Participatory Data Analysis: A New Method for Investigating Human Energy Practices

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***Abstract* — This paper presents a novel data-driven method to investigate the interdependence between technology design and human energy practices. The method – called Participatory Data – makes use of fine-grained energy data collected via smart meters and smart plugs, and behaviour visualisation during home visits to spark self-reflection among householders.**

I. Introduction

The relationship between people and energy is changing. Many years ago, when energy prices were low, people were content to act as passive consumers of energy with only a faint understanding of the relationship between their behavior and the money they had to spend for energy monthly or half-yearly. Today, this situation has changed dramatically for three reasons: 1) energy prices have skyrocketed which has forced consumers to pay attention to costs of energy 2) increasing awareness of climate change has led people to question the impact their action have on the environment; 3) alternative sustainable energy technologies allow people to generate their own energy at home using for example, solar PV or ground heat pumps. Together these changes are transforming people's attitudes towards energy and lead to a widespread change of domestic energy practices.

Digital technology is playing a key role in mediating the relationship between people and energy. On the one hand, people increasingly use comparison websites such as uSwitch and GoCompare to seek out the cheapest energy tariffs and switch suppliers (although most people tend not to switch suppliers often). On the other hand, plenty of studies have shown that energy display and similar energy feedback technologies can facilitate behaviour change with the goal of reducing energy consumption (some of the people, some of the time) [1].

The smart grid represents the next wave of the digital technology revolution in the energy sector and is likely to have a transformative impact on the relationship between people and energy. The smart grid enables two-way communication between generators, consumers and those that do both, and turns the (soon to be) "smart home" into an intelligent end-point of the electricity grid, thereby paving the way for widespread adoption of innovative schemes such as dynamic demand response and peer-to-peer energy. The changing relationship between people and the energy system is depicted in Figures 1 and 2. While formerly transactions between people and energy companies were dominated by energy and money, transactions in the smart grid are dominated by information exchanges including - among others - real-time consumption and generation data, price signals and demand load shedding signals.

As the relationship between energy and people is becoming more complex a new challenge is emerging for designers of energy systems, HCI researchers and social scientists who are interested in understanding the interdependence between technology design and human energy practices: what methods do we use to investigate behaviour change, and changes in attitudes and self-image? Observing and understanding behaviour change in a real world context, such a home or a large organisation, is difficult. The home is a highly contextual environment steered by everyday life, habits and implicit rules. To understand how people accept new concepts and technologies in their domestic life, we need to get people thinking and talking about it. There is a birth of established methods and methodologies (e.g. ethnography, technology probes [2]), all of which are useful in different ways.

The increasing amount of fine-grained data about energy consumption and generation data – collected via smart meters and smart plugs – makes it now possible to add data analytics and data visualisation methods to the methodological tool chest. However, the difficulty is how to combine more traditional human focused methods with new data-driven methods. In this short paper we highlight a novel method which we call *participatory data analysis.* The key novelty of this method is the use of energy behaviour visualisations during home visits to spark self-reflection among householders.

II. Participatory Data Analysis

Participatory data analysis is a method to understand human energy practices by enabling people to reflect on their own behaviour. These reflections in turn provide insights into factors that influence people's behaviour such as attitudes, self-image, and motivations as well as social conventions and norms. To understand the motivation and purpose of this new method we will describe participatory data analysis in the context in which we first developed and applied it.

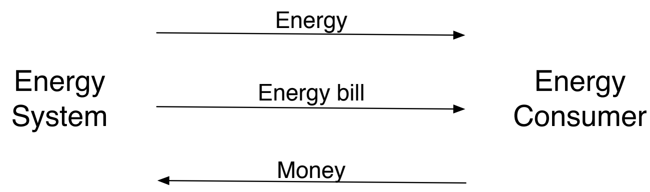

Figure 1. Old-style Relationship between People and Energy System

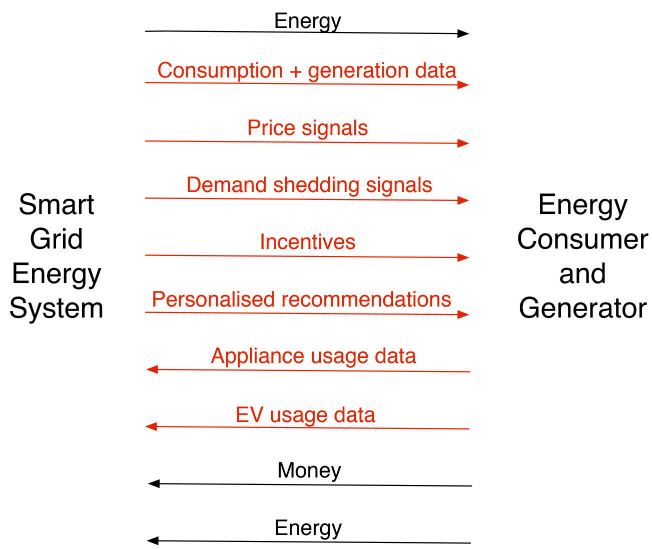

Figure 2. New-style Relationship between People and Smart-Grid Energy System

A. Motivation and Purpose

We developed and applied participatory data analysis during a recent study [3,4] that explored the potential of interactive electricity demand-shifting – a particular form of technology-mediated behavior change where electricity consumption is shifted towards times that are optimal in terms of cost or CO2 emissions. Specifically we focused on households with residential solar electricity generation and explored how these households can maximise self-consumption of locally generated "green" energy. To limit the scope of the study we honed in on energy self-consumption for doing the laundry and using washing machines and dryers.

We conducted a participatory user study with 18 households, over a period of 6 months. During this period residents carried out their normal laundry routines and we were able to track their electricity data through a variety of meters and smart plugs. The user study was situated within a wider program of research, involving some 75 households investigating issues around household electricity usage. The 18 selected households had all invested in solar electricity. From earlier focus groups and in-home visits we had become aware that participants had a keen interest in the amount of electricity they were generating and wanted to consume as much of it as possible. We learned that they manually shift some of their loads, like the washing machine or the dishwasher by "chasing the sunshine", that is, looking out of the window and switching on when it is sunny.

The aim of our study was to investigate more precisely how household members were carrying out this process of manually shifting their appliances. What were their struggles and constraints when aiming to maximize their self-consumption? How good were they at manually doing this, and what scope was there for further improvement?

B. Energy and Behavior Data

Over the course of six months we collected fine-grained data about appliance use and energy consumption. Each household was equipped with three smart meters to measure: (i) imported electricity from the grid (the typical fiscal meter), (ii) generated electricity from the solar panels and (iii) the exported electricity to the grid. In addition smart plugs were deployed to monitor the electricity consumption of individual appliances every five seconds.

C. Visualisations

To inform the design of technological interventions we conducted interviews with each household with the aim to let residents reflect on their own laundry routines and their relations to local energy generation. These interviews were conducted in-home lasting between 25 and 50 minutes and at a time suitable for the participants.

In order to enable this process we developed customized visualizations of people's personal electricity data. For each participant, we printed out a set of three visualizations for the most relevant summer month on A3 size paper (one of which is sown in Figure 2). The visualizations were developed to give participants an overview of their washing machine loads over a month. Each washing machine load was indicated as a distinct event in the week and month, and was represented as a multi-colored dot. The y-axis indicates which time the wash was started and the lower x-axis indicates the day of the week and date for the wash. The actual weather for each day – important for estimating energy generation from solar PV - was displayed at the top x-axis in the form of a "sunshine" or "cloud" symbol etc.

As an example, the first visualization uses a pie chart model for each load, showing for each load how much electricity was coming from the solar PV (lightly shaded part of circle = green in the original printed version) and how much electricity was coming from the grid (dark shaded part of circle = red in the original printed version). The bottom of the pie chart represents the actual start of the load. For example, during the day on the far left this household did 3 lots of washing, one before 8 in the morning (using mostly grid electricity), one around noon (mostly electricity coming from solar energy) and one at 4 in the afternoon (again with mostly grid electricity). The participants were all very familiar with the concept of importing and exporting electricity and this visualization was designed to draw their attention to potential opportunities to increase their self-consumption. We deliberately gave this the

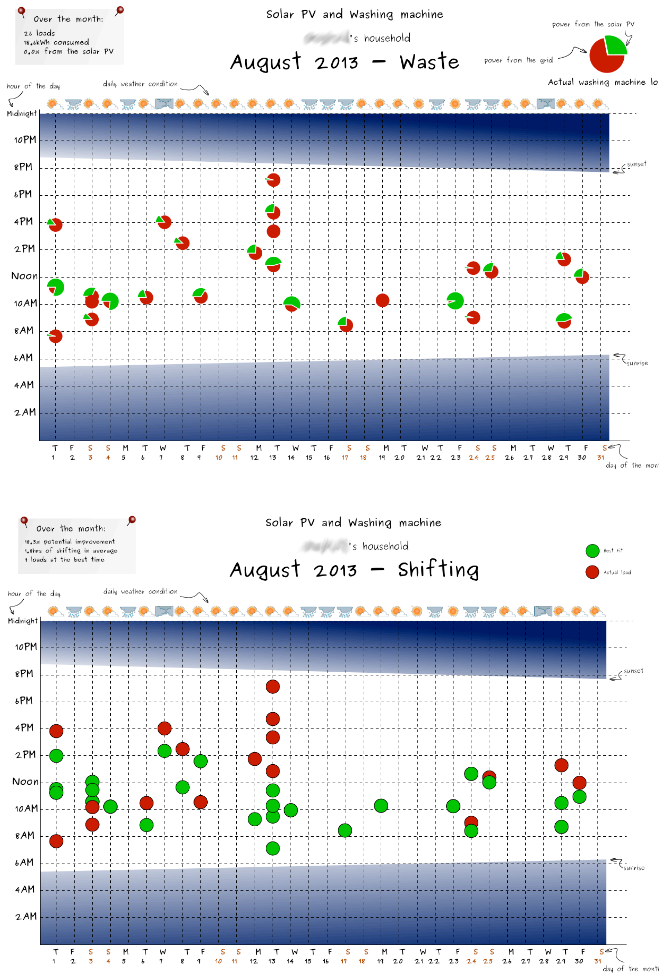

Figure 3. Behaviour Visualisations for Participatory Data Analysis

title 'Waste' – to be provocative (even though there is no actual waste) and to make the point that participants could have consumed more electricity coming from solar energy and thus reduced their electricity import from the grid. The objective would be to have a full green circle, which means that the washing machine load had been entirely powered by the solar PV. This visualization thus gave a quick overview of the "green-ness" of the household's loads over the month and helped open the discussion.

The second visualization was designed to show participants when would have been the "greenest" time to start the washing machine and how much delay it would have implied. The bottom of Figure 2 shows an example of this shifting visualization with the actual loads as dark circles (red in the original) and the best time for this load in light circles (green in the original). For example, towards the middle of the month this household carried out four washing loads, during the afternoon (shown as dark circle), and as light circle is indicated that the morning would have been a better time for these loads, given the specific weather conditions for that day. Using this chart the questions were phrased in terms of "Would it have been possible to...".

III. Discussion

Participatory data analysis (PDA) uses fine-grained, longitudinal data from smart meters and smart plugs to create high-level visualisations of household behaviours. By using visualisations during interviews we enabled participants to reflect on their own behaviour and ground discussions. In our experience participatory data analysis as a method has the following advantage:

- PDA visualisations create a common ground for discussions between experts (researchers) and non-experts (households).
- PDA grounds discussions by providing an accurate representation of (past) behaviours. This avoids discussions drifting off into unrealistic hypotheticals.
- PDA can be used to inform the design of novel technology interventions and does not require development and deployment of prototypes. (In our case we used PDA to inform the design of a recommendation system to help people optimise self-consumption [4]).
- PDA makes it possible to collaboratively explore the possible impact of technology interventions. For example, participants can be asked to create their own visualisations to represent behaviours *after* deployment of technology interventions.

So far we have used PDA only in the context of domestic energy self-consumption. We believe that PDA has similar potential to explore behaviour and social aspects in fully smart-grid connected homes, for example for investigating behaviour responses to dynamic demand response approaches [5,6].

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