Information Interfaces for Domestic Energy Microgeneration

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ABSTRACT
Domestic energy generation using solar panels and heat pumps has become a feasible option for most homeowners, yet lack of ICT solutions for microgeneration means that user understanding of their own domestic energy is poor. In this paper, we explore the design of in-home information interfaces for future domestic energy microgeneration services. We present concrete design proposals and report insights from a wizard-of-Oz field trial.

Keywords
Energy microgeneration, sustainability, human computer interaction, smart homes, solar panels, user interfaces.

1. INTRODUCTION
Distributed microgeneration is considered one of the cornerstones of the future energy infrastructure and domestic energy generation using solar panels, heat pumps, etc. has become a feasible option for most homeowners [1,2,3]. As consumers become more aware of and more willing to adopt emerging energy technologies, traditional energy providers realize that they need to develop innovative product and service offerings for domestic energy generation. Since its broad availability in the early nineties[1], consumers have been able to benefit from domestic microgeneration systems mainly through government mandated feed-in tariffs (FIT) [4] where customers are paid a certain amount of money per generated KWh. This approach implements a monetary incentive for customers to install and use domestic microgeneration, yet because a typical energy bill in the UK does not state the amount of energy fed back into the grid it effectively makes the locally generated energy invisible to customers and prevents them from developing a precise understanding of their own energy generation.

Over the last 12 months we have been working with a major UK energy provider to investigate the role of ICT in the design of innovative microgeneration products and services. In particular our work has focused on understanding the requirements and the design space of in-home information interfaces to increase the transparency of microgeneration for consumers. We have conducted design studies and field trials that have resulted in a series of design prototypes that allowed us to gain insights into customers' perception and understanding of domestic microgeneration, with implications for design of future information interfaces.

Even though the design of domestic energy systems has become an important topic for the HCI community, research has for the most part focused on energy feedback displays for consumption data [6]. The emergence of new energy infrastructure and their potential for reconfiguring sustainable practices and creating new energy products and services has been recognized before [7,8,9,10]. However, with the exception of [11], there have been no concrete design proposals for domestic microgeneration.

Our research has been conducted in two stages: Stage 1 consisted of focus groups with a large set of domestic energy customers and has resulted in a set of design proposals. In Stage 2 we conducted week-long wizard-of-Oz evaluations of these designs in six households with a total of 19 people. Four of the households already have microgeneration (solar PVs), whole the other two are considering it. In the following we briefly describe our approach for both stages and summarise the key results.

2. METHODOLOGY
Our research has been conducted within the context of a multi-year smart-energy trial run by a large UK energy company. The company's trial explores consumer energy issues (perception, adoption and business models related to smart meters, microgeneration and electric vehicles) through an extended field trial involving involves 75 suburban one-family homes. As part of the trial the company has been installing prototype systems of energy technologies such as smart plugs and solar panels across the participating households. Our own study was designed and run independently from this large trial but has been conducted in cooperation with the company and has been using the same set of participants.

Stage 1 of our research consisted of focus group sessions with the 75 households of the commercial smart home trial. During these sessions participants discussed experiences with smart home technologies such as smart plugs, smart meters and domestic energy generation technology. Video and audio recordings were created to aid analysis of the discussions. The research team used the insights of these sessions to generate several hypothetical design proposals (Figure 1 and 2). The designs use well-known visual metaphors (the dial, the battery, the switch etc.) and apply them to microgeneration. The designs was purposefully kept incomplete and rudimentary: rather than as a design endpoint they were intended as a starting point for freewheeling discussions and collaborative exploration by groups of users.

Stage 2 was designed to get feedback about the design proposals from current users of microgeneration technology. We set up a

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[1] By September 2012 there were over 360,000 domestic microgeneration installations in the UK, with a constant pace of over 1,200 installations added per week [5]. As of March 2012, domestic PV systems registered under the Feed-in Tariffs reached 800 megawatt, which is about 0.1% of UK domestic electric consumption.

test display infrastructure consisting of several Apple iPads for use in the participant's homes and a central server for remotely controlling the display of the iPads. iPads were used for displaying concrete instantiations of the designs from Stage 1. Since our designs assumed (or better anticipated) energy technology that had not yet been available (such as domestic energy storage) we have been using a wizard-of-Oz approach where data about energy generation, storage and consumption necessary to drive the displays has been synthetically generated and thus has been unconnected to the energy infrastructure that existed in the participants household. A set of iPads was installed for one week in 6 households (19 participants in total) to allow participants time to explore and discuss the designs among themselves. A follow-up interview was conducted with each family.

3. INSIGHTS AND RESULTS

3.1 Household-level vs Appliance-level

The key outcome of the group sessions (Stage 1) with respect to microgeneration was the importance of the distinction between energy issues that relate to the whole house vs those that relate to just specific appliances. For example, domestic appliances like washing machine and dishwasher play a particular role in energy consumption: their use is primarily determined by household practices and social norms, they are used regularly and often, the timing of their use is negotiable (within limits), and they use up most of the non-negotiable energy other devices (such as TV and radio). There was indication that the importance and special role of appliances merits energy interfaces for each appliance in a household. Taking this insight into account we have split our designs into two groups: house-level designs (Figure 1) and appliance-level designs (Figure 2):

There are four house-level designs:

1. *Current Solar Power Generation (Figure 1, left)*: This design shows a display that indicates how much solar power is being generated at the current moment.
2. *Available Renewable Power (Figure 1, second to the left)*: This design indicates how much stored renewable power the customer has currently available for the household (Note: this assumes energy storage technology that is technically feasible, but has not yet been deployed commercially).
3. *Energy Generation and Consumption for the Last 24 hrs (Figure 1, second to the right)*: this design shows how much energy the customer has generated in relation to the amount of consumed energy during the last 24 hours. In essence, this design highlights the "energy gap" between generation and consumption.
4. *Renewable Energy Forecast (Figure 1, right)*: This design indicates how much energy the customer is likely to generate in the next 5 days. Technically, this design requires the ability to predict energy generation from historical patterns and in particular the ability to predict the weather and it's impact on energy generation. (Note: the required fine-grained data about local micro-weather and environmental conditions is not available for most locations in the UK).

In addition to these four house-level designs we identified three appliance-level designs (Figure 2):

1. *Available Renewable Power (Figure 2, left):* this design indicates how much renewable power the customer has available for a specific appliance, for example the washing machine or the dishwasher. This design assumes that solar power has been reserved or assigned to the appliance.
2. Number of Available Wash Loads *(Figure 2, middle)*: this design is specific to the washing machine and indicates how many loads of washing the customer is able to do at the moment using available self-generated energy.
3. Power Options *(Figure 2, right)*: this design indicates an interactive switch (i.e. not just a display) that allows the customer to select the type of power to use for the appliance (grid or self-generated).

3.2 Displays vs. Controls

Most of the literature on HCI issues of domestic energy systems focuses on displays. However, during group sessions and the field trial we uncovered evidence that consumers desire to control the use of their own generated energy in a much more fine-grained way than is possible today. For example, in the discussion session it emerged that one father uses remote controllable smart plugs to curtail his kids Internet use. During the field trial a secondary use of the energy switch (*Figure 2, right*) emerged: the mere presence of a switch that allows (or forces) one to chose the energy source for an appliance or device might be incentive enough for a behavior change ("Perhaps if there was a switch on the TV, or on the girls' computers, that it would have an impact on the girls. That would make them think"). Similar issues of fine-grained control have also emerged in the context of home wifi network controls [12].

3.3 Transferring Knowledge

When designing the battery indicator for both the whole house and the appliance we assumed people would be able to rely on their experience with battery powered electric devices and laptop computers to infer a meaning for the microgeneration battery symbols. However, interpretation of these symbols proved surprisingly difficult. One participant felt that the battery for the house as a whole was lacking a concrete unit to help him interpret what 100% full means, or 75%. For others the ambiguity of the meaning was precisely what made this symbol useful. Given the importance of local storage for energy demand shifting [13] it is necessary for designers to identify suitable interface metaphors.

3.4 Misplaced Trust

Although this was a highly motivated group of individuals who had studied microgeneration extensively there were many misconceptions about the amount of generated energy and how generation is influenced by external factors. We discovered that some people firmly believed they could accurately estimate current level of generation when in reality their understanding of factors that influence generation such as cloud covers, tree foliage, orientation of the house to the sun, time of day and yearly season was very sketchy.

4. Conclusion

The design of future domestic energy microgeneration services will rely to a large extent on the provisioning of information that helps consumers make sense of their own energy generation habits, patterns and behaviors. Yet the design of information interfaces is made difficult by the fact that vital components of the future energy infrastructure (e.g. domestic energy storage, EVs) are not yet available. Using a wizard-of-Oz study that relied on synthetic yet realistic energy data we were able to engage with current and future users of microgeneration to test interface design prototypes. We believe that this methodological approach will prove useful for other energy studies.

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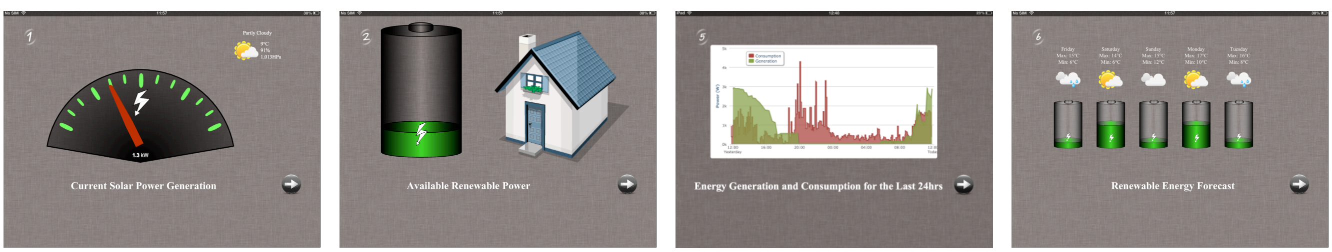

Figure 1. House-level Displays for Microgeneration

Figure 2. Appliance-level Displays and Interaction Elements for Microgeneration

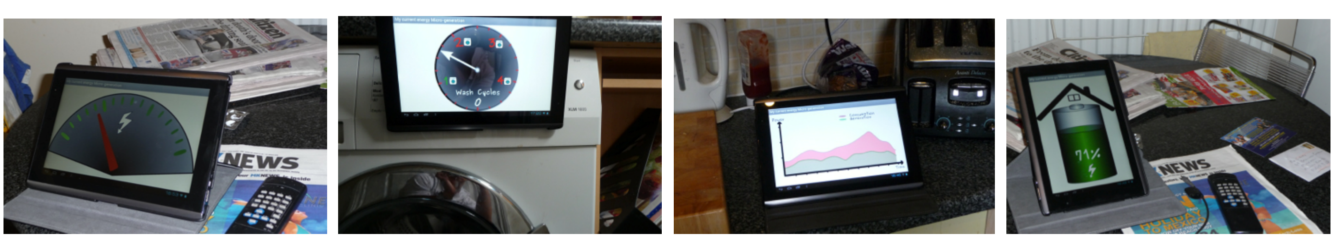

Figure 3. Information Displays during Test Trial (using early interface design)