At Home with Agents: Exploring Attitudes Towards Future Smart Energy Infrastructures

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ABSTRACT
Energy systems researchers are proposing a broad range of future smart energy infrastructures to promote more efficient management of energy resources. This paper considers how consumers might relate to these future smart grids within the UK. To address this challenge we exploited a combination of demonstration and animated sketches to convey the nature of a future smart energy infrastructure based on software agents. Users' reactions suggested that although they felt an obligation to engage with energy issues, they were principally disinterested. Users showed a considerable lack of trust in energy companies raising a dilemma of design. While users might welcome agents to help in engaging with complex energy infrastructures, they had little faith in those that might provide them. This suggests the need to consider how to design software agents to enhance trust in these socio-economic settings.

Author Keywords
Agent-based systems; smart grid; whiteboard animations; sketching; participatory design; envisioning; focus groups

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

General Terms
Human Factors; Design.

INTRODUCTION
Energy has emerged as a major societal challenge resulting in a raft of sustainability initiatives across a broad range of countries. Political responses have focused on the issues of energy policy and security seeking to address the uncomfortable question of how to manage with less [12]. Research endeavours have explored the development of new energy technologies often focusing on smart grids. Responding to the challenge of sustainability has motivated an interest in reducing energy consumption as a significant application domain within HCI. Recent reviews have found the dominant genre within this work to be persuasive technologies, which often focus on providing feedback on consumption to raise awareness and promote behaviour change [1,5,9,14].

Researchers have started to critique the framing of sustainability within these systems [7], for example narrowing on 'optimizing metrics' [1] or disregarding the potential 'rebound effect' that may result from an emphasis on energy efficiency [25].

There is a growing call within HCI to be sensitive to the broader social context [19] and more aware of existing energy research. A recent review by Pierce and Paulos suggested that work within HCI remains disconnected from emerging energy systems [14]. For example, the authors point out that the emergence of new smart energy grids is a key issue where HCI could contribute but has yet to do so. As Pierce and Paulos put it;

"*Another important role that HCI can play is prototyping future energy applications before the technical infrastructure, service and policy systems to support them are fully in place*." [14: 672].

This paper takes up this challenge and makes two substantial contributions to address it. Firstly, we provide an exploration of UK energy users' attitudes towards future smart energy infrastructure that combine the widespread use of smart meters with embedded autonomous software agents to manage demand on energy networks. Secondly, we demonstrate the effectiveness of whiteboard animations to expose the nature of a future infrastructure in such a manner that we can solicit views from users about both the elements that are visible to them, as well as a host of critical behind-the-scenes issues particularly relevant in the UK.

Our findings highlight the critical influence of the lack of trust between consumers and energy providers and suggest that designers need to understand and mitigate for this in how they develop agent-based systems. This is further amplified by the fact that energy infrastructures are as much the product of cultural, political and economic drivers as the technologies that realise them. We propose a focus on trust enhancing approaches to design and suggest a number of key design principles.

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FUTURE ENERGY SYSTEMS

A key feature of existing energy systems is the ways in which complexity is hidden from view. The aim is to make the end point of delivery as simple as possible; customers are not required to understand the various behind-the-scenes complexity required within the infrastructure. Indeed, utility systems have been so successful with this approach that they are often drawn upon by analogy. For example, utility-based models are often invoked for service-based computing with the desire that things should be "as simple as flicking a light switch" seen as the ultimate realisation of the vision of utility computing.

Energy systems are undergoing a shift that will make it increasingly difficult to hide all of the complexity of the infrastructure. Current power grids are largely centralised systems that distribute power from generators to consumers, with limited abilities to respond to the ever-fluctuating demand. *Peak demand,* periods of strong consumer demand, present a critical problem that can lead to power outages. Providing for peak demand makes power production and distribution inefficient due to large capital investments and short periods of use. An issue exacerbated in the UK due to the unpredictable nature of the British weather and the very limited capacity for energy storage in the energy system. The mismatch between demand and response is likely to be exacerbated when future grids will obtain an increasing proportion of its supply from renewable energy generation. Renewables generation can fluctuate strongly due to being dependent on local environmental conditions such as sun, wind, waves, and tide [cf., 12]. Peak demand and intermittent supply are expensive both economically and ecologically and are pet problems for government agencies to justify smart grid technologies to enable *demand response* (DR) [4,26].

One of the key premises underpinning DR is a closer coupling between energy use and energy generation. Research has shown that small shifts in peak demand could have large effects on savings for consumers [21]. A focus on *demand-side management* techniques such as *dynamic pricing* (variations of which are known as real-time, or Time-of-Use pricing), will seek to reduce peak demand by encouraging *shifting* of demand to off-peak periods through higher prices at peak times [26]. This load shifting offers major benefits in the overall efficiency of the grid by optimizing the use of generated energy.

A key technology of the smart grid that is seen as an enabler of demand response is the *smart meter*. Smart meters provide two-way communication between suppliers and consumers; for example according to smart meter specs for the UK, a household's energy consumption data will be transmitted to the supplier every half hour [20]. The government in the UK plans to roll out smart meters to more than 50m households by 2020 [4], and similar programs have been reported in the literature for the US, Italy, Japan, Canada and Australia [cf., 14]. Smart meters are often seen to include an *in-home display* (IHD) to allow residents to monitor their energy consumption in real-time and retrospectively.

Of the various techniques and technologies that characterise emerging energy systems, it is arguably only the provision of electricity consumption feedback that the IHD provides that most of the work in HCI to date speaks to [cf., 9,14]. However, emerging techniques such as *demand response* bring about a closer coupling between energy use and generation. Consequently, do emerging energy systems expose more of the principles of the infrastructure to customers? With the added complexity, what does it take for these systems to be intelligible and accountable? Essentially, future energy grids will need to capture more information about energy use. They will also need to provide more feedback to users to actively shift demand by encouraging use at different times. The challenge is how we might solicit views about a future infrastructure to understand how the embedding of this interaction might play out in the future.

Agent-Based Energy Grids

Our particular interest focuses on understanding users' views of future smart grid energy infrastructures that exploit machine learning techniques [18] and embedded autonomous software agents [16]. These techniques are often suggested as a way to gain insights from energy information collected via metering systems and to exploit this information to act on behalf of the user or the energy provider. The dynamic nature of agent-based infrastructures makes it possible to realise a broad range of services. These might include passive personalised energy guides or much more active interventions including automatic appliance control [15] and automated home heating based on occupancy [18]. The potential that these systems will affect and change people's activities may have far-reaching consequences, particularly in the context of the home [3]. In particular, the notion of autonomy raises challenges for HCI that we wish to explore. Rather than to advocate either a passive or active role for agents, our work aims to understand the various arrangements of people and agents. We are interested in the extent to which users might understand and engage with an active infrastructure that is likely to expose more of the complexities that are currently hidden. We were particularly interested in three key research questions surrounding the use of agents in a smart grid.

- How do people respond to the issues of ***autonomy and control*** within the infrastructure and the extent to which they may accept energy agents?
- How much do people ***trust an active infrastructure*** given the obvious need to rely upon it for a crucial utility?
- How do people feel about ***the monitoring of energy use*** and the extent to which this might impinge on their privacy?

EXPLORING FUTURE SMART INFRASTRUCTURES

Gathering feedback on the acceptability of a future active infrastructure poses two significant challenges. Firstly, energy systems require substantial capital investment to realise them (for example, a new generation and transmission system could take over 40 years from initial plan to realisation). How then do you reveal the behind-the-scenes complexity of an infrastructure that is yet to be realised to allow users to comment on the nature of the infrastructure? Secondly, many of the key features of energy systems and the infrastructure technologies that realise them are motivated by broader societal, economic and political concerns. How do you convey the socio-economic issues in energy systems to avoid “narrowing the vision” [1] and allow users to comment on the broader issues shaping the infrastructure?

Sketching the infrastructure

To convey the infrastructure, we developed an approach based on animating sketches. The substantive part of our engagement with users was centred on an ***animated future infrastructure*** sketch, which conveyed the nature of a future agent-based energy infrastructure. Bill Buxton has described sketching as “the archetypal activity of design” [2: 111] used in the early stages of ideation and design exploration [24]. By comparison with more sophisticated techniques such as physical or even video prototyping, sketches are quick to make and inexpensive. A few key attributes of sketches [2] are particularly relevant to the context of this work. Sketches are:

- Disposable – The fact that we are merely sketching the technology instead of making it may help the audience to be more openly critical without fear of upsetting the creator/researcher.
- Minimalist – Sketching allows us to draw attention to the aspects of the future technology that we want the audience to focus on. The “sketchiness” may also allow the audience to fill the gaps with their own experiences.
- Explorative – This is at the core of our research objectives; we want to explore future technology suggestions together with participants.
- Ambiguous – the fact that they may be interpreted in different ways more easily than a full-fledged prototype makes it easier for members of the audience to relate it to their everyday lives.

Sketches already have a tradition of use in participatory design activities, for example to bridge the gap between seed data and refined conceptual design [8], or to engage participants in sketching their ideal thermostat [24].

Video sketches have been used in teaching to encourage students to explore pervasive computing [27]. Our animated sketch is distinct in that we drew on future-oriented design techniques to inform the design. Firstly, in the tradition of participatory design we have held a workshop [10] on potential systems for home energy management with domain experts from which overarching themes emerged that informed the design of the sketch focused on in this paper. Secondly, similar to other *envisionings* of future technologies in UbiComp and HCI [17], we developed the sketch by drawing on existing enabling technologies, projections from technological capabilities and specifications [20], policies [4], and existing socio-technical systems. In the following section, we detail the design of the animated sketch of the future agent-based energy infrastructure.

We chose whiteboard animations to animate our sketches of future technologies. Among others, the UK-based charity Royal Society for the Encouragement of Arts, Manufactures and Commerce[1] (RSA) popularized whiteboard animations[2] in its free educational lectures to illustrate typically complex and/or complicated concepts and ideas as diverse as, The Power of Networks, The Divided Brain, or 21st Century Enlightenment. Essentially, the animation illustrates a concept or idea through an oral presentation by a narrator while a hand draws a single or multiple drawings that illustrate the spoken words. This allows us to convey the nature of the overall energy systems bringing together the key technologies, the underlying concepts, key stakeholders and the nature of the end-to-end system.

DEVELOPING THE SKETCH

The animation sketch was designed in three parts to be shown separately with a pause between them where participants were invited to give feedback on what they just saw. This division was also intended to reduce the complexity of the video, to make it easier to follow and to allow the focus of each discussion to be centred on a certain set of issues. The first part explained the ***current state of the world*** in terms of power production and distribution, relevant technologies and resulting problems. The second part described the ***near future***, with forecasts based on current policy, trends and anticipated technologies. The third part went ***further into the future*** describing a plausible yet fictional world where software agents become integrated into home electricity management. An overview of the key concepts introduced in the video is presented in Figure 1. The video is also available on-line[3].

Grounding visions in the present

The first key concept of our sketching technique is grounding in the present [cf., 17]. Through showing relevant existing technologies, we aim to establish common ground for our audience when moving towards future technologies that borrow the concepts, or rely on the infrastructure, of present technologies. We chose to ground our sketch in the following existing technologies:

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[1] http://www.thersa.org

[2] http://www.youtube.com/course?list=EC39BF9545D740ECFF&feature=plcp

[3] http://youtu.be/UePV6Wazz40

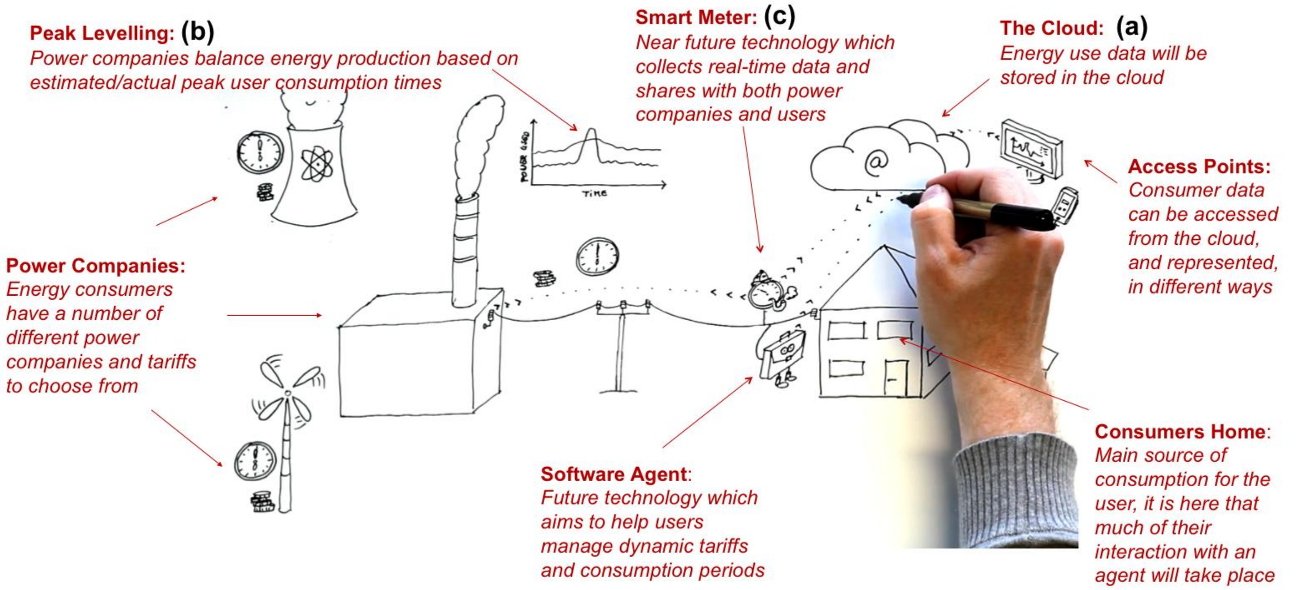

Figure 1: Key behind-the-scenes concepts introduced through the animation.

Meter-based energy charging model. We highlighted that the current model requires the energy supplier to send a representative to the user's home to read the meter (Figure 2). Also, the bills between these readings are based on estimates of energy usage, rarely on actual usage.

Off-the-shelf electricity monitoring devices. These can be readily purchased and some power suppliers offer them for free to provide an in-house energy display to consumers.

Electricity consumption data in the cloud. An uplink to the Internet enables app or web-based services, e.g. historic usage analysis and mobile or remote monitoring (Figure 1 (a)).

Peak levelling. Periods of high consumer demand are presented as a critical problem that can lead to power outages and inefficiency in power production. In the video, this is presented as a major incentive for smart grid technologies as a solution (Figure 1 (b)).

Elaborating trends, extrapolations and predictions

The second key element of our sketching technique is to forecast likely ***near-future technologies*** by drawing on public policy, technology trends and future-orientated technology research. For the purpose of our sketch, we chose to anticipate the following technologies:

Smart meters. Technical details that were important to convey were that smart meters can be connected to the Internet in addition to a direct link to the energy supplier and that the meter transmits energy usage data every half-hour (Figure 1 (c)).

Figure 2. Currently power companies send representatives to read meters and use estimated billing.

Dynamic pricing. In particular, we were interested in including dynamic pricing to gauge the reactions to the complexity it adds to understanding energy pricing as well as to motivate and explore technology support systems for this complexity.

Presenting agents in the infrastructure

Having described a future where smart meters lead to an electricity infrastructure where prices change dynamically based on usage, we wished to unpack people's reactions to a future where software agents become critical parts of the infrastructure. We present a software agent installed in the user's home that has the following functionality:

Electricity monitoring. The agent monitors the user's electricity usage, in much the same way that electricity monitors do in the present.

Switching provider. The agent has the ability to determine the best energy provider based on the on-going rates of power companies and the user's consumption habits.

Controlling appliances. The agent also knows how best to alter the user's habits in order to reduce the cost of their electricity bill.

Relating to the user's world

Throughout all parts of the video, we created hooks for the participants to relate the vision to their own experience. We achieve this by:

- Grounding complex ideas with examples they can relate to – we give everyday examples such as "putting the kettle on during half-time of an important football match" to illustrate concepts such as peak demand.
- Referring to activities they do in the home (watching TV, doing laundry) and how they are affected by future technologies (e.g., scheduling agent for washing machine).

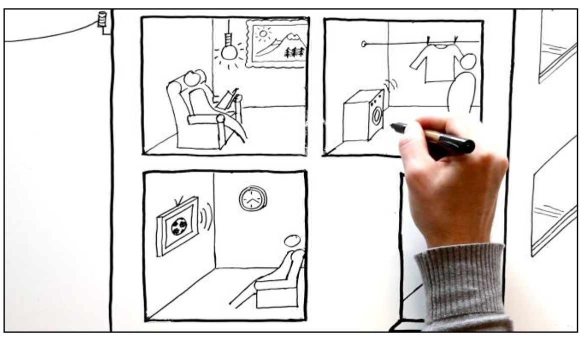

Figure 3. Throughout the videos we go inside the users' home to illustrate how their day-to-day life is affected.

Fiction, contrast and configuration

To promote discussion and unpack people's reactions to the key issues of autonomy, trust and monitoring surrounding embedded software agents, we presented two alternative scenarios that vary in subtle ways.

Control and autonomy. We present two contrasting views of autonomy and control. In one scenario, the agent seeks user permission before switching provider, in the second scenario, this happens without the user's involvement. Similarly, when the user wishes to run a certain appliance, one scenario shows the agent suggesting a cheaper time, whereas in the second scenario the agent has the power to prevent the appliance from running, effectively forbidding its use until a more appropriate time.

Ownership and trust. In one scenario, the software agent is explicitly described as a device the user installs in his or her own home, whereas in the second scenario, this agent is installed in the home by an ambiguously defined entity.

Privacy and data storage. In one scenario the data that the agent collects is held in a private data cloud that only the user has access to. In the second version, this data is shared with power companies, who in turn use this data to provide targeted advertising for users, such as sending ads for more efficient washing machines if the user consumes too much on laundry.

The purpose of these contrasting scenarios is to provoke discussion. An approach that has proven successful in video prototyping approaches such as Contravision [13].

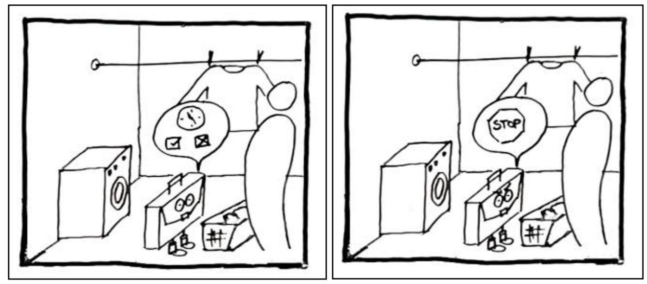

Figure 4. Contrasting views of agents dealing with a user who wishes to do their laundry at an inappropriate time. In one the agent suggests, in the other the agent forbids.

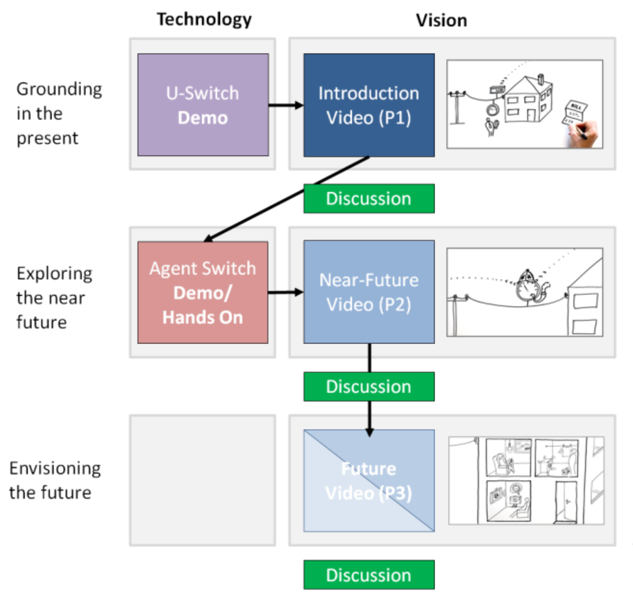

Figure 5. Participant path within the focus group

PRESENTING FUTURE ENERGY INFRASTRUCTURES

Structured focus groups were used to help users move from current experiences of energy infrastructure to commenting on the future energy infrastructure presented in the video. We chose to use focus groups to capitalise on emergent dialogue between participants [11] but limited their size to 3-5 participants.

Participants

We recruited 17 participants for the focus groups. Ten were enlisted from the general public via a specialised recruitment agency and seven were drawn from one of our previous studies. They were between 25 and 77 years of age, were of mixed socio-economic background. The only requirement we asked was that they regularly dealt with the energy bill of their household.

Focus Group Sessions
We ran four sessions each involving between three and five participants. Each session lasted for 60-75 minutes and consisted of three key stages (Figure 5).

Stage 1: Grounding in the present
Participants were initially given a brief demonstration of an online service that helps people compare energy providers and their tariffs and switch between providers. This was followed by Part 1 of the video. The intention was to first ground participants' understanding in existing energy technologies and to begin building a picture of current infrastructures. This was followed by a discussion focusing on people's perspectives on current energy systems.

Stage 2: Exploring the near future
Participants were then introduced to a ***grounded agent demonstration***. Working with project partners we developed a web service called AgentSwitch that would interrogate energy monitoring data collected using IHDs and draw upon on-line services to recommend the most appropriate tariff to users. The aim of this service was not in itself to implement a demand side management approach but to demonstrate how software agents might be used in practice and provide a practical example of how agents and data analysis might be manifest. AgentSwitch was used as an anchor point, giving participants a tangible link to the near-future energy technologies and infrastructure presented in Part 2 of the video. The aim was to help support, and enhance their grasp of the increasingly complex picture being constructed. This was followed by a second discussion focusing on the emerging trends.

Stage 3: Envisioning the future
Finally, participants were presented with Part 3 of the video, an envisagement of future energy systems focusing on autonomous software agents. Participant groups were shown one of two alternate, fictional views of the future. This was designed to elicit different perceptions of future scenarios, and was followed by the final discussion.

FINDINGS
In the following sections we consider how people related to the future infrastructure during our sessions. One of the striking aspects was the way people's practical reasoning of the infrastructure interleaved rationales that were technological, economic and societal. Participants would interlink the ways in which a technology might be realised, the economic drivers that might shape it and a broader societal reflection on the energy governance and policy. This interlinking became particularly important in terms of people's views on autonomy, trust and the role of agents.

Engaging with the infrastructure
Users' views of energy were strongly grounded in the current infrastructure. Their engagement with an energy infrastructure tended to be expressed in terms of the economic relationship with utility companies. By and large users expressed little motivation or interest in engaging with the infrastructure, seeing this as a low priority.

*"It's **having time basically**, the bill comes, and they send me a notice my bill is coming up I think, oh, and put it on a pile and never look at it."* (Emphasis added)

This is not to say that users did not want to optimise their energy use and understanding. Rather, they felt energy was not a day-to-day priority for them. Energy monitoring facilities had often simply faded into the background.

"[My energy company] sent me out an energy monitor, I did use it very briefly, then I stopped using it, just another thing using electricity."

Users felt that they should be more interested in energy use although they were not, and wondered if a future active infrastructure might help motivate more engagement.

"I don't know how my energy consumption fluctuates. If I had an alert come through and said your bill for this would actually be this, then I might think, oh what have I got turned on ya know – it would make me think more."

Users appeared to be torn between the desire to "do the right thing" and simply getting on with life. The call to be virtuous in energy use was balanced by cynicism about the extent to which they would actually actively engage with the energy infrastructure and their energy usage.

"I'm trying to imagine myself like looking at some kind of e-mail or notification to change energy supplier once a week, its gonna bore the shit out of me."

The challenge is that users recognised the need to be more proactive in their energy engagement but are not interested enough to do anything about it. This would appear to identify an ideal role for autonomous software agents. However, the appeal of having software agents absorbing this overhead was balanced with significant concerns about control, trust and privacy.

Autonomy and Control
Although disinterested in day-to-day management of energy consumption and tariffs, when presented with autonomous agents, users expressed a strong initial reaction about the loss of autonomy and control within their own home.

*"I don't know… **I think if a machine tried to tell me when to put the washing machine on I'd probably break it**… I can see the benefit... but I think it might be a step too far."* (Emphasis added)

"… we should have the choice of how we use energy in our home, at least that! Our home for crying out loud!"

This resistance tended to focus on technological automation within the home and the imposition of any control from outside. This echoes many of the concerns raised by users about automation in domains such as smart homes [23]. Our users negative reaction was also linked with a more particular concern about the viability of time shifting. Users' reasoning about their routine reflected a position that they felt unlikely they had the space to time-shift activities.

"… if you got a routine it is almost certainly there for a reason not just because you like doing things at certain

times; that is how your time has to be organized to get everything done. Most of us go to work from 9-5 and then have children or pets or whatever that need to be dealt at specific time. Baby bottle sterilization things are expensive to run right, but you are not going to have an agent say 'don't feed your baby because it will cost you more money.' If I want to do my washing, I just have to do it, because it has to be done. It is something you have to do. 'Oh! I will not wash my clothes today. I will go to work reeking tomorrow cause it is cheaper to do my washing in the weekend.' That is not gonna happen."

The concern was amplified by a suspicion about the motivation for time shifting. Participants felt that the energy companies sought to maximize profits and that time shifting was really about the identification of peak time to charge more.

"*I do have a problem though with making peak time that expensive."*

"People would pay an extra premium to use the service at that time but they wouldn't stand for it (blocking the appliance). Like [banks] these days."

This suspicion was further amplified by the sense that within the UK the companies had established a complex set of tariffs in order to minimize consumers' ability to exercise choice and change.

"A lot of people are feeling it's too complex. They don't feel they have the personal power to make an informed choice anymore by themselves. They think they have to go along with whatever they are being told."

The advantage then of agents was not about the control of devices in the home. Rather the appeal to participants focused on agents empowering them to exercise greater economic autonomy from their energy provider by exercising control outward from the home. Although they were cynical that companies would essentially respond by reducing the choice available.

"It is better for the energy companies to not make it easy to find this information about their pricing structure because that might change my behaviour and that is why I think that this system, although it is efficient and it has all the potentials, when you are dealing with overwhelming need and not just a moral desire, just an overwhelming need for these companies to make profit and to show growth because that is how they judge and they survive and to me that is kind of, that is a potentially contradictory situation where the end user would potentially not end up benefiting as much as they could from this system."

"If the agents are constantly operating and constantly flicking between best provider at that time of day, wont that ultimately squeeze the pricing of the suppliers to a very narrow band? So, there is very little difference to choose between them anyway, which would sort of obviate the need for the agent in the first place."

Users felt that government policy would be critical in ensuring that the agent-based systems that control their relationship with energy providers would work.

"The government are realising that something needs to be done, so that they are forcing the hand of energy suppliers, but they wouldn't have done it otherwise."

This concern about overall feasibility meant that users wished to maintain some involvement in the process such that they exercised bottom line choice.

"Different tariffs might be recommended, and then you can decide rather than have it bombard at you."

Or they wished to ensure that they could inspect the rationales for the agents' interaction.

"[If the agent]… had said after three months we've been monitoring you for three months, you're using this amount of electricity at night time, we think you ought to switch to this, and then you might go and say ok I'll do it"

Much of these desires reflected unease about the extent to which users would trust the overall energy systems to emerge from these smart grids.

Trust and complexity

The users felt very strongly that the energy system as a whole needed to be trustworthy and were suspicious that this would ever be the case. One issue for the users was a concern about introducing more complexity. This was manifested both in terms of the technology:

"If there's a bug, where ya know, it's interpreting the data from the sensor wrong, or its getting the wrong corpus of available tariffs and choosing them incorrectly, then I'm essentially paying more because of some software bug."

And the complexity of the dynamic energy model being introduced:

"I don't know how an old lady in her 80s is going to understand all this?"

"More and more complex and undesirable tariffs."

Users did not view energy companies with as particularly trustworthy and felt that these companies were exploitative. This was often expressed as a desire for agents to be involved in holding these companies to account.

"I would feel like I wouldn't mind paying more, if I felt that because the producer, who is government run, it was not specifically for profit agency, therefore they would potentially have some green potentials and that would feel quite good. I would feel quite positive about handing out my money to someone I know that is actually not going in their pockets, which is how I feel now half the time. I know some of it is paying for electricity but quite a lot is going in to some extremely rich persons' big pockets."

The role then for an agent that might emerge for these users was as advocates who would look after their interests.

"This system has become the middle bit and determines the pricing according to consumption and production, rather than what we have at the moment which is all these lots and lots and lots of companies offering different tariffs based on their own internal mechanism."

However, this hung very much on whom the users perceived the owners of the agent to be and whom the agent was acting for.

"Who's going to own the agent? That's going to be us as an individual is it, or a power company?"

"I think they would probably limit it to their own tariffs, ... no agent owned by a company is going to search the others companies tariffs and encourage you to use those."

This issue of ownership also applied to the data collected and analysed by agents, with users feeling that it was important it was open and available to them.

"Do you know if the information from the smart meter is going to be publicly available? So you were talking about the concept of keeping records of your own power consumption, would that be available to me as a consumer regardless of who my supplier was, so that it would make it easier to shop around using that information?"

These issues of trust also manifested in terms of how people thought about the issues of monitoring and privacy.

Monitoring and Privacy

Although smart energy systems require considerable monitoring of the energy data, users expressed less concern about the nature of this data. For many, this was analogous to their existing online activities.

"I have no problem with my data being out there. In fact so much of my data is out there anyway. I don't see how energy data is that different compared to my Google searches which are all traceable."

The issue of privacy for users centred much more on how companies might exploit this data. In particular, they were concerned about the ways in which energy companies may seek to make commercial advantage from this either through the use of advertising or selling on of the data.

"There are positive stuff that you can do with that data but I suspect the principal goal being for large power companies to make large profit."

These concerns were also tied up with a practical understanding of consent and the need to be informed about the use of the data.

"I would like to know who can access the data, I wouldn't like my data to go to them, and let's say for my provider to then sell it to a different agency or to make it publicly available; it's got to be secured and it's the data, ***it is my data that I am letting them use*** *rather than it being their data they can sell on."* (Emphasis added)

People consequently felt that government policy and regulation would need to be developed that would align with the collected information. Indeed, the major concern for the users was that the technology was aligned with appropriate controls and safeguards on the use of the information.

"You have to trust in the fact there's going to be sufficient regulation, who ever monitors the data or collects the data."

As part of these regulations users also felt that the system should offer them some assurances about how the collected information is used.

"I wonder if there would be anyway of, you accessing the data to the extent where you could monitor what it has done over the last period of time, so that if you had any doubts about that, you would be able to see a snapshot for whatever you choose, that ya know, this is what it was choosing from at this time. So you could see what the agent is actually doing with that information."

DISCUSSION

What is clear from our sessions is that energy infrastructures are understood economically, socially and technically. We would suggest that the design of future smart infrastructures needs to take seriously from the outset that the endeavour has a socio-political dimension rather than factor off the design of the technology and user interfaces. As Dourish comments [7]:

"Political, social, cultural, economic, and historical contexts have critical roles to play ..."

A holistic perspective is critical given that a range of sociotechnical forces shapes infrastructural systems. Many parts of an energy infrastructure result from policy decisions that cannot be designed away or ignored. For example, countries might politically choose not to allow a particular form of energy generation or to only allow its use in particular settings for sound political reasons irrespective of the nature of the technology.

Understanding this broader context of the system as whole is essential in assessing the overall benefit of any intervention. For example, the UK has an ageing electricity grid that operates predominantly as a hierarchical distribution system with energy flowing from generation to use. Consequently, it is not guaranteed that consumption reductions promoted by energy displays within households can actually be converted into significant savings in the generation of energy. Indeed, these reductions may end up simply being absorbed at the local transformer level.

The particular socio-political environment also plays out in initiatives such as smart meters. Concerns over privacy and the level of regulation inevitably vary from country to country. The amount of control and influence available across the system varies. For example, the UK has deregulated energy with the result that generation, supply and transmission are all controlled by separate entities that operate an internal market making any end-to-end change particularly difficult. Obviously, these different contexts will play out in a myriad of ways depending on the technical intervention and the nature of the system. It is critical that designers attend to these differences and recognise the particular impacts of a given socio-political context and elaborate designs that are sensitive to these contexts.

Addressing "The Trust Dilemma"

We would like to highlight in the UK context the relationship between consumers and energy providers as a major framing influence in realising smart agent-based infrastructures. Six energy companies provide 98% of UK households. These companies have coordinated significant price rises across the tariffs they offer and are seen as being unresponsive. This context is one of the reasons our users expressed such a deep-seated distrust of energy companies. We would suggest that this presents future UK energy consumers with an intriguing ***dilemma of trust***. Essentially, consumers recognise the need to do something about energy but lack sufficient motivation and know-how to delve into the complex details of a smart infrastructure. However, they also fundamentally don't trust those who provide the infrastructure, a finding echoed in smart home research [3].

To tackle this dilemma we would propose a design orientation that recognises from the outset the suspicion users have of commercial and government influences in energy. We would suggest the need to design future embedded agent systems in a manner that they actively promote and enhance trust. To aid developers of these systems we would offer a number of key design guidelines.

Principle 1: Articulate to users the ownership, intent and permitted activities of embedded agents. Participants' suspicion and trust was often undermined by an uncertainty surrounding whom an embedded agent was acting for and what the permitted actions of this agent might be. We would suggest that making explicit who owns and controls any embedded agent and the stated aims and limits of the agent will be essential, if users are to develop any trust in these systems. Is an agent acting on behalf of an energy supplier, and are actions limited to monitoring, analysing and reporting behaviour? Is an agent acting on behalf of a user to monitor the activities of the infrastructure and alert them of significant changes? There is an opportunity for the agent to be perceived as a mediator between the energy company and the activities within the home. The challenge for HCI is in developing the appropriate means of simply articulating these relationships and the permissible activities of the agents. This articulation may eventually require standardisation and regulation. An approach that is increasingly the norm is financial agreements and contracts.

Principle 2: Promote and support an open infrastructure. An inherent feature of the distrust of users was feeling of not knowing what energy companies were doing with their data. Closed and proprietary approaches to the design and development of smart grid infrastructures are likely to amplify these concerns. We would suggest that there are two key features critical to an open infrastructure. Firstly, mirroring calls by other initiatives (e.g., www.greenbuttondata.org and data.gov), a commitment to open energy data is essential. Users should be empowered by allowing them to apply alternative analysis and understandings of monitored data. Secondly, an agent infrastructure needs to be open allowing an easy interchange of agents. Thus, if consumers do not trust an agent's actions they should be able to easily replace this with an alternative. HCI has a critical role in outlining the key user needs in the development of these open models.

Principle 3: Design accountability reports of action into the agent. Participants' lack of trust was also manifest in a concern that software agents in the infrastructure would do things that a user would not understand or that users could not hold the agents to account for these actions. This suggests that autonomous agents need to be designed from the outset to provide users with understandable accounts of their actions. They should be able to provide information about what triggered a particular action or drove a given strategy. This is particularly challenging given that many of these agent-based systems exploit statistical machine learning techniques where inference is driven by a balance of probabilities. Expressing the nature of these algorithms and rationale for action provides a significant challenge for the HCI community. This also suggests the need to carefully consider the technical and social nature of accounts [6].

Principle 4: Provide an on-going mechanism of consent and withdrawal. Participants demonstrated little trust in how energy companies would handle information about them and what they would do with it. Current models of consent with their focus on single moment of approval do not align well with systems that are driven by continual monitoring of users. The process is unwieldy and users seldom feel that they have sufficient information to make a genuinely informed choice. We would argue that this suggests the need to provide a strong dialog-based approach to consent where it is an on-going process and users will maintain the right to withdraw or renegotiate the levels of consent provided. Finding simple ways of conveying different levels of consent represents a major challenge that the HCI community is particularly able to address.

The provision of these principles as a feature of future systems will require an alignment between technologies and policies. Technology developers will need to engage in a dialog with the various agencies involved in setting policies. We would suggest that the HCI community is ideally placed to communicate the desires of users and the rationale for these features and to act as an intermediate in discussions of this form.

CONCLUSIONS

We have presented our experiences in soliciting views about a future smart energy infrastructure using animated sketches. Participants' engagement with future energy infrastructure was fundamentally socio-technical. It is critical that HCI researchers recognise this and develop approaches to the design of infrastructures that reflect these. Moreover, this is a domain that is fundamentally political in nature and design needs to understand and reflect these critical drivers.

Studying and understanding an infrastructure also presents significant challenges in conveying the complexity and nature of something that seldom becomes visible [22]. An issue compounded when the infrastructure is not yet built. Our sketching approach allowed us to explore these issues by articulating the broad socio-technical nature of these future infrastructures and conveying their core concepts to our participants. As well as promoting a reaction to the technical infrastructure, our animation approach also provided the space of expression to allow users to articulate broader concerns centered on a lack of trust of the commercial entities involved in energy provision. These concerns critically frame the infrastructure and need to be systematically addressed by designers.

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REFERENCES

1. Brynjarsdottir, H., Håkansson, M., Pierce, J., Baumer, E., DiSalvo, C., and Sengers, P. Sustainably unpersuaded: how persuasion narrows our vision of sustainability. *Proc. CHI ’12*, ACM Press (2012), 947-956.
2. Buxton, B. Sketching User Experiences. Morgan Kaufmann Publishers Inc., 2007.
3. Chetty, M., Sung, J.-Y., and Grinter, R.E. How smart homes learn: the evolution of the networked home and household. *Proc. UbiComp '07*, Springer (2007).
4. Department of Energy and Climate Change (DECC) and the Office of Gas and Electricity Markets (OfGEM). *Smart Metering Implementation Programme*. 2011.
5. DiSalvo, C. and Sengers, P. Mapping the landscape of sustainable HCI. *Proc. CHI ’10*, ACM Press (2010), 1975-1984.
6. Dourish, P., Button. G. On "Technomethodology": foundational relationships between ethnomethodology and system design. *Hum.-Comput. Interact.* 13, 4 (1998), 395-432.
7. Dourish, P. HCI and Environmental Sustainability: The Politics of Design and the Design of Politics. Proc. DIS ’10, ACM Press (2010), 1–10.
8. Forlizzi, J. and DiSalvo, C. Microsketching: creating components of complex interactive products and systems. *Proc. C&C ’09*, ACM Press (2009), 87-96.
9. Froehlich, J. and Findlater, L. The design of eco-feedback technology. *Proc. CHI ’10*, ACM Press (2010), 1999–2008.
10. Kensing, F. and Madsen, K.H. Generating visions: future workshops and metaphorical design. In J. Greenbaum and M. Kyng, eds., *Design at work - cooperative design of computer systems*. Lawrence Erlbaum Associates (1991), 155–168.
11. Kitzinger. J. Introducing focus groups. *BMJ*, 311 (1995), 299-302.
12. MacKay, D.J. Sustainable Energy - Without the Hot Air. UIT Cambridge Ltd., Cambridge, 2009.
13. Mancini, C., Rogers, Y., Bandara, A.K., Coe, T., Jedrzejczyk, L., Joinson, A.N., Price, B.A., Thomas, K. and Nuseibeh., B. Contravision: exploring users' reactions to futuristic technology. *Proc. CHI '10*, ACM Press (2010), 153-162.
14. Pierce, J. and Paulos, E. Beyond energy monitors: interaction, energy, and emerging energy systems. *Proc. CHI ’12*, ACM Press (2012), 665-674.
15. Ramchurn, S.D., Vytelingum, P., Rogers, A., and Jennings, N.R. Agent-Based Homeostatic Control for Green Energy in the Smart Grid. *ACM Trans. on Intell. Sys. and Tech.* 2, 4 Article 35 (2011).
16. Ramchurn, S.D., Vytelingum, P., Rogers, A., and Jennings, N.R. Putting the ‘smarts’ into the smart grid. *Communications of the ACM* 55, 4 (2012).
17. Reeves, S. Envisioning ubiquitous computing. *Proc. CHI ’12*, ACM Press (2012), 1573-1582.
18. Scott, J., Brush, A.J.B., Krumm, J., et al. PreHeat : Controlling Home Heating Using Occupancy Prediction. *Proc. UbiComp ‘11*, Springer (2011).
19. Shove, E. Beyond the ABC: climate change policy and theories of social change. *Environment and Planning* 42, 6 (2010), 1273–1285.
20. Smart Metering Design Group. Industry’s Draft Technical Specification. *Smart Metering Implementation Programme*, 2011.
21. Spees, K. and Lave, L. Impacts of Responsive Load in PJM: Load Shifting and Real Time Pricing. *Energy Journal* 29, 2 (2008) 101-123.
22. Star, S. L. The ethnography of infrastructure. *American Behavioural Scientist* 43, 3 (1999), 377–391.
23. Taylor, A.S, Harper, R., Swan, L., Izadi, S., Sellen, A., Perry. M. Homes that make us smart. *Personal Ubiquitous Computing* 11, 5 (2007), 383-393.
24. Tohidi, M., Buxton, W., Baecker, R., and Sellen, A. User sketches: A Quick, Inexpensive, and Effective way to Elicit More Reflective User Feedback. *Proc. NordiCHI ’06*, ACM Press (2006), 105–114.
25. Tomlinson, B., Silberman, M. S., & White, J. Can More Efficient IT Be Worse for the Environment? *Computer* 44, 1 (2011), 87–89.
26. US Department of Energy. Benefits of demand response in electricity markets and recommendations for achieving them. 2006.
27. Zimmerman, J. Video Sketches: Exploring Pervasive Computing Interaction Designs. IEEE Pervasive Computing, 4, 4 (2005), 91–94.