afford to have at home. Similar ideas about sharing spaces with access to e.g., heating and cooling have been suggested previously as a more low-energy alternative than for every household to invest in one's own technologies [74], or as a collective effort to create low-energy practices that more directly can offload a strained grid [60]. Digital platforms are used to facilitate many types of sharing but building trust among the users can be challenging [17]. Community ownership of items to share, rather than individual, could be one way of addressing trust issues [48].

Finally, HCI could look into designing support that *makes use of 'crises' to form communities*. Crises, such as more extensive power outages, can connect strangers and form new relationships when people help each other [66]. Digital platforms could be used to maintain and develop such relationships and mobilise support also for (smaller) future disturbances.

6 DISCUSSION

6.1 Household energy resilience as a lens for investigating renewable energy futures

In addition to the specific suggestions and design considerations for HCI presented above, we believe that household energy resilience as a concept can be valuable for HCI to pursue further. Below, we first reflect on the general concept of household energy resilience and considerations when exploring renewable energy futures. Second, we discuss the more overarching role HCI could play in household energy resilience and point to risks of digital technologies reducing resilience. In this study, household energy resilience was used as a lens to investigate renewable energy futures from a household perspective. Our ambition was to shift the focus from *if* households can and would reduce or change their energy use, as in studies of voluntary or incentivised change, to *how* households can adapt to disturbances in power supply, that is, addressing adaptation [82]. To get a variety of insights regarding this 'how', we sought for a range of experiences when inviting participants for this study. The differences between the households provided rich data and indicated both where there were and were not links between certain experiences, exposure to disturbances, preconditions, or dwellings and specific strategies or expectations. Those with more experience naturally had more personal examples to draw from, had more training, and were more prepared. For example, in relation to response diversity, their 'responses' were ready. Yet, experience did not seem to result in specific preferences of strategies or expectations. An exception was however the off-grid households who actively sought a 'slower way' of living and/or independence, and these ideals were not embraced by all. Another link exists in relation to living context; rural contexts appear to facilitate the development of household energy resilience. Rural contexts include both incentives to develop resilience because of e.g., unstable grids [45] but also conditions that support some aspects of resilience building, in the form of more space, including outdoor space, and often stronger co-located social networks. In contrast, in urban areas many lack extra space, lack agency to invest in alternative energy sources, and lack driving forces or supporting social norms to build a network among neighbours.

As the study was performed in a resource-rich country with stable electricity supply, most participants had few experiences of electricity disturbances and could only speculate on what life might be like with more frequent disturbances. This lack of experience might have contributed to a, from time to time, almost romantic view on disturbances. For participants with few experiences, it may have been difficult to imagine the full impact of such disturbances, as the reliance on electricity in today's society can be hidden in plain view [75]. In contrast, participants with recent experiences of more frequent (and longer) power outages discussed more practical ways of dealing with disturbances as a part of everyday life, strengthening the importance of having opportunities to develop resilience. However, the more experienced participants also brought up the positive sides of disturbances in electricity supply.

Imagining power shortages, that limit but do not cut off electricity supply, proved to be particularly difficult. Exceptions were the participants who had experiences of off-grid living or older electricity systems with power limitations. For future research, it would be useful to draw more from such experiences, to arrange actual temporary limitations to electricity use in regular households, and to study low-resource settings, as suggested by for example [15], where limitations in electricity supply are common.

As the core idea of household energy resilience is to make disturbances more acceptable by ensuring *a good life* despite power outages and shortages, this lens opened for reflections on when and how electricity and ICT contribute positively to everyday life and when they do not. The participants provided a variety of examples of how practices can be adapted to maintain a good life also without electricity. Similarly, previous research has indicated that limitations in consumption can increase quality of life in some aspects but it requires experimenting with and questioning norms related to convenience and what is important in everyday life [23, 28]. Such processes are urgently needed in affluent communities to challenge constantly increasing demands for convenience [38, 60, 74, 76] and to decouple norms about how a good life is created from increased electricity and internet demand.

However, we acknowledge that it is not possible to make all types, frequencies, or durations of disturbances acceptable in the eyes of an affluent society, even when trying to ensure a good life. We are not promoting poorly functioning energy systems, injustice, or hardship, or that we should all become off-grid households. Experiences from other countries and communities show that not only does highly unreliable and limited electricity supply create instability in people's lives, but it also hinders full participation in an increasingly digitalised society because the uptake of digital services and solutions often take for granted a fully functioning energy infrastructure [15]. In addition, power disturbances may be consequences of events such as flooding or extreme temperatures [35], meaning that lack of electricity is just one of several urgent problems for a household to simultaneously manage. However, striving for ensuring a good life while managing at least less frequent and shorter disturbances will likely improve resilience for, and experiences of, also more severe disturbances.

An additional obstacle for power disturbances to be perceived as an acceptable part of life could be if disturbances are considered unjustly distributed [40]. In visions of renewable energy futures, financial instruments are often suggested to address discrepancies between demand and supply [19, 67] but such measures may be problematic for vulnerable households [21] or families with children [51]. In line with these concerns, many participants in our study considered limitations that affect all households fairer and only a few participants suggested financial incentives. Returning to Trentmann's argument that disruptions "raise questions about accountability (who is to blame), entitlement and social justice (who should get what), and, most profoundly, about 'normality' (how can or should members of a society live)" [83:69], we believe that using the concept of household energy resilience was useful in triggering reflection around these questions and it could further be used to facilitate discussions of, for example, alternatives to financial instruments in a renewable energy future.

Still, some of the examples of resilience, especially related to the strategy response diversity, require investments that not all households can afford. So, even if all households would be equally affected by disturbances, they would not have equal opportunities to manage them. Hence, community energy resilience, and shared

resources for energy resilience, could be interesting to investigate further from a justice perspective.

While we found many examples of, and ideas for, community energy resilience in our study, there is, as acknowledged by some participants, a conflict between a desire to be self-sustainable and to be part of a society that addresses challenges together. A future with more disturbances could lead to increased efforts by households to become independent of shared infrastructures, and current energy resilient technology is often intended for individual households. Power outages can, for example, lead to an increased interest in acquiring private fossil fuelled generators [1]. Unreliable access to electricity can also reduce the trust in utility companies [13], potentially increasing the demand for off-grid solutions. To avoid that the only imagined path to energy resilience is to focus on individual solutions for households, HCI and other relevant actors need to consider how energy resilience for households can be met and supported on a community or societal level.

6.2 The role of HCI in household energy resilience

Our study showed that household ICT devices, such as computers and mobile devices, are part of everyday practices that were considered both important and inflexible. Being without functioning devices would be a concern, particularly if the timing is bad. As such devices usually require low power compared with other household appliances [63, 94], and often have batteries, they are less likely to be affected by power shortages and shorter outages. But longer power outages may still cause problems, as well as unplanned disturbances coinciding with needs to charge. Furthermore, many ICT practices rely on internet access and, for shorter disturbances, disruptions in internet access were often more of a concern for our study participants than loss of power for charging devices. Specific internet services could also be affected by local energy disturbances elsewhere since data centres can make up a significant part of local power use [33]. This would likely impact households, particularly since household peak use of internet services has been found to overlap with peak demand for electricity [49]. Hence, there are many reasons for stakeholders in HCI to engage with household energy resilience and take resilience into account when designing new devices, services, and infrastructures. Ensuring *response diversity*, creating *opportunities to develop resilience*, and building *community energy resilience* are three possibilities for HCI to contribute to supporting household energy resilience.

Energy resilient ICT solutions are, however, not a trend that we currently see in affluent societies, with increasing digitalisation and a following dependency on reliable and uninterrupted availability of electricity. The design of digital services and devices drives an expansion of digital infrastructures, which in turn enables even more energy intensive services and devices [61]. There is an apparent conflict between increased digitalisation and an endeavour to be energy resilient and ensure a good life in a future with intermittent electricity supply. However, as digital technologies both can contribute to a good life and are envisioned as tools to help combat climate change, with a central role in the transition to a renewable energy system [34], this is a complex issue. In striving to mitigate problems of climate change and power disturbances, we risk inhibiting adaptation to a future with power disturbances. The usefulness of digital technologies in the renewable energy future we have explored, including many of our suggestions for how HCI can support energy resilience, thus depend on devices and services being resilient in themselves.

There are also cases when new technology may only marginally contribute to a good life but significantly increases energy dependency. ICT can work as an 'intermediary' that increases complexity [64], for example, by adding connectivity as a feature to traditional domestic appliances. This makes appliances both directly and indirectly (through internet) dependent on electricity and incorporating them into energy resilient practices becomes more difficult. As several researchers in Sustainable HCI have argued as well, we should sometimes consider the option of not designing new technology but finding alternative low-energy ways to support a practice [4, 7, 74]. This is also relevant to consider for energy resilience. In our study, still having access to old technology or not having upgraded to new technology was an important part of existing energy resilience. Interesting questions in line with this are if and how we can design to preserve [24] existing, but endangered, resilient practices – for example by rediscovering the meaning of manual work [41] – or restore [59] practices that already are extinct. When digitalising and electrifying, it is important to not only consider what can be gained – in terms of for example convenience, energy efficiency, or load balancing – but to also consider what is lost in terms of electricity and internet independency, the skills connected to manual work, and the creativity that comes with 'managing without'. While our work supports previous efforts in HCI to encourage low-energy alternatives that still contribute to a good life, we believe that acknowledging disruptions and focusing on household energy resilience can complement these efforts and trigger new questions, reflection, and perhaps other incentives for households and energy actors to participate in a renewable energy future.

7 CONCLUSION

In this paper, we have presented a study in which we used the perspective of 'household energy resilience' to explore an envisioned, yet unknown, future where the electricity supply is coming mostly or fully from renewable energy production. We have argued that for affluent communities – such as the one in this work – where constant and reliable supply of electricity is currently taken for granted, a transition to intermittent supply is likely to involve disturbance of different kinds, and that working *with* rather than *against* the disturbances could help speed up a transition that is urgently needed from a climate perspective. 21 households in Sweden took part in the study, which explored both their experiences of being energy resilient today or in the past and their expectations for and reflections on a future of intermittent supply. Based on their insights, we described three strategies that the households employ today or imagine for the future, which are supported by resilience literature [86]: (1) *response diversity*, i.e., diversity in ways of carrying out normally electricity-dependent practices, (2) creating *opportunities to develop resilience*, and (3) building *community energy resilience*. We believe that HCI in many ways could, and should, help strengthening these strategies, as one effort to expand our research on adaptation to better deal with a future of limits

[50, 82]. Otherwise, there is a risk that HCI instead inhibits possibilities for adaptation through increased digitalisation and dependency on stable electricity supply. With our study, we have begun to show with empirical insights what that adaptation – or resilience – looks like in certain households today, and to outline design considerations for how digital technologies can contribute to strengthening resilience.

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