Sustainable Load Shifting in the Context of Domestic Energy Generation

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Abstract
Domestic energy generation such as through solar panels and wind turbines is considered an important piece in the puzzle of our future energy strategy. This research aims to explore the concept of domestic energy demand shifting through autonomous and engaging scheduling of energy loads. A mix of analysis, user-centric and design methodologies will be employed to help people understand how they can narrow the energy gap between domestic electricity generation and electricity consumption.

Author Keywords
Domestic energy generation; load shifting

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

Introduction
The development of alternative energies is increasing in many countries. Even if the adoption of solar photovoltaic is still slow, it means that potentially ordinary households can become 'energy farmers' in the near future. However, we observe an energy gap: there is high energy consumption throughout the day

and the night; the daily consumption pattern is not nicely balanced; and local electricity generation and electricity consumption are out of sync. Here we ask, how can we support residents to use local electricity generation effectively?

Related Work: Energy Shifting and Residents

The concept of energy shifting refers to the use of an appliance during a 'better period' of time. We can shift loads to synchronize supply and need. By this method we consume only what we need. For example, Scott and colleagues proposed an automatic heating system schedule based on resident's occupancy [8]. A different approach is where we shift loads to flatten the overall energy consumption. Barker and colleagues worked in this direction with background appliances such as air conditioners (A/Cs), refrigerators, freezers, dehumidifiers, and heaters [2].

Electricity feedback is the way to provide information to residents about their electricity management. Studies have shown that electricity savings can range from 5% to 15% thanks to electricity feedback (see Darby for a review [3]). A recent method to provide electricity feedback is ambient displays which allow blending electricity in everyday life. However, this electricity feedback focused mainly on electricity *consumption* rather than electricity *generation*. An exception is the Local Energy Indicator [6] which shows the current local electricity generation from the wind and the sun.

Finally, energy shifting cannot be done without scheduling. This schedule should be shown to the residents giving them the possibility to interact with. Bapat and colleagues proposed a dynamic provisional schedule, like a Gantt chart, showing when it is the best period to use an appliance [1]. The aim was to inform residents about how they could organize their electricity loads to reduce peak consumption.

Research Objective

The overarching objective of this research is to manage domestic energy in a sustainable way by reducing the environmental impact and maintaining resident's comfort. As far as the literature shows, there is only one publication mentioning the concept of double dividend about domestic solar electricity generation [5]. Keirstead showed that introducing electricity generation in the home environment not only produces renewable electricity but also changes people's behaviour and reduces the electricity consumption. Thanks to local generation, electricity production will become closer to the consumption and will play a major role to drive energy behaviour change [4]. By providing effective feedback on the local electricity generation, we put the energy issue in everyday life, far beyond the home boundaries. This research will aim in a first stage to investigate deeper the concept of double dividend by verifying and measuring its impact on the electricity consumption. In a second stage the project will lead to find out tools to amplify the double dividend effect. These tools will focus on load scheduling methods tackling electricity issues from different angles: autonomous shifting of appliance loads which do not require resident intervention; and engaging shifting through HCI such as high-level recommendations and controls supporting and teaching residents. The combination of these two approaches is led by the following hypothesis: *The combination of local energy generation and load scheduling is a sustainable method to help people understand and reduce the impact of their energy consumption on the environment.*

Figure 1: Study 1, Technology probe approach about solar electricity availability

Methodology: Engineering and user-centred

In this project, three types of methodologies will be used: analysis of household energy data; user-centric approaches; and design of software. These methods mix engineering and empirical approaches to provide a solution strengthened from the interplay between the methods. **Data mining** is used as a starting point to motivate the research, understand energy data and evaluate potential impact of energy load shifting. It allows identifying the role and the impact of the multiple factors such as net cost, carbon intensity and energy losses on the resident's energy bill and on the environment. The residents must take a central place in this project because they are directly affected in their home. **User-centric approaches** will drive the investigations to find out which elements can support and teach people efficient behaviour. In this perspective, focus groups, user studies, interviews and technology probes approach will be implemented to inform and evaluate designed solutions throughout the projects. **Designing** pieces of Software, User Interactions and Algorithms takes a central place in the whole methodology of this research project. These artefacts will be informed by data mining and user-centric approaches to support experiments.

This project will take advantage of the E.ON European wide Energy Thinking project to conduct a long-term experiment and validate the overall hypothesis in actual domestic settings conducted in 75 households.

Work in progress: user study and simulation

Until now, two studies have been conducted in this project: a user study based on technology probes approach and a simulation.

Study 1 - User study: Technology probe approach

The first study was focused on *prosumers*, the solar photovoltaic owners who produce and consume electricity. We used the Technology Probes approach with six participating households over six household participants. Our probes were common metaphors about green electricity availability implemented on two IPads per households (Fig 1). The study highlighted that participants have some misconceptions about how much they generate and when and metaphors such as battery icons are hard to understand. Participants talked about manual demand shifting and how they reflect on their system: *'it's a bit cloudy, let's wait till this afternoon'*. However, questions still remain such as what they can do, how much and when. Creativity and reflections about the feedback location in the house have emerged and the electricity forecast feature has been particularly appreciated. People used to plan their next few days based on weather forecast and electricity forecast had easily taken place in their daily routines.

Study 2: Cross-country energy load shifting simulation

Before experimenting with energy shifting in the field, a simulation has been conducted to evaluate the potential economic, environmental and efficiency impact of this process over three countries – the United Kingdom, Germany and France – through three different scenarios: (1) current energy policy of each country; (2) maximize consumption of locally generated electricity with a battery; (3) and maximize consumption of locally generated electricity by shifting use of washing machine, dishwasher and dryer loads towards the best fit, with a battery. Preliminary results showed that the direct impact of energy demand shifting is beneficial in each country from the environmental point of view. It is more efficient to shift

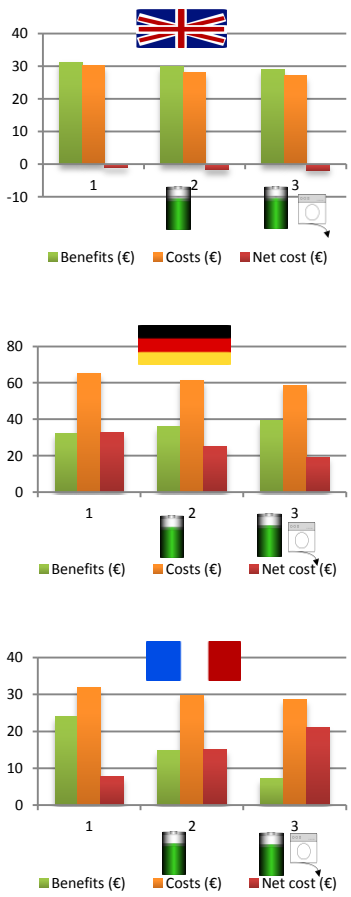

Figure 2: Study 2, cross-country energy load shifting simulation

appliances rather than trying to store all the non-use locally generated electricity and the combination of battery and appliance load shifting appears as a right balance. Finally, while energy demand shifting has a positive impact on residents' electricity bills in the UK and Germany, this is not the case in France where the electricity bill largely increases because the residents get subsidies only when they are drawing their locally generated electricity to the grid (Fig 2).

Research Plan

The next step is about to start. This is a user study which involves twenty participating households and will inform the acceptability, the format and the effectiveness of energy demand shifting recommendation. In a first stage, a designated person in each of the households will receive a text message each time the washing machine is switched on advising him/her of whether or not it was a good time to run the washing machine and if not when the next good time would have been. Twice a week, participants will receive an email advising them of suitable times to run the washing machine based on the solar generation forecast and historical generation and consumption. The objective is to observe how participants react to contextual energy feedback and suggestion through text and email messages.

In a second stage, the participants will receive a small electronic tablet to attach to their washing machine. The tablet will provide a web-based interface giving information as to their constraints for a given washing load (e.g. *'finish by 5PM'*, *'don't leave clothes wet in the drum for more than 1 hour'*, *'use as much green electricity as possible'*). This new function will collect all requirements and constraints and will suggest a plan based on start/end times, cost and CO_2 emissions. The objective is to observe how participants interact with 'demand-shifting' control and suggestion.

This work will inform the design of a domestic energy platform which will be implemented to support energy load shifting decision. It will follow a long-term study experimenting this platform through an iterative process of user feedback, quantitative measurement and improvement.

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