Energy Demand Shifting in Residential Households: The Interdependence between Social Practices and Technology Design

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ABSTRACT

Emerging energy technologies, such as smart meters and solar photovoltaic systems (solar PV), are changing our relationship to energy. There is increasing evidence that households with solar PV on their roof tend naturally to shift their energy consumption in time to match their local generation, but what do people actually do to achieve this and how ICT can support them to optimize their consumption? In this paper we present a year-long user study to understand social practices around laundry routines and local energy generation. We highlight four challenges for the next generation of home energy management systems.

Introduction

There is increasing evidence that households with solar photovoltaic systems (solar PV) exhibit energy-saving behaviours intended to maximize the use of local energy and to reduce the use of imported grid energy. Keirstead et al [7] use the term 'double dividend' to refer to the fact that microgeneration produces green energy and gives rise to energy saving behaviour. They describe how households with microgeneration engage in '*demand-shifting*' - a particular form of behaviour change where energy consumption is shifted towards times when residential production is at its highest. In a previous study [10] involving households with solar PV installations, we found that people were keenly interested in shifting energy intensive activities and attempted to estimate when their houses generated the largest amounts of energy and moved household activities like doing laundry and doing dishes to these times. However, we also highlighted the complexity and in transparency of residential energy generation systems. The non-linear correlation between local weather variations and energy output, the presence of seasonal variations or the complexities of generation systems and feed-in tariffs are some examples that makes it a difficult task for end users to predict domestic electricity generation. Combining these difficulties with the social constraints of family life make it difficult for residential consumers to predict their electricity generation and develop effective demand-shifting strategies. We found that a typical response was to develop practical shortcuts to estimate local generation, which led to unreliable and suboptimal demand shifting strategies.

In this paper we report the results of a year-long study involving 19 residential households with solar PV installations which investigated the viability of a technical system that helps households develop more effective *Demand-Shifting* strategies. Through a combination of ethnographic studies and data analysis we were able to uncover social constraints of family life that inform energy *Demand-Shifting* practices and were able to find out to what extent different technology designs obeyed or violated these social constraints.

This paper extends the growing body of research on energy *Demand-Shifting*. Yet in contrast to most previous work, we focus on domestic energy generation and strong end-user involvement in scheduling decisions. In the remaining sections, we highlight a research gap through our studies and related work, then we present four challenges for future home energy management systems.

Exploratory Study: Technology Probes

Over the last few years we have investigated the context of residential solar electricity generation through a combination of user-centred approaches such as technology probes, participatory analysis and interventions. In this context, there is an energy gap: local generation is produced mainly during the day while consumption happens mainly during the evening. Although solar PV households can export the surplus of production into the grid, it is more efficient to use it locally. In the UK, it is also more cost-effective for householders because of government tariff incentives.

We used technology probes [10] to explore how people interact with microgenerated energy and how information and communication technologies can support them. We designed features related to the entire home energy as well as for a specific appliance. These features were informed by previous focus groups. They represented common metaphors such as a battery, dial or energy forecast. We implemented these features on electronic tablets and we set up two of them in each of our six participating households. After a week, we conducted an interview to let participants express their ideas and feedback. We found that people were naturally shifting some of their consumption in time, trying to use most of their local production. The energy forecast was particularly appreciated, giving users the opportunity for planning.

In contrast with existing research targeting energy consumption reduction, emerging energy technologies such as solar PV bring the need for more efficient energy consumption, which includes artificially increasing consumption at certain timesl. Householders with solar PV tend to change their behaviour, trying to match their consumption and their local energy generation. What are the social practices behind these behaviour changes and how do new technologies fit in these social practices? In our study we looked at how we could support solar PV householders in improving their energy *Demand-Shifting*, i.e. using energy they need at a time energy is cheaper or greener.

Settings

The result of this exploratory study motivated a long-term user study over a year with 19 households having solar PV on their roof. During this period, we monitored electricity coming from solar panels, electricity imported from the grid and the surplus of generated electricity exported into the grid. We also monitored the electricity consumption of appliances such as the washing machine, the dishwasher or the tumble dryer. Each household had a washing machine able to communicate via ZigBee, giving the opportunity for detailed monitoring and control.

Participatory Data Analysis

Objective: Understand the Needs and Constraints with Householders

Based on energy data we collected, we designed three high level data visualisations [4] linking parameters that are correlated to solar energy generation (weather, sunset and sunrise) with washing machine load (Figure 1). We used these visualisations to conduct an interview with each of the participating households. In this approach, our objective was to present householders with their own energy data in an unusual format relating energy and wash cycles. This participatory data analysis aimed to translate everyday routines into the needs and constraints around Demand-Shifting practices in collaboration with the user. We chose to scope this user study on laundry routines, focusing on the washing machine, as it appears like a potential shiftable activity related to many other routines in the house but not directly with energy management.

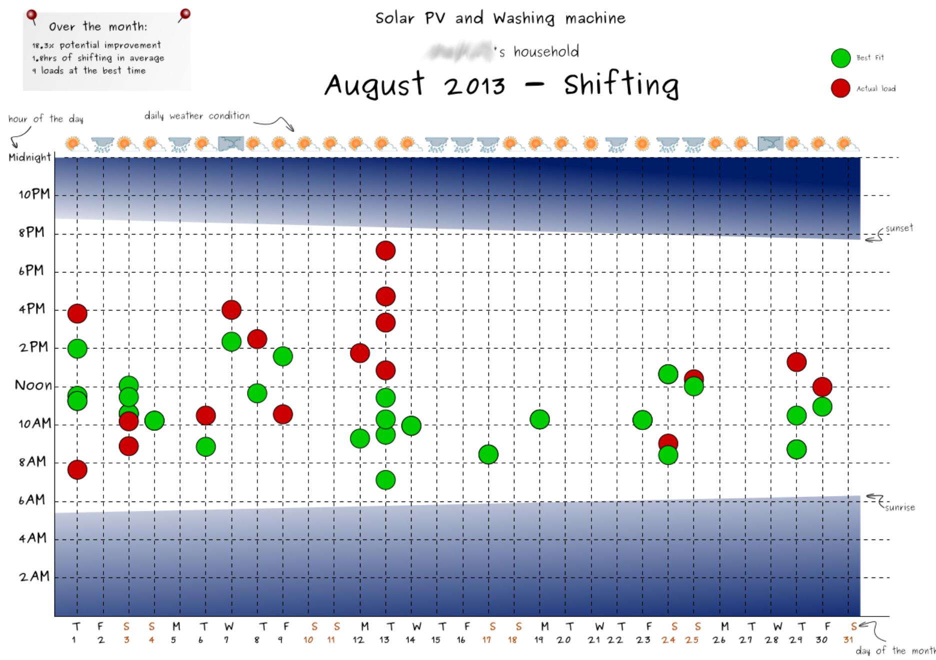

Figure 1. Data visualisation

Social Practices

Most participants were trying to use most of their own locally generated electricity. Depending on the household and householders, motivations and engagements for doing so were variable. While costs and the environmental impact are the most visible motivations, it appears that consuming their own energy was a motivation in itself. Most participants felt reasonably proud of producing their own green energy.

To maximize the use of their production, participants use different source of information. They look out of the window and make their own weather prediction, they check the weather forecast on their smartphone, they check the instant energy consumption on the solar panel inverter or on a dedicated display, they observe energy generation and consumption graphs on the display of their Energy Management System, they expect the best generation period depending on the orientation of their solar panel, and so on. Combining multiple sources of information, the decision process behind *Demand-Shifting* is often a transparent but complex process. In short, participants combine multiple variables to take a decision on the time to start an appliance. Such sources of information are not always interpreted properly as it is difficult to appreciate instant values against prediction and the impact of turning another appliance ON or OFF.

Participants describe the need for more information to answer questions such as *'which appliances can I turn ON or OFF to fit with my local generation?*' Or control such as *'I'm out for the day, run this appliance at the best time before I come back*'.

Most constraints of shifting the laundry activities in time are about going out and coming back home. Looking at the visualizations, household members clearly recognized when they were coming back from the gym or were waiting children from school before starting the wash cycle. In the first case, people just want to wash their sport clothes and even people that are convinced by 'green consumption' do not want to change anything. The '*shiftability*' of an appliance depends more on the household, the resident and the specific situation than the appliance in itself. However, there are strong interactions between appliances reducing possibilities for shifting. Participants knew which appliances were high consumers and so avoided turning them both at the same time. Since wash cycles can last from one to three hours it reduced the potential for *Demand-Shifting*.

We observed diverse interests and motivations under the same roof. Most of the time there is one person in the house very concerned about energy for money, environmental impact or personal curiosity. This makes it difficult to talk about energy to other members involved in different tasks and routines in the house. However, discussing laundry routines with the visualizations widened interests of members who were not especially involved into energy management before.

Finally, *Demand-Shifting* requires a lot of effort compared to the potential economic benefits. Based on the overall energy consumption, generation and washing machine loads, we evaluated an average potential benefit of GBP 0.50 (EUR 0.60, USD 0.80) per month among our participants. Reacting to this figure, participants were only half surprised and most of them still wanted to go further with more appliances.

Demand-Shifting Interventions

Objectives

Going further into our investigation of social practices in the context of residential electricity generation, we designed and deployed a '*Demand-Shifting* recommendation system' [3].Based on a real-time analysis of detailed household energy demand and generation data from smart meters and smart plugs, the system would inform users about optimal timings and strategies in using appliances each day such as the washing machine, dryer and dishwasher. In contrast to automatic demand management approaches, our system realised an 'interactive Demand-Shifting' approach where users were at all times in control about timing and operation of their appliances. Over 8 months we mixed the deployment of four interventions (Figure 2):

1. **Feedback** – We sent emails to householders every three days, showing the solar

generation over the past few days in relation with the washing machine loads

2. **Real time feedback** – We sent text messages to householders at the end of each washing machine load, providing information about how much electricity came from the solar panel to power the washing machine and when, if so, it could have been better.
3. **Proactive suggestion** – We sent text messages to householders, providing the best expected time to run the washing machine in order to maximize the use of solar energy.
4. **Contextual control** – We provided an electronic tablet sitting on the washing machine to automatically run wash cycles at a time maximizing electricity coming from solar PV, given a 'not before' and a 'finished by' deadlines.

'If you want to run your washing machine today, then 13:15-15:15 should be the greenest time, but running it tomorrow between 10:45 and 12:45 would be better.'

'If you want to run your washing machine today, then 12:30-14:30 should be the greenest time. It is a better day than tomorrow.'

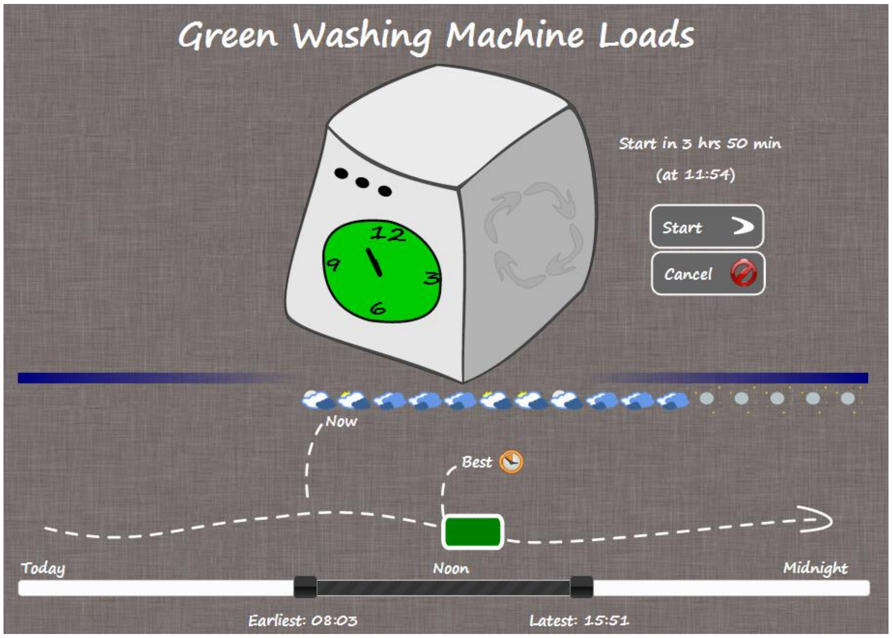

Figure 2. Proactive Suggestions (on the left) and Contextual Control (on the right)

In this study, our objective was to understand how this support can be used alone and in combination with each others. Can we highlight both promising and less promising directions for the design of energy management support? Can we generate new ways of thinking about energy in the house?

Rooms for Technologies in the Context of Residential Energy Generation

Beyond the exploration of social practices, we observed that the most useful information was high-level information providing opportunities to anticipate, to react and to knowledge of a period of high or low local generation.

Most participants preferred proactive suggestions over reactive suggestions. This information gave householders the opportunity to plan in advance. They could take action that would not necessarily require more effort but would increase efficiency. Although reactive text messages provide contextual feedback on potential time and performance, householders were not able to make use of them. *'It's like shooting in the dark [...] you get the exam before the course'* explained one participant. In contrast, proactive information gave householders a way to anticipate. Disseminating information is also about time and place. Depending on each householder, the frequency of receiving information should be regular or following daily routines, should be in the evening before or in the morning, and so on. We observed the same variability about the place to receive information: from text messages to emails and to a dedicated display. While proactive text messages could be used to react to an over or under-production, participants expressed the need to know in real time which appliances they could use to adapt their consumption. Finally, although feedback and real time feedback were not the best option for planning, some participants used them as a check on how they performed.

Conflicts between appliances were far more visible with contextual control. While text messages provided information householders had freedom to use (or ignore), the electronic tablet controlling the washing machine made the process more automatic. Participants described a number of situation in which they did not use the electronic tablet because of another appliance was already running at the suggested time. They also noted that such a control allowed a precision they could not achieve manually.

Our focus on laundry routines allowed us to widen interest in energy by taking on board householders who were not especially interested in energy management but involved in doing the laundry. While participants doing laundry were involved during the participatory data analysis, they were also more involved in the study, receiving text messages and getting more interested in optimizing their energy consumption. In the next section we will present how this research fits in relation to existing work.

Related Work

Emerging Energy Technologies

Emerging energy technologies bring opportunities such as natural engagement with production and consumption. Keirstead [7] coined the term ‘double dividend’ to refer to the dual effect of installing solar panels causing people to intentionally consume less energy in addition to producing green energy. Based on interviews with solar PV householders, he showed that people became more aware of energy in the context of local generation and implemented saving behaviour such as unplugging appliances or turning off lights. Hondo and Baba [6] shed light on the impact of local generation beyond energy. They showed that beyond energy saving and shifting behaviour, these householders increased the level of communication within and around the household. However, these new technologies increase the level of complexity of a system in which it was already difficult to understand what to do. Thus,there is a need for ICTs to support these new engagement behaviours: How to reduce the effort and complexity while increasing the engagement about energy?

Energy feedback has been researched for decades, focusing on how to increase energy awareness in order to reduce energy consumption [5]. While a growing literature highlights the important role of emerging energy technologies in behaviour changes [11], promising but yet limited projects shed light on the potential of ICTs around these technologies to support householders towards a more efficient use of energy. In the context of green houses, Banerjee highlighted the need for the user to anticipate [1]. Kobus and colleagues [8] deployed a smart washing machine in 24 households that is able to start when the solar electricity generation is at its highest. They report some household members were unable to become interested in the washing machine as a smart appliance with energy saving potential, as doing the washing was not part of their role in the home. This is in contrast with our results which highlighted a widen engagement on both energy management and laundry activities.

Demand Side Management and Scheduling

Demand Side Management (DSM) is an umbrella term that groups together techniques to reduce or optimize the end-user's energy consumption in order to reduce the cost and the environmental impact. A review by Palensky and Dietrich [9] presented a taxonomy of these techniques, including Demand Response and Demand Shifting both of which address the issue that, because electricity is very costly to store, it is important to consume most of it when it is available. The limit of demand response is that such techniques focus on one objective: the production cost for the energy provider. Furthermore, such techniques are mostly transparent for the user because they focus on background appliances, which reduce the effort (nothing to do for the user) but also the engagement.

The analogy between 'Smart Home' systems and computer operating systems has been presented multiple times as an answer to heterogeneous technologies. The diversity and evolutionary use of home appliances match with the concepts of devices, drivers and plug-and-play in Operating Systems (industrial and research examples). However, this comparison could also be extended to the task scheduler. Households are composed of resources, background tasks and interactive tasks.

From the user point of view, only Bapat and colleagues [2] have proposed a set of optimal schedules of appliances to suggest to users. However, this research does not consider multi objective scheduling and user studies evaluating the user interaction around such schedule.

Challenges

Our user studies have extended the growing research aimed at understanding the resident-energy relationship in the context of local electricity generation. In combination with existing research, we shed light on a research gap that can be summarized in two points:

- First, home emerging energy technologies make energy management more complex while allowing opportunities for new energy behaviours. These technologies require new user interfaces that support energy decision making through information and control provided in advance.
- Second, this support has to be adaptable to users (with whom it is interacting), objectives (which goals it is targeting) and the context (which capacities are available and which constraints have to be satisfied).

In this section we present four challenges for future home energy management systems.

Scheduling

In the previous sections we highlighted the need for solar PV householders to anticipate periods of high and low generation. Anticipation is a key aspect of energy management in the context of highly variable carbon intensity and costs. The weather forecast, the local generation prediction, the prediction of import tariff, all these predictions are available or on the way to being available to householders. However, there is still a long way to go between prediction and decision making. There is a missing key element providing an optimized schedule that would implement or suggest behaviours that use energy more efficiently.

Which energy actions can householders implement that would fit their current objectives and comfort while making their consumption greener or cost effective?

Although systems for such schedules have been proposed, they were focusing on one objective and were not deployed in the home. Scheduling needs to be based on multiple objectives changing over time such as maintaining the comfort, minimizing costs or minimizing the environmental impact. Such schedules would provide support for controlling appliances (e.g. start the hot water heater in advance to catch solar energy) but also for disseminating user suggestions in advance and giving them the opportunity to anticipate.

Giving such opportunities to householders does not mean forcing them to apply proposed schedules. How do householders deal with such scheduling information? What are effective ways to disseminate such planning suggestion?

Reactivity

Although providing optimized schedules to householders will give them opportunities to anticipate, householders are masters in their house and will decide or not to follow such schedules. Furthermore, scheduling information would be based on prediction for a given confidence interval allowing for error. Scheduling has to be combined with a reactive algorithm to handle unanticipated events, such as a device starting or the local generation dropping unexpectedly. In combination with scheduling, the system has to handle unexpected events and look for potential optimisations. As an example, a short peak of consumption such as the coffee machine or the kettle that would require import from the grid even though there is plenty of local generation. Simply pausing some of the appliances running at the same time would avoid that. Conversely, an unexpected amount of local energy is generated. The system should be able to look for potential ways to use this green and cheap energy.

How to make coherent the dual process between scheduling and reactive decision? Research has been done in this direction in robotics and artificial intelligence.

Interactivity

Existing research on demand side management has been focusing on demand response and background appliances. These appliances, such as the hot water heater, can be started and stopped depending on the grid tariffs. Although this background consumption represent a large part of the overall consumption, interactive loads such as washing machines or coffee machines are the loads that appears at peak time consumption. These devices cannot be shifted automatically (e.g. need to fill the washing machine up) or even shifted at all (coffee time). It highlights the need for ICTs that provides information in advance such as proactive suggestion or contextual control that takes control from householders whenever householders specify in order to optimize their consumption. As an example, the user should be able to run several appliances at the same time, letting the system synchronize loads with each other and synchronize with the local energy generation.

What is the balance between effortless energy management and engaging energy management? Assuming it is different for each householder and changes over time, how can we dynamically set up this balance?

Adaptability

Previous research in the field highlighted that every householder, even under the same roof, has different requirements on information they want to access or receive, on the action they want to perform, on automation they want to be done, on objectives and priorities they want to target, and all these parameters change over time. We also observed that looking at specific everyday routines such as doing the laundry can widen the audience of householders involved in energy management.

Is the diversity of user interactions relating to energy an effective way to increase engagement towards energy management?

Conclusion

In this paper we highlighted a research gap in home energy management systems in the context of local electricity generation: although emerging energy technologies open new opportunities for greener energy and behaviour changes, they make energy even more complex and difficult to manage manually. This process is time consuming and imposes a ‘social cost’ that is sustainable only by highly motivated householders. A key finding is that opportunistic planning plays a key role in both the organisation of household routines and energy demand shifting strategies, and that an interactive *Demand-Shifting* recommendation system can unify household routines and *Demand-Shifting* strategies. We extracted and detailed four challenges – Scheduling, Reactivity, Interactivity and Adaptability – to support households toward a more intelligent use of their energy in the context of local generation.

References

[1] Banerjee, N., Rollins, S., and Moran, K. Automating energy management in green homes. In Proc.SIGCOMM HomeNets ’11, ACM Press (2011), 19-24.

[2] Bapat, T, N Sengupta, S K Ghai, V Arya, Y B Shrinivasan, and D Seetharam. “User-sensitive scheduling of home appliances.” 2011. 43--48.

[3] Bourgeois, J., van der Linden, J., Kortuem, G., Price, B.A., Rimmer, C. “Conversations with my washing machine: an in-the-wild study of Interactive Energy Demand-Shifting with self-generated energy” UbiComp. 2014

[4] Bourgeois, J., van der Linden, J., Kortuem, g., Price, B. A., Rimmer, C. “Using Participatory Data Analysis to Understand the Social Constraints and Opportunities of Electricity Demand-Shifting.” International Conference on ICT for Sustainability (ICT4S). 2014

[5] Fischer, C. Feedback on Household Electricity Consumption: A Tool for Saving Energy? Energy Efficiency 1, no. 1 (May 6, 2008): 79-104.

[6] Hondo, H. and Kenshi B. Socio-psychological impacts of the introduction of energy technologies: change in environmental behavior of households with photovoltaic systems. Applied Energy 87.1 (2010): 229-235.

[7] Keirstead, J. “Behavioural responses to photovoltaic systems in the UK domestic sector,” Energy Policy, 35/8, Aug. 2007.

[8] Kobus, C.B.A., Mugge, R. and Schoormans, J.P.L. Washing When the Sun Is Shining! How Users Interact with a Household Energy Management System. Ergonomics 56, no. 3 (March 2013): 451-462.

[9] Palensky, P. and Dietrich, D. Demand side management: Demand response, intelligent energy systems, and smart loads. Industrial Informatics, IEEE Transactions on 7.3 (2011): 381-388.

[10] Price, B.A., van der Linden, J., Bourgeois, J., Kortuem, G. When Looking out of the Window is not Enough: Informing The Design of In-Home Technologies for Domestic Energy Microgeneration. ICT for Sustainability (ICT4S). 2013

[11] Pierce, J. and Paulos, E. Beyond Energy Monitors: Interaction, Energy, and Emerging Energy Systems. In Proc. ACM SIGCHI 2012, 665-674, 2012.