Interactive Demand Shifting: in the Context of Emerging Energy Technologies

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Abstract — **We are entering a key time period for home energy. While ubiquitous computing takes an increasing space in our daily life, emerging energy technologies including local generation and electric vehicle are leaving the stage of pioneer's users to become more common. This research highlights the potential of new energy behavior supported by digital tools in the context of domestic solar electricity generation.**

Keywords—Domestic Energy; User Interaction; Solar Panels; Electric Vehicle; Emerging Behavior

I. Introduction

The combination of ubiquitous computing and emerging energy technologies is about to radically change the home energy landscape [10]. In the UK like in many countries, a national rollout is about to start implementing smart meters in every houses. It creates opportunities for energy control and display. Meanwhile, domestic microgeneration is increasing at high pace, dominated by solar photovoltaic [6]. Domestic heating and transport are also shifting to electricity based technologies. Typical examples are heat pumps and electric vehicles. These changes represent a complete reshape of the home energy landscape, pushing for moving around household's budgets as well as creating new energy behaviors. However, these transformations generate a new challenge that we call the domestic energy gap: Microgeneration is mainly uncontrollable production, happening when the sun is shining or the wind is blowing. In contrast, domestic energy consumption tends to happen mostly during the evening. Consumption and microgeneration are out of sync. This research focus on understanding and supporting new domestic practices in the context of domestic solar energy generation and electric vehicle, looking at 'Demand-Shifting' – a particular form of behavior change where energy consumption is shifted towards times of the day when local production is at its highest, thus using 'green energy'. The overarching research question of this work is the following:

How can digital tools leverage emerging energy practices in the context of domestic self-generated energy?

The remainder of this paper highlights a selective literature on domestic energy and demand-shifting. Then we break down the research question in 3 sub-questions which we address.

II. Background

Evidence is beginning to emerge that households with solar PV exhibit saving behaviors intended to maximize the use of local energy and minimize the use of imported grid energy [9]. These behaviors translate a natural engagement into Demand-Shifting. Research on Demand-Shifting has been focusing on energy consumption, specifically with Demand Response (DR) mechanism controlling appliances automatically based on tariffs [8]. However, such an approach does not consider the local generation. Molderink and colleagues manage domestic generation and storage in a three-step process [11]. They predict local generation, then build a resource planning at micro-grid scale (sub-network of the grid) and generate a local schedule for each house. SmartCap is a more local approach of Demand-Shifting aiming at the flattening of peak electricity demand [2]. It focused on background loads only, which do not require any intervention from the resident such as air conditioners (A/Cs), refrigerators, freezers, dehumidifiers, and heaters. Neither of these 3 approaches apply interactive appliances, those that require user interventions such as washing machines, electric vehicles or kettles.

Energy consumption feedback raises energy awareness and a number of projects have already shown a significant impact on domestic overall consumption [7]. Yet dominated by complex graphs, there is no emphasize of local energy and electricity is shown as an unlimited and on-demand resource. Budget [5] and scheduling [1] based user interfaces are only becoming to appear, targeting impact on Demand-Shifting.

To sum up, the energy eco-feedback literature focuses on demand reduction and background appliances while research on domestic solar energy and its potential impact on user behavior is under-explored.

III. Research Objective

Based on the context and the existing literature, we formulate the following issue. Emerging energy technologies are all motivated by the same objective of addressing global climate change. However, these technologies are out of sync, producing and consuming electricity at different time, creating a domestic energy gap. In contrast with previous research focusing on driving behavior change toward consumption reduction, this research proposes supporting behavior changes we can observe in the context of emerging energy technologies to reduce the energy gap. We address the overarching research question in three steps:

RQ1. *What are the new behaviors taking place in the context of emerging energy technologies and their potential?*

The first step of this project consists in building a qualitative understanding of the potential impact. What are the new energy practices, their conditions and their flexibility? Is there a consistency in these practices over time, between households or across appliances? From a quantitative perspective, what are the potential savings?

RQ2. *Does supporting emerging energy practices require new ways of interacting with users?*

Dealing with home energy consumption requires dealing with inhabitants, especially when dealing with peak demand consumption. Is typical energy feedback a suitable way to support emerging energy practices? If not, what are the constraints and the new requirements?

RQ3. *Which digital system to enable the support of emerging energy practices?*

Based on RQ1 and RQ2, can we design a system and realistically prove the validity of supporting new behavior.

To address these research questions, we looked at households with solar photovoltaic. We worked in collaboration with EON on the Thinking Energy project. It brings the opportunity for fine-grain monitoring and close interaction with inhabitants of 75 households around Milton Keynes through each stage of the research.

We built a first case study around the washing machine in the context of self-generated energy. The washing machine is the opposite of an emerging energy technology. Taking place in most households, it has a well-established behavior, intricate in householder's delay routines, not a huge electricity consumption but with a supposed relative flexibility of usage. It provided us with a clear understanding of the context.

We are now working on two extensions. First, we are building a second case study on Electric Vehicle. Electric vehicles are emerging energy technologies - yet replacing conventional petrol cars - with a significant electricity consumption. Our objective is to understand differences and similarities compared to the washing machine. Second, we are building a home system to support emerging energy practices.

The following section provides the methodology along the preliminary findings and answers to each of these 3 questions.

IV. Methodology and Findings

The methodology used in this research mixes engineering and empirical approaches, mutually strengthening and informing one another to provide an overall solution. It includes qualitative and quantitative research through data collection, participatory data analysis, longitudinal studies, interviews, co-design, simulation and real world testing. Throughout this research project we use user-centric methodology at each stage to inform and validate the research.

A. Exploring Emerging Energy Practices

Throughout this research project, we use a set of exploratory methods to get a clear understanding of the domestic context.

1) Data collection: user study and monitoring

We conducted an initial study with 6 households using the technology probes methodology to explore how people interact with microgenerated energy and how information and communication technologies can support them [12]. 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 batteries, dials or energy forecasts.

To get a deeper insight of emerging practices in the context of local generation, we set up a long-term user study over a year with 19 households having solar PV on their roof. Based on energy data we collected, we designed three high level data visualizations [3] connecting solar electricity generation with washing machine loads. We used these visualizations to conduct participatory data analysis [4] to translate everyday routines into the needs and constraints around Demand-Shifting practices in collaboration with the user.

We are now investigating electric vehicles. We conducted 16 exploratory interviews with participants across England, with diverse electric vehicles, with and without solar panels. We also looked at 2 online forums. Similar to the washing machine, the objective was to understand which routines are taking place in this context. Then we started looking in depth at routines around this new home appliance and its implication with a subset of 7 households. We monitored trip data from car manufacturer and asked participants filling a trip diary. We combined these data and designed visualizations that we discussed with participants.

2) Emerging Energy 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. However, there is often one person in the house more concerned about energy. It makes difficult talking about energy to other members involved in different tasks and routines in the house. Centering the discussion on laundry routines widened interests of members who were not especially involved into energy management before.

To maximize the use of their production, participants use multiple sources of information including looking out of the window at the weather, checking the weather forecast, looking at the instant power generation on the solar panel inverter, guessing based on their installation, and so on. They combine these information to decide whether or not starting an appliance in a complex process leading sometimes to mistakes.

Most constraints of shifting the laundry activities in time are about going out and coming back home. 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 know which appliances consume more and avoid turning them on at the same time.

Shifting the washing time requires a lot of effort compared to the potential financial benefits. When participants were told they could only achieve a very limited benefit by shifting the washing machine they were only half surprised and most of them still wanted to go further with more appliances. Based on actual data we computed the impact of shifting a single appliance such as the washing machine. Preliminary results show that this appliance alone would save less than GBP 0.5 per month in average while rescheduling multiple appliances including the electric vehicle would reach more than GBP 0.5 per day.

As an answer to the **RQ1**, emerging energy practices are dominated by manual demand-shifting and natural energy demand reduction. The potential of shifting one appliance such as the washing machine is very low while multiple appliance shifting can generate significant improvement. The shape of a positive answer appears to the **RQ2**. In fact, user interaction based on forecast, planning and suggestion seem to be more appropriate answer than typical energy feedback.

B. Designing to Leverage Emerging Energy Practices

Going further into our investigation, we designed and deployed a 'Demand-Shifting recommendation system' [4]. In contrast to automatic demand management approaches, our system realized an 'interactive Demand-Shifting' approach where users were in control about timing and operation of their appliances at all times. Over 8 months we mixed the deployment of four interventions about feedback, proactive suggestions and contextual controls. These interventions were based on text messages, emails and electronic tablets.

1) Engaging User Interaction

Beyond the exploration of social practices, we observed that the most useful information was high-level information providing opportunities to anticipate, react to and acknowledge 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. Although reactive text messages provide contextual feedback on potential time and performance, householders were not able to make use of them. Disseminating information is also about time and place. Depending on each householder, the frequency of receiving information should be regular or following daily routines. The same variability about the place to receive information: from text messages to emails and to a dedicated display.

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 to control the washing machine 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.

We confirm the initial answer to the **RQ2**. Typical energy feedback providing information about past events does not work because there is not much to learn from the past in this context. User supports should be proactive and as contextual as possible. Furthermore, a trade off should be found between manual and automated action to reduce user effort without reducing her/his engagement.

2) Interactive Energy Management System

Through the exploratory studies and interventions, we highlighted a set of system requirements: demand-shifting can have a significant impact by considering multiple appliances and objectives and by negotiating with the user who keep the final decision. Supporting inhabitants in reducing their energy gap involves solving the problem *a priori* and finely adjusting in real time the system to address unanticipated events. We address the **RQ3** through the design of a computing system which aims at automatically proposing and shifting electricity consumption while letting the inhabitants in charge of the final decision on which actions to undertake. It requires to look ahead in order to estimate the electricity production and consumption to optimize the system. In combination, the system has to quickly react to any unanticipated events, which will undoubtedly happen since humans are kept within the decision loop. We are currently evaluating our system with a simulation based on actual data through two axes: the operational efficiency and the impact of the user commitment.

V. Conclusion

This research project focuses on domestic microgeneration through the research question: *How can digital tools leverage emerging energy practices in the context of self-generated energy?* In contrast with previous research in the field aiming to drive behavior change toward consumption reduction, this research focuses on existing behavior change in the context of emerging energy technologies. Building on the washing machine case study, the current stage aims to provide a better understanding by looking at electric vehicles to highlight contrasts and similarities. The last stage of this research will provide an energy system supporting emerging practices.

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