Peer-to-peer energy markets: Understanding the values of collective and community trading

Denise J Wilkins
Microsoft Research
Cambridge, UK
t-dewilk@microsoft.com

Ruzanna Chitchyan
University of Bristol
Bristol, UK
r.chitchyan@bristol.ac.uk

Mark Levine
University of Lancaster
Lancaster, UK
mark.levine@lancaster.ac.uk

ABSTRACT
Peer-to-peer energy-trading platforms (P2P) have the potential to transform the current energy system. However, research is presently scarce on how people would like to participate in, and what would they expect to gain from, such platforms. We address this gap by exploring these questions in the context of the UK energy market. Using a qualitative interview study, we examine how 45 people with an interest in renewable energy understand P2P. We find that the prospective users value the collective benefits of P2P, and understand participation as a mechanism to support social, ecological and economic benefits for communities and larger groups. Drawing on the findings from the interview analysis, we explore broad design characteristics that a prospective P2P energy trading platform should provide to meet the expectations and concerns voiced by our study participants.

Author Keywords
Peer to peer energy trading platforms; semi-structured interview; sustainability; thematic analysis .

CCS Concepts
•**Human-centered computing** → **User studies;** *User centered design;* Social engineering (social sciences);

INTRODUCTION
The way that people can participate in the energy market is changing. It is expected that by 2030 at least 27% of Europe's energy generation will come from renewable sources [1]. Much of this new generation will not be produced by large-scale and centralized generating stations, instead it will be produced by local small-scale, geographically-distributed 'microgenerators' - including households, community and co-operative schemes - who typically produce electricity for their own consumption, with any excess exported to the grid [49].

Transition to renewable energy sources is largely motivated by the pressing decarbonization agenda due to accelerating climate change. Harnessing locally available, clean sources (such as sunlight and wind) for energy generation is a key avenue for the traditionally fossils-based energy systems' decarbonization. Although these new forms of (micro-)generation present many opportunities for advancing the decarbonization process, challenges exist [10]. These include the development of new energy transaction models that can adequately *motivate, compensate and incentivize* distributed generation [12].

Peer-to-Peer (P2P) energy trading is a model that could address many of these challenges [5, 6, 38, 44]. We consider energy trading to be P2P if energy is produced by microgenerators with the excess generation (i.e., what is left after the self-consumption needs of the generator are met) sold directly to other (micro-)consumers. Thus, the microgenerators are able to freely and continuously buy and sell their excess generation to/from each other; they can leverage dynamic pricing and aggregation of electricity generation, and provide incentives for changed patterns of electricity consumption to balance supply and demand. P2P energy trading must be supported with a digital platform where the buying, selling, billing, and reporting takes place. Yet, research is scarce on *how people would like to participate in P2P trading and what would they expect to gain from such platforms* [4, 17, 37].

If P2P energy-trading platforms are to be widely adopted and successful, we need to consider how to create socially, economically, and ecologically sustainable platforms [18]. Given that many technologies and system architectures can underpin P2P platforms, which provide different opportunities for participation, control, anonymity and transparency [4, 13], it is pertinent to study how prospective users perceive the P2P energy market, what they would expect from these systems and other platform participants, and the type of participation they would seek. Here we present the first such study. We ask: how do members of the public understand P2P energy trading and how can P2P energy-trading platforms support public participation in the decarbonization process? We explore these questions through interviews with people who have a self-defined interest in renewable energy.

We draw on our analysis to present design characteristics that a P2P energy-trading platform should provide to meet participants' expectations and concerns. Our contributions are detailing prospective users' expectations of a P2P trading platform, and the design characteristics such expectations entail.

Below, we outline related work, then present methods and analysis, we conclude by outlining findings and implications.

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RELATED WORK

Sustainability in HCI

There has been a wealth of devices and technology exploration to promote sustainable lifestyles by supporting people's awareness of their energy consumption and how related behavior may impact the environment [20, 21, 40, 41]. For example, there are tools to support energy awareness and efficiency in the home [23, 24, 32], applications that help users switch to a low-carbon electricity supply [56], and efforts to help users shift consumption to more favorable times [52, 33]. However, most existing research is concerned with energy *consumption*, personal use and rational choice. In contrast, P2P energy-trading systems are designed to support both the *consumption and generation* of RE, and highlight the social, collective and community dimensions of energy sustainability.

To our knowledge, limited research has examined the human dimensions of P2P energy trading that support widespread use, acceptance and participation in the decarbonization process. Although real-world examples of P2P energy-trading systems exist, such as the Brooklyn Microgrid [43, 57], these tend to be small-scale, experimental deployments focused on the platform's technological and economic viability. Research outside of HCI has primarily reviewed the aims and approaches of such projects, but does not examine design implications in depth. For example, Zhang and colleagues' review [57] identified that commercial projects primarily focus on business models and marketplace design, but largely ignore the needs and requirements for supporting local markets. Chitchyan and Murkin [13] found that existing projects can help individuals adopt more active roles in the energy market, however they did not explore users' wants and needs. Likewise, Sousa and colleagues [53] reviewed existing projects to create a typology of market designs. However, their typology omitted issues around who makes financial decisions within the market.

In contrast, the HCI community has started to explore design implications and a human centred approach. For example, Meeuw and colleagues [42] designed an interface to support understanding of electricity (generation, consumption and electrical grid) by visualizing electricity quantity and location information. They demonstrated user demand for local energy, but concerns about sharing location data. Similarly, Pschetz, Pothong, and Speed [47] examined user interests and values: they demonstrated prominent user concerns for autonomy, control and economic equality. However, both papers focused on specific operating models and designs.

Altogether, P2P energy markets are largely unexplored in HCI. Pierce and Paulos' literature review identified a dearth of HCI research examining smart grid and distributed generation technologies. They outlined opportunities for examining "*experiential, behavioral, social, and cultural*" dimensions of these technologies, including designing to facilitate a sense of ownership and responsibility over energy, and designing to support norms of community sharing [45]. Despite this theoretical contribution, empirical research has focused on the individual and economic dimensions of trading electricity, so we have limited insight into other user values and interests in this context, and how these platforms can support environmental sustainability. This is important because it is likely that P2P energy markets are not just used as a resource exchange platform, but rather bound-up with a sense of community and wider social, ecological and emotional benefit (e.g., [45]).

The Sharing Economy

To help understand P2P energy trading, we conceptualize it as a specific instance of the **sharing economy**. This is because participants transact over spare resources (generation and consumption capacity), and can choose to donate, sell, or exchange it. The sharing economy includes commercial markets such as Airbnb and Uber, as well as non-profit initiatives like Couchsurfing and timebanks [8, 22, 28, 34]. Similar to Uber, Lyft, and Airbnb, P2P energy platforms match suppliers with customers who seek to rent access to the product for a limited period. We use the term 'P2P' (instead of the more generic sharing economy) because it implies direct individual control over own spare generation/use needs. This becomes possible because ownership of individual generation and consumption records are attributed through the platform. In other models (e.g., community-owned hydro station sells generation to a utility provider who resells it back to the station owners for consumption - as is today's norm) sharing happens in financial terms, but there is no direct individual ownership over individual generation/consumption.

Research examining the sharing economy demonstrates the importance of understanding what motivates users and reflecting these motives within the platform interface. Users have different motives for participating in the sharing economy and can obtain different benefits (e.g., [26, 35, 39]). *Social* benefits are important for the use of non-profit services like timebanking and Couchsurfing; these include developing individual and community capabilities, social relations, social care, self-respect and satisfaction [8, 28]. There are also non-financial benefits of commercial ridesharing services: users gain social and *cultural* resources from each other; including informational and emotional companionship support [53]. However, other research has highlighted the role of basic self-interested and *instrumental* motives, such as obtaining what is needed at a good price with high convenience, for a variety of sharing applications including transportation services and Airbnb [28, 7, 16]. Significantly, research demonstrates that a mis-match between user motives and the benefits of use can be detrimental for participation, thus it is important to appropriately understand and embody user motives within the interface to create successful platforms [8, 7].

Additionally, the field of HCI has recently adopted a critical approach, exploring the sharing economy's equality and social justice implications (e.g., [15]). On the one hand, this research seeks to understand how to enable everyone to participate: Research tends to demonstrate that low-income households are unable to participate in and benefit from platforms such as Uber and Airbnb, for example due to low digital literacy and restricted payment methods [14, 31] Simultaneously, this work demonstrates the additional challenge that P2P platforms can reflect and reproduce inequality. This has been accompanied by calls for the CHI community to find ways to support "*ecological, economic and social sustainability, with the goal to* *promoting a fairer distribution of goods and labor, ultimately creating a stronger sense of community"* [18].

These considerations are particularly relevant for P2P energy trading, where there are important questions about sustainability, including how to support the participation and welfare of those in fuel poverty and how to support energy security through aggregating supply and demand [10]. In sum, in addition to understanding what motivates users, we also need to explore how these platforms can support social, economic and ecological sustainability.

METHOD

To explore how P2P energy trading is understood today by its prospective users, and how it could support sustainability, we undertook a series of in-depth interviews with people who have a self-defined interest in renewable energy.

Participants

Participants (n = 45) were recruited through advertising in newsletters and social media channels of the host university, and UK-based community and cooperative energy groups. The advertisements asked for participants who have a self-defined interest in renewable energy, however no prior knowledge of technology was required. We targeted individuals with interest in renewable energy as we expect them to be one of the primary user groups of P2P energy-trading platforms.

Most interviews (35) were conducted on a one-to-one basis. Yet, as we expect energy trading to be a household activity we also conducted 5 interviews with pairs of cohabiting partners. Our large interview sample aimed to meaningfully capture perspectives of generators *and* consumers. Twenty-two of the forty households had solar photovoltaics, which is an ideal electricity generation technology for P2P energy markets. Participants were aged 29-86 years (median = 60 years), 14 identified as women (31 men), and worked across a range of energy related (e.g., project development, consultant, solar thermal fitter, farmer; n = 7) and non-energy related (e.g., university administration, language interpreter, legal; n = 15) occupations (retired, n = 15; unspecified, n = 8).

Design and Procedure

Interviews were semi-structured and conducted either face-to-face, over the phone or via videoconferencing software, they lasted approximately one hour. There was no compensation for participation, but travel costs were reimbursed. The first half of the interview used open questions to explore participants' interest and involvement with renewable energy (e.g., tell me about your current interest in renewable energy?), perceptions of and experiences in the current UK energy market (e.g., tell me about your experiences in the current energy market?), and perceptions of a new P2P electricity market (e.g., what do you think the benefits of a new P2P system would be?).

The second half of the interview used vignettes (e.g., [25, 36, 51, 54]) and sketches of possible designs (see Figure 1 for sample vignette and sketches), which functioned to probe how participants make decisions about key *behaviors of interest*. First, we wanted to explore how people make decisions about: (1) buying green energy vs fossil fuels; (2) using a P2P system vs traditional energy company; (3) maximizing profit vs contributing to fuel poverty; (4) trading as an individual vs trading as a group; and (5) automated trading. In turn, we wanted to explore what the prospective P2P trading platform users would expect of such a platform.

Given that P2P markets can have a variety of configurations, our designs enabled different levels of *localized trading, recommendation from authoritative source, and third-party regulation*. The sketches varied in terms of whether the trading platform was presented as: (1) a local vs national network; (2) recommended by the Government vs non-governmental advisory group vs other users; and (3) unregulated vs regulated by a national energy supplier. We created these designs by drawing on existing research examining P2P energy trading that emphasizes issues of location, trust and governance in these markets [42, 47, 10]. Thus, rather than looking to examine systematic differences in participants' responses to the different designs, we sought to draw out broader principles about location, trust and governance.

To help the prospective users better relate to the P2P trading notions, we created a story about a character (Sali) who needed to make these decisions about their own energy, the character was either described as a buyer or seller of electricity. The story was made of 4-5 related scenarios, which mapped directly to our 5 *behaviors of interest*. Before beginning the story we asked participants what they imagined their role in the new energy market to be (buyer, seller, or both), which determined the story they were told (we picked a story at random for participants who answered 'both'). Within each story we randomly varied the designs between participants. After each scenario participants were asked to describe: (1) risks and benefits of each option; (2) what the character should do and how they made the decision; and (3) what the interviewee themself would do and how they made the decision.

We developed vignettes following Schoenberg and Ravdal [51], who highlight the importance of *"context-sensitive, realistic and familiar scenarios"*. To create scenarios we drew on: (1) our own experience: co-authors had worked with this topic for over three years prior to the present study; (2) a workshop on current and future directions of p2p energy trading, which had over 40 community energy, legal, distribution networks and academic participants; and (3) our literature review. We first identified the key behaviours of interest, sketched a variation of sketches, and then drafted vignettes. We pre-tested materials on the extended research team, one energy industry professional, and two members of public: one with renewable generation capacity at home (prospective supplier); one with no generation capacity (prospective consumer). We iterated materials in response to feedback.

Interviews were recorded and transcribed verbatim, then analyzed using thematic analysis [9]. We adopted a contextualist approach to the analysis [9] and used a hybrid coding process, which develops themes and patterns from the data by combining deductive and inductive coding strategies [19]. To begin with, we arranged our analysis around two deductive categories: the ways that participants talked about the de-

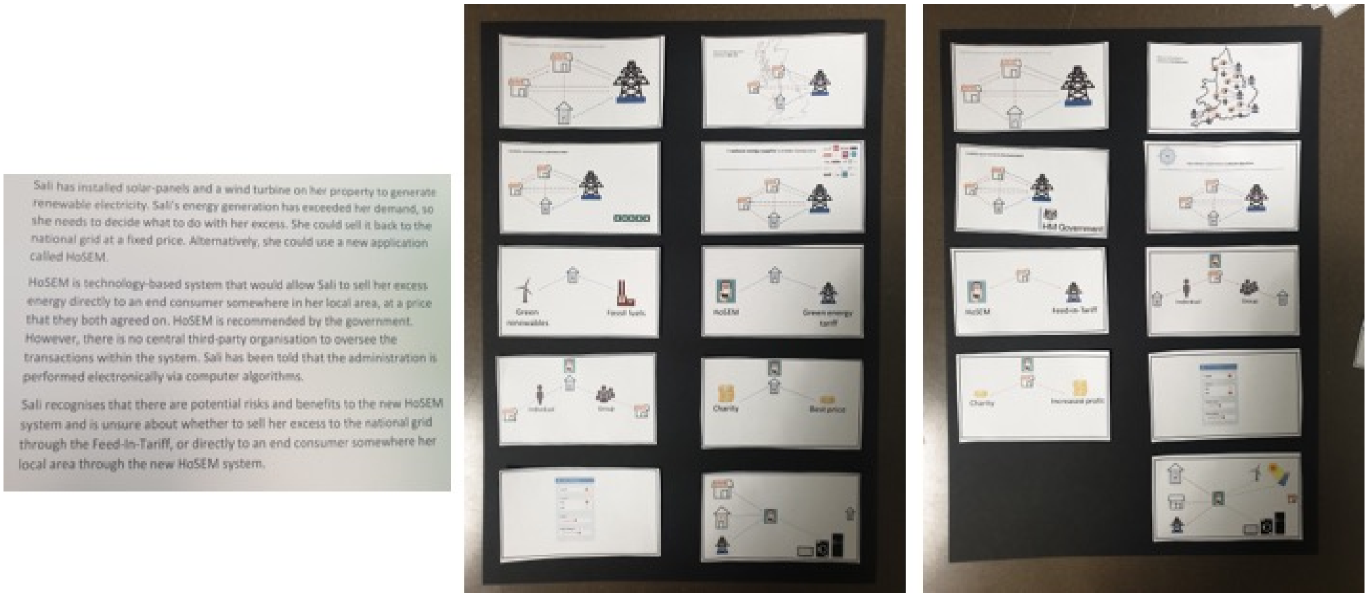

Figure 1. Sample vignette and sketch desings.

carbonization process and the ways they talked about a P2P electricity-trading platform. We chose these categories based on our primary research interests. We then followed the six steps of thematic analysis to develop five inductive themes.

ANALYSIS AND P2P PLATFORM DESIGN IMPLICATIONS

Here we consider two main questions:

1. How our participants talk about the decarbonization process of energy in general?

2. How our participants talk about the P2P platform itself?

In presenting our analysis, we integrate vignette and interview responses (rather than present separately) because although we created our vignettes to stimulate discussion around the key behaviors of interest, and issues of location, governance and trust, many of our participants spoke about these topics proactively - prior to vignette presentation - and we wanted to acknowledge all discourse.

Decarbonization Process of Energy

A Component of a Sustainable Lifestyle

The first theme described engagement with the decarbonization process as a component of a sustainable lifestyle. Participants described consuming, generating and investing in renewable energy as sustainable behaviors. In turn, participants characterize these behaviors as being bound up with other actions that they engage in to 'live sustainably'; for example, growing their own food or shopping locally.

Engagement with renewable energy is characterized as supporting sustainability by: (1) doing something good for the planet; (2) using resources efficiently; and (3) increasing security. Specifically, participants described the ecological benefits of renewables, which includes powering homes without contributing to climate change. They also described how renewable energy prevents waste and supports a more *effective use of limited resources*. For example, not wasting the energy produced by the sun and freeing-up petrochemicals for pharmaceuticals. Similarly, they described how renewable generation enables different types of *security for different entities*; including for individuals, communities and nations by enabling self-sufficiency and independence from centralized or foreign suppliers. In this way, participants described how their own personal engagement with the decarbonization process is underpinned by different values, which center around different 'ways of being', including being 'green', resource-efficient, and secure. In turn, decarbonization initiatives are expected to support these values.

> [It's] a good feeling that we're getting our heating…without fouling up the planet. (P1)

Design Implications for P2P platform: Given that the sustainable lifestyle appears to be a major driver for the interviewees, the impact that new energy-related activities (such as a P2P trading) has on the environment, resource consumption, and energy security should be clearly visible to the platform users. This could be presented, for instance, in terms of amount of CO_2 emissions saved through P2P trading (for environmental impact); amount of oil/gas saved (for resource efficiency), and number of KWh of energy self-generated due to trading participation (for energy security).

A Mechanism that Enables Individuals and Groups to Take Ownership of Sustainability

The second way that participants talk about the decarbonization process is as a mechanism that enables individuals and groups to take ownership of sustainability. Thus, decarbonization also represents a way of 'doing' - or organizing - society.

On the one hand, top-down governance structures - such as policy makers and energy supply companies - are characterized as occupying an ambivalent position: fulfilling important roles for DP, but also acting in their own interests and insensitive to the needs of UK society. For example, while participants welcomed Government subsidies for facilitating household generation, they were critical of subsidy reductions and skeptical of Government motives. Similarly, although alternative energy companies were characterized as vanguards of the decarbonization process through sourcing their electricity entirely from renewables, 'the Big 6' energy companies were described as entirely motivated by profit at the expense of customers and the environment.

> [Privatized energy companies] will just carry on hiking and hiking prices to increase profits. No amount of profit is ever enough, they always want more. (P11)

In contrast, participatory modes of engagement were characterized as efficacious for the decarbonization process; participation was frequently characterized as local in orientation, and individuals and membership groups were described as key participants in, and drivers and beneficiaries of, renewable energy initiatives. For example, participants described how installing renewable generation on their homes allowed them to experience a sense of self-sufficiency and independence from private energy companies. Similarly, community and cooperative energy schemes, and workplace initiatives were characterized as a way to promote public participation, independence, social change. For example, participants described how - through local meetings and leadership opportunities - community and cooperative schemes create ways to engage where people are, raise community awareness, build community cohesion, and enable groups to have responsibility, decision-making power and ownership over the energy issues that affect them. They also outlined how these schemes bring tangible benefits for local communities through investment opportunities, keeping money in the local economy and steady streams of income.

In sum, generating and consuming renewable energy are understood to be participatory modes of enacting decarbonization, in which individuals and membership groups are the primary leaders, actors and beneficiaries. In turn, these bottom-up modes of organization are described as mechanisms to facilitate community participation, independence and social change, thereby creating a virtuous cycle where participatory modes of enacting decarbonization support further benefits by encouraging the broader community to engage with the decarbonization process.

> At [cooperative energy scheme] there were a lot of face to face talks in village halls, and meetings and local community groups, to really get buy in at an individual level and then everybody understands actually more about their energy use, becomes more aware of it and then energy use changes. (P27)

Design Implications for P2P platform: The lack of trust in large energy companies and desire to localize the leadership and decision-making authority are likely to lead to dramatically different models of P2P energy-related activities between various communities. This implies that the business models governing P2P trading arrangements over the trading platform should be flexible. In other words, the platform should not provide a single model, but allow self-organization of platform users. If one community chooses to structure its trade activity into a cooperative for self-consumption optimization, and another chooses to organize into a for-profit energy trading entity, the platform should support both trading structures.

Challenges in the Current System

Our third theme described engagement with the decarbonization process as challenging in the current system. Participants talked about challenges in three different ways.

Firstly, participants suggested that the broader public's 'hearts and minds' need to change to increase support for renewable generation technologies and participation in energy efficiency behaviors. Part of this discourse described how people have *alternative priorities*, which do not include decarbonization. Similarly, participants also talked about local *objections* to renewable generation technology; for example, how local renewable schemes can face community opposition due to being geographically 'too close' to the community. Participants presented interesting discourses about *knowledge* and *changing behavior*; on the one hand, some characterized greater knowledge about energy and cognizant behavior change (e.g., shifting consumption to coordinate with solar generation) as integral to the decarbonization process through leading to a trajectory of increased engagement. In contrast other participants presented a discourse that advocated for low-threshold (low effort/understanding) interventions that make engagement accessible by not requiring radical behavior change or deep understanding of energy (e.g., through energy-efficient light bulbs, insulated homes).

Participants also talked about 'social structure'; they described policy makers, traditional energy supply companies (see Section 'A Mechanism that Enables Individuals and Groups to Take Ownership of Sustainability'), popular sources of information and financial measures as inadequate for increasing engagement with the decarbonization process. For example, participants describe how it is difficult to obtain unbiased *information* about renewable energy generation equipment as it primarily comes from commercial companies. Regarding *financial* dimensions, participants characterize renewable energy tariffs and generation equipment as expensive and inaccessible. Similarly, they describe how the current billing system does not facilitate an understanding of energy or behavior change by emphasizing price rather than consumption. Thus, participants understood current resources as largely insufficient for mediating widespread change.

> We only talk about money, so people only understand their bill. . . there's a complete disconnect between consumption and money. (P12)

Finally, participants described how limits to natural and technological resources create challenges for energy security and the environment. For example, how solar panels and batteries cannot support consumption over the winter due to reduced sunlight and high storage loss. Thus, even despite structural and psychology challenges, participants describe the need for technological advances to support the decarbonization process. Specifically, a need to make renewable energy constantly and readily available from sustainable sources.

Design Implications for P2P platform: To change hearts and minds, as well as to circumvent engagement hindered by limited understanding of hardware, and financial and technical issues, the P2P platform should: (a) provide staged-engagement opportunities; and (b) serve as a continuous educational and information asset. Staged engagement can be supported by allowing participants with no self-generation to join the platform as consuming-only parties. Such participation would not require any initial financial or technology commitment, but will provide the participants with an opportunity to benefit from local generation, become part of the community, and learn. Learning could be delivered through informal chats between the platform participants about hardware, beneficial practices, skill sharing, as well as formal statistical reports generated from the participation data, newsletters, and reports. As participants gain more knowledge and confidence, they would likely wish to participate in generation activities as well. Through the P2P platform, the community members could also set up partnerships with local hardware installation companies, and other service providers, further supporting the engagement of new and existing members.

How do Participants Talk About a P2P Energy-Trading Platform?

A Tool that can Support Users in Shaping Society

Participants describe P2P energy-trading platforms as a tool that can support users in shaping society. Specifically, in terms of its capacity to enable them to address challenges in the current system, and support the decarbonization process and broader sustainability goals. Participants outline two different ways that the platform could support this type of social change.

Empowering Individuals and Community Groups to Meet the UK's Energy Needs

First, they depicted the platform as a resource that could enable a network of small, distributed suppliers to meet the UK's energy management needs. Part of this discourse described how novel technical and economic features might of the platform might automatically enable better electricity prices, and a more efficient electricity network. However, participants go further than this and depict this process as changing the behavior of users and non-users alike. For example, they described how it could increase the supply of renewable energy by supporting new and better mechanisms for *return-on-investment* beyond government subsidies, thereby stimulating investment in local generation schemes. Similarly, participants described how local schemes could increase community support for, and engagement with, local schemes by *supporting benefits for the local community*, such as less expensive electricity supply.

Similarly, participants talk about the system's capacity to shape energy demand by enabling users to have different levels of awareness of - and engagement with - energy. On the one hand, participants present a discourse that describes how an *automated trading process* could reduce awareness and understanding of energy by disconnecting energy from people's lives. However, they also describe the opposite situation where *participation in a P2P trading platform* would increase the commitment that most people have to energy as a concept, and therefore reduce consumption.

Thus, participants described how P2P energy markets could facilitate engagement in the decarbonization process by supporting different types of psychological (i.e. hearts and minds) and structural (i.e. economic, technical) change, which enable users to have a greater sense of control over energy supply and demand. Moreover, they described how these technologies could support psychological and financial investment in renewables by those who are not users of the platform, through supporting engagement and shared benefit between users and other groups (e.g., investors, local community).

> Wouldn't it be better if communities were independently powered and looked after their own power sources... [with technology] it can be done in a much more scientific technical way. (P1)

Creating Opportunities for New Social Relationships

The second subtheme described the platform as supporting users to shape the social relations that are central to the decarbonization process. The ability to trade between individuals and groups is characterized as creating opportunities for different kinds of social relationships. At the community level this involves supporting greater *social connections and cohesion* within local communities, by *"build[ing] up a community where people want to feel like they're committing to the community"* (P18). Thus, it is described as a mechanism for facilitating community responsibility and relations. At the system level, participants talk about the platform as having the capacity to support *changing user relationships with policy makers and energy supply companies*. Specifically, by enabling users to make decisions about their energy supply and excess generation as an alternative to top-down and centralized control over the UK's energy challenges.

> People having control ... they're generating energy and they can profit from that and they can do that how they see fit. (P18)

Thus, in this theme we see that rather that only supporting personal economic benefit, P2P energy markets are valued when they support users in changing the relationships and culture that shape DP, by enabling users to have: (1) a different type of engagement with energy through supporting greater awareness and understanding; and (2) different relationships with others through supporting community cohesion, decision-making power, and benefit.

Nevertheless, our participants considered these benefits to be neither automatic nor inherent. In our final theme participants presented a discourse of 'benefit for whom', which described the benefits of P2P energy trading as being contingent on the way that platforms are designed and highlighted design challenges.

Design Implications for P2P platform: Here the social and cultural change is driven by individuals who organize into like-minded groups and share their views with newcomers. To support the groups in expressing their views and enabling other like-minded individuals to join these groups, the P2P platform should enable explicit verbalization of the group's goals and objectives (e.g., by providing a description of these for each group on the platform). For instance, if a group is formed with a goal to alleviate fuel poverty in the Easton community of Bristol city, it could have a policy that each member will donate 5% of their excess generation to the Easton's fuel poverty fund, which will then be distributed to those in Easton who are identified as fuel poor (e.g., through city council's register) free of charge. This implies that anyone joining the given group volunteers the specified portion of their generation for the specified cause. Such features within the platform also imply that while some groups will be focused around geographical localities, others may be centered on ideological grounds (e.g., animal rights groups, etc.). Thus, the platform should support geographically co-located as well as widely distributed community trades. It should be noted that such solutions are likely to have different implications for the physical power systems over which the energy trading is taking place: while geographically localized groups may lead to localization of the physical infrastructure, the distributed groups will continue to rely on the interconnected national (and international) energy grid.

Responses to the Platform Itself

Our final theme is concerned with participants' responses to the platform itself. Different elements are talked about in terms of having the potential to encourage and/or hinder platform use and support different types of benefit. Thus, participants offered positive and negative views.

Increased Digitization, Increased Risk

First, participants describe how P2P energy-trading platforms would mean an increasingly digitized energy market. They draw on negative personal experience and social narratives about digital technology to describe how increased digitization presents increased risk.

One concern is *transparency*: participants want to be able to access and understand information about how decisions are made about payments and energy supply. For example, they described a negative situation where users are unable to understand *"why you're getting what you're getting"* (P2), which is characterized as a bad thing. They use discourses of simplicity, visibility and honesty to describe desired values.

Participants also express concerns about *privacy*: that their data is secure and confidential. For example, one participant talked about the risks of *"advertising the fact to the world that I'm on holiday"* (P25) because they're not consuming electricity at home. Perhaps due to the P2P nature of the system, participants were concerned that sensitive information could be directly exposed or inferred by other users. A further concern was *hacking*, both in terms of people exploiting weaknesses in the system to gain access to other digital tools like bank accounts, and users manipulating the system itself to misrepresent their own generation or consumption. Similarly, participants described how a new or untested system might be unable to offer the same customer protections as the traditional energy market, in terms of secure supply and accurate billing. Thus, P2P energy markets were understood to be potentially less secure than the traditional energy market, which is a challenge for design. Nevertheless, participants described how trust could be facilitated by knowing who you are trading with, where energy has come from, who is benefiting from production, and that production is sustainable. Given the importance of privacy, participants outlined how knowing *"the population as without knowing specific individuals . . . who's using in general terms, in terms of the shape of the community"* (P2) would facilitate good feelings, participation and a sense of community without being intrusive.

Finally, participants talked about *digital exclusion* and age. They highlighted that, in the current market, older friends and relatives were financially disadvantaged because limited internet access, low computer literacy, and a distrust of digital technology left them unable to access online-centric benefits, such as switching suppliers or discounts for paperless billing. They expressed concerns that a market that was only accessible via digital technology would further exacerbate these issues, and thereby have a negative effect. In contrast, participants described the benefits of being able to *"talk to an individual about it and talk through some of [your] concerns and worries"*(P18). At the same time, they described how mechanisms for 'offline' trading could be supported through the platform. For example, a community-owned battery that was housed in a community center with solar panels where members of the community could come and recharge their own batteries from this community source.

Different Power Relations, Same Lack of Power

Our second subtheme described power relations: putting power in the hands of other people or algorithms. Drawing on some of the aforementioned discourses about digitization, participants characterized P2P energy markets as enabling new and different types of power relations, but potentially the same negative position of low power for everyday users.

There was a discourse about automation. Participants described a negative situation in which *algorithms* make it difficult to understand *"who's monitoring you, how's it been designed, what's it looking for and how is it going to work out"* (P22). However, automation could also be seen as empowering, if participants could indicate their preferences: they described how users could set up the system and then carry on with their lives without further effort or concern.

Similarly, participants also present a negative discourse about big tech *corporations* having control in the place of large energy companies and at the expense of users. Participants draw on narratives such as the Facebook-Cambridge Analytical data scandal to characterize how technology owners could exploit the lack of transparency and personal information within the system for their own benefit.

Likewise, they describe concerns about unequal relationships between *users*. For example, one participant described the platform enabling sellers have power over buyers by deciding who to sell to at what cost. They expressed concerns that consumers could be judged by suppliers and not sold to, or sold to at a higher cost. There were similar concerns that some users could be disadvantaged in price negotiations if the tool were individualized in nature with limited safeguards.

> Making the individual [negotiate]... I feel I could personally handle a situation like that because... I'm fairly streetwise... [my son] is a solicitor... but an awful lot of people haven't got those safeguards. (P1)

Thus, our participants describe how P2P energy markets can negatively complicate notions of control and present challenges for empowerment. In turn, in our final subthemes, participants described how the structural organization of a P2P energy network might enhance or diminish these concerns.

Large Networks for Trusted Energy Supply, Small Networks for Trusting People

The first way that participants talk about structure is in terms of the size and geographical boundaries of a P2P energy market. They describe a tension between larger networks that offer higher levels of energy security, and small local networks that enable users to feel a sense of *responsibility* over energy and other local issues, and perhaps the feeling of *security about personal data*. For example, how a small local network would allow community members to take responsibility about what they're producing and using, and how it might be less open for abuse. In contrast, a larger network is described as being better equipped to deal with fluctuations in supply and demand, and perhaps economically fairer in locations with limited generation capacity by increasing supply. In addition to grouping by geography, participants describe how aggregation of supply and demand could be facilitated by enabling users to come together in small groups made up of *like-minded users* with elected group leaders. Participants describe how coalescing with like-minded others would increase trust between users, and willingness to defer decision-making to elected leaders.

> It could be an international global peer thing ... Or it could be local, I am much more interested in doing whatever is possible at a local level. Because with energy there are different issues that you can solve locally. (P27)

Participation and Decentralization, not Structurelessness

In our final subtheme participants discuss the need for the system to enable a third-party - beyond the users and technology developers - to govern and regulate the system. Considering the aim for individual and group participation in DP, they describe: (1) the different types of governance that could be appropriate; and (2) who should occupy a governing role. Rather than coming to any concrete conclusions, participants drew on notions of independence, ethics, transparency and user benefit to describe different entities as more or less desirable. Moreover, participants described how an official form of governance could provide added benefits over mere 'recommendation' from trustworthy sources.

Participants describe a variety of governance mechanisms including new regulations, charters, and organizations that oversee the tool and transactions. Part of this included a discourse about energy, financial and data *security* for users. However, participants also described how governance structures could support those in *fuel poverty*. To begin with, they described how a P2P market might leave low-income households at the mercy of other users' altruism and charitable giving, which stands in contrast to the current market where protections for fuel poverty are built-in. Although some participants suggest that charitable donations could be increased by providing assurances about where and how donations are being spent, others suggested that a third-party such as national Government should be responsible for providing support.

In terms of who should occupy a governing role more generally, several suggestions were provided including charities, non-profits, entrepreneurs, technology companies, local councils and cooperative energy schemes. They described how any form of governance should uphold certain values including ethical and transparent conduct. Moreover, they emphasized how commercial companies might need additional regulation to be effective in this context.

> Somebody's got to run it, but I'm not really sure whether I think it should be a registered charity... [a commercial company would need] very clear regulations and, I don't know, a charter, to know what they're doing and why, and very clear limitations. (P6)

Design Implications for P2P platform: The ability to ensure participants' privacy and security is central to the willingness of the prospective users to engage with the trading platform. In particular, issues of data ownership, access to data, and data monetization have to be resolved, ensuring that the P2P platform participants (who are also the data subjects) have full ownership and secure control over it. The precise governance structure would significantly depend on the specific business model agreed upon by each community (as discussed in section 'A Mechanism that Enables Individuals and Groups to Take Ownership of Sustainability' above).

To ensure that each small network of trusted people (i.e., a P2P trading group/community) is assured access to larger than itself energy trading network, the P2P platform must provide wider linked-up infrastructure either to the national grid, or to many other P2P networks. One could envision either a "supplier of last resort" contract between the P2P community and the grid, whereby the community purchases a kind of an insurance service from the gird that energy demand would be satisfied, should such demand arise at any given time. Alternatively, similar contracts or mutual support could be established between several P2P communities that would ideally harness renewable energy from a mix of sources, providing back-up supply when one of the renewable sources (e.g., sunlight for PV generation at night time) falls short. Additionally, integration of long-term storage facilities (e.g., hydro stations, bio-gas banks, etc.) into the P2P platform network would also help to alleviate the supply security concerns. Finally, to enable engagement of less digitally abled, the P2P trading platform that aims for just transition to a clean energy system would provide energy trading participation as a service, whereby such users could subscribe to the P2P trading service as they currently subscribe to an energy consumption service with their energy utilities.

DISCUSSION

Our analysis provides evidence of the ways that prospective users understand and seek to engage in P2P modes of energy trading. We demonstrate how P2P energy trading is valued as a means to advance social and ecological goals. In particular, we demonstrate the values of collective and community-level energy trading for facilitating sustainable lifestyles, building meaningful interactions within communities, and enabling communities to become empowered agents in the energy market. We also presented a series of design characteristics, outlining how P2P energy-trading platforms can support users in: (1) understanding the impact of P2P trading on the environment; (2) accessing flexible business models; (3) staged engagement and continuous education; (4) the externalization of group goals and objectives; and (5) engaging with bridging infrastructures. In turn, we suggest that these recommendations provide a way to meet participants' expectations and concerns about P2P energy trading. In the following subsections we discuss our analysis and design implications in relation to our main research question and behaviors of interest.

Choosing Green Energy and a P2P System

Participants valued the ways in which P2P energy markets can support widespread engagement with energy issues. Given the value of sustainable lifestyles, in order to support participation in P2P energy trading, platforms should *support users in understanding the impact of P2P trading on the environment*.

Our analysis also highlights the value of changed intergroup relationships. Part of this involves enabling prospective users as a group to become empowered through greater decision-making. At the same time, tangible benefits for local communities and groups were important; participants understood locally-oriented trading as providing opportunities for increased community support for local schemes by enabling direct benefits to local communities. Thus, participants valued the ways that P2P energy markets could support users in transferring the responsibility for - and benefits of - energy generation and management from private companies to local citizens. Accordingly, we advocate for *flexible business models* that enable users to self-organize and structure trade activity to meet self-determined goals.

The variety of such business models is emerging in business practice, e.g, the Brooklyn trial focused on trading directly between peers [43], the Btixoton trial [2] looks at shared self-consumption, energy donation to community and exchange, while the Sonnen model [3] provides free energy use for assured company access to a portion of the household's battery storage. Despite this variety, all these activities have a common core platform functionality, and could be provided through a single platform, if it supports flexible self-organisation of participants into different business models.

Interactions Within and Between Groups

Participants valued the intragroup dimensions P2P energy markets. Participants saw that platforms could provide opportunities to build community relations. Part of this was bound-up with expectations about geographical boundaries and network structure: platforms were understood as supporting local and community-led trading. Simultaneously, there was an expectation of 'like-mindedness' between users, which presented opportunities to coalesce and trade electricity around shared ideologies. Given the value of shared group membership, P2P energy markets can provide opportunities to organize around like-minded groups by *enabling users to externalize goals and values*. However, P2P energy markets also need to enable *wider linked-up infrastructure* that supports interactions between communities: participants described a tension between the value of small trusted groups and the desire for larger networks for assured energy supply. Thus, platforms need to provide opportunities to balance these concerns.

Although prior research has examined ways to facilitate a technical understanding of P2P energy trading and multifaceted stakeholder relationships [42, 47], our analysis demonstrates the ways that participants valued the social dimensions of P2P energy trading, and saw opportunities to cultivate social and collective resources through platform use. Platforms can acknowledge the value of enhanced intragroup relationships by enabling users to externalize values and organize around shared group memberships. At the same time, platforms must provide the infrastructure to interact between groups. Although existing research has examined how sharing-economy applications can support social experiences [8, 28, 29], it has tended to focus on supporting relationships between individuals. In contrast, we highlight opportunities for supporting users to plug-in to and harness meaningful groups.

Our analysis indicted that individuals in a group would want to use some of the financial benefits obtained from P2P energy trading for a common goal. To validate this we asked low income householders (n = 12), who were knowledgeable about renewable energy, to indicate whether they would like to keep funds from energy saving activities to themselves or use them for some common purpose. We asked this question as part of a co-design workshop for a demand-side reposes service provision, which was not directly related to P2P trading, and had participants enrolled through city hall records. Participants left anonymous responses on sticky notes (on an unmonitored wall). These responses are shown in Figure 2. Out of the 11 responses received, 6 wanted to use funds for themselves, 3 opted for fully communal use, and 2 wanted to share the savings between personal and community use. Though this small exercise does not provide any generalizable conclusion, it does validate the desire for common good and common goals voiced by the present interview study participants.

Fuel Poverty and Automated trading

Although distinct concerns, participants understood issues around fuel poverty and automation in terms of structurelessness. Automated trading, that takes account of user preferences, was understood to support widespread engagement with the decarbonization process by offering low-threshold entry to participation. However, automation had negative implications for some: it could conceal energy consumption and exacerbate digital exclusion. Similarly, while some participants valued opportunities to donate towards fuel poverty, others argued

Figure 2. Use of financial savings from energy saving activities: personal vs communal goals.

for more formal support mechanisms within P2P markets. We suggested that structures are put in place to support vulnerable populations in participating and benefiting from P2P energy markets; this includes proving opportunities for *staged engagement and continuous education*, energy trading as a service, and group-led policies for charitable donations.

Prior research emphasizes support for digital literacy, simple yet transparent pricing structures, brand visibility and infrastructures that support financial inclusion in order to enable empowerment and trust [15, 31]. For example, installing public kiosks where people can access ridesharing services and receive training about transactions [15]. Our analysis also suggests that participants valued support for greater inclusion in, and understanding of, P2P energy markets. However, our findings extend this work by emphasizing the value of structures that help regulate the market and support users in making decisions about how these markets are run. We argue that the design of P2P energy markets should take account of these values to enable the empowerment of users as a group. Although previous research examining the sharing economy highlights the benefits and challenges of evidence-based and top-down policy [11, 48], we outline how structuring opportunities can be provided within-app and decided on by users themselves.

Limitations and Future Work

We were limited to the specific context of the UK energy market, and only engaged with participants who had a pre-existing interest in renewable energy. Thus, our findings may not generalize to other national contexts and populations, such as individuals with a primary interest in technology or business opportunities. Nevertheless, we believe that our design implications could provide opportunities for renewable energy engagement in those with low pre-existing interest/experience with renewables by supporting energy awareness, new business models, staged engagement and education opportunities, and social relationships centred around renewable energy. Future research could explore these opportunities.

Moreover, our participants had not previously engaged in P2P energy trading, so could only reflect on their own imaginations and perceptions of participation. This was partly due to regulatory barriers in the UK that prohibit P2P energy trading between microgenerators, which meant that we could not speak to existing users or deploy a prototype platform. Similarly, we only analyzed talk, we did not observe behavior or test participants' lay hypotheses around the factors that could support participation and sustainability. Rather, we explored how participants understood phenomena. Finally, our study was technology agnostic examining platforms in general, however specific technologies, such as distributed ledger technologies (DLT), are a large part of the narrative around P2P energy markets [13, 27, 50, 55].

As well as addressing these limitations, future research should examine how communities with low resources and limited renewable generation capacity understand and seek to participate in P2P energy markets. Evidence suggests that the decarbonization process and P2P energy trading could place additional burdens on low-resource households and communities [10, 46]. Thus, it is important to explore implications for these populations. Our research also highlighted how automated trading might influence engagement with the decarbonization process. Future research could examine when and how automated energy trading affects widespread and deeper engagement with energy. This would present opportunities to explore the intersection between humans, P2P energy markets, Internet of Things devices and DLT, and how these entities could work together in partnership to selectively trade electricity to achieve sustainability goals (e.g., [30]).

Conclusion

We extend HCI research examining P2P energy markets by analyzing how prospective users understand, value and seek to engage in these platforms, with a focus on members of the public who have a pre-existing interest in renewable energy. Our participants valued experiences that enable communities to organize around shared values, build an understanding of P2P platforms and the ways that trading impacts the environment, and to configure their own selective engagement with business models and broader energy infrastructure. Our analysis emphasizes the importance of nurturing and supporting groups within P2P energy-trading platforms, particularly for populations who already have an interest and engagement with renewable energy. Likewise, our findings are consistent with existing research that highlights the need for autonomy, control and economic equality in these markets. More broadly, our research speaks to examinations of the sharing economy, we bring together research that emphasizes the social dimensions of sharing with calls to examine the social justice implications of sharing-economy applications. Specifically, we outline how users can harness groups to advance sustainability aims and how platforms can provide infrastructure and opportunities to support these efforts. Thus, our contributions can provide insights for the HCI community, private companies and policy makers in developing P2P energy markets.

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