wEnergy: A Field Experiment on Energy Consumption and Social Feedback

Anders Dalén, Timm Teubner, Christof Weinhardt
Institute of Information Systems and Management
Karlsruhe Institute of Technology (KIT)
Karlsruhe, Germany
dalen@kit.edu, timm.teubner@kit.edu, weinhardt@kit.edu

***Abstract*—This paper presents the work-in-progress research project *wEnergy*. The aim of the project is the conception, execution and evaluation of a medium-scale field experiment on the impact of different forms of feedback on electricity consumption in private households. The 45 participating households (students' shared apartments) will be equipped with a non-intrusive and low cost sensor device. Energy consumption is then tracked in a high timely resolution and fed back live to the participants through the project website. After a calibration phase, the actual experiment begins. We employ a between-subject design to test the effect of a) feedback on one's own current and historic consumption (control) versus b) social feedback, comprising the consumption data of a peer group of households (treatment).**

***Keywords*-social feedback; energy consumption; smart metering; experimental economics; field study.**

I. Introduction

Smart metering is on the rise and consumers are seeing an increase of utility efforts to make the traditional energy meter information more transparent. However, enticing already busy consumers with direct access to their meter data has proven to be difficult. Two of the largest information driven businesses, Google and Microsoft, have both pulled the plug on their energy feedback projects due to lack of interest (google.com/powermeter, microsoft-hohm.com).

However, the potential for energy efficiency in households through more knowledgable consumers still remains: similar households in terms of location, size, appliances and dweller demographics have shown a difference in energy usage with a factor of two(!) [1].

Until now, the impact of direct feedback on energy consumption is not conclusive. There are several research and commercial projects that continue to develop visualizations and flexible control of energy consumption (e.g., luciddesigngroup.com, tendrilinc.com, mysmartgrid.de, rrrevolve.ch, discovergy.com). However, it is still debated to what point end users can be informed and motivated to become more energy efficient. Furthermore, field evaluations of social feedback and mechanisms that allow for comparison and collaboration among energy users are predominately based on questionnaires and lack access to the energy data and the ability to correlate the stated influence to the measured one [2], [3].

By gathering and presenting energy information we want to make the interaction with energy more transparent, and, by adding a social, collaborative component, we hope to explore and promote the effects of interpersonal comparison and sharing of best practices for energy efficiency gains in the scope of the project. We want to evaluate whether a collaborative form of sharing energy information can help sustain the interest for energy information and promote action in a field study. We want to contribute to understanding the effects of making people realize their actual consumption and giving them understandable and easily operable tools for exploring, visualizing, and evaluating this data—both in a private and a social context. To this end, we use non-intrusive hardware that are easy to install and low cost.

The remainder of this paper is structured as follows: Section II provides a brief overview on related literature and projects regarding energy data gathering and sharing. Sections III and IV describe the underlying architecture and user interaction logic of the platform website and give insight into technical related issues such as hardware, measurement, data handling and precision. In Section, V the experimental design and the evaluation approach are outlined. Since the project is work-in-progress, we conclude with a few ideas on methodological and topical extensions and plans for future research.

II. Energy Data Gathering and Sharing

Information is understood as a fundamental component of the future, more dynamic and efficient, energy system [4]. Energy consumption metering is traditionally supplied from the utility, but more privately owned measuring devices are becoming prevalent. Having direct access to energy information on total consumption has shown to produce savings of $5-15\%$ in a number of studies [5].

With more detailed information on specific appliances users have shown even further behavioral changes like lowering overall standby power consumption and operating appliances more stringently [6].

As energy information become more pervasive and available over the internet, more sophisticated informational campaigns are possible. Improving the access to the energy information is, for example, becoming easier to do through modern portable devices. This is leveraged in the eMeter project, which has shown great success in making energy feedback more convenient and ubiquitous [7]. Another promising use of energy consumption information, which will be further evaluated in this project, is simply to exchange this information with other participants. Previous studies in this field have found these comparative and collaborative properties to have an exceptionally high impact on consumption behavior [8] [9].

One important distinction to make about social feedback is that there is seldom a feedback model that will be appreciated by every participant. For example, one British study found that the subjects disliked being compared to their peers and questioned its legitimacy, while a similar Norwegian study found a positive response to the comparative information [2] [3]. In general, social feedback has been found to be more effective than self comparison with historic data. This effect is stronger when the proclaimed goal is relevant and precious, and also when participants can relate well to their peers, for instance because they are similar—or in a similar situation [11]. Where previous studies have either evaluated a range of feedback mechanisms, or focused on social feedback in aggregated form, this study aims to combine these approaches. By strictly evaluating the effects of sharing energy information with the aid of highly granular and modern information technology this paper specifically addresses the research gap of social feedback in a smart-meter era.

III. Platform Architecture

The wEnergy visualization framework is designed around a database driven website. Users can log on to their private account with username and password. The platform consists of four sections, the dashboard, the consumption overview, the appliance overview, and the social ranking.

The *dashboard* gives a very direct consumption feedback to the user. The m latest consumption measurements are plotted where m can be selected among different values (25, 50, 100, and 250) in order to enable an intuitive exploration of the data. A status bar indicates how much energy is used at the moment—color-coded from green to red. This measure is normalized to the interval [0, 1] where the current consumption is divided by the 90 percent quantile consumption in the last 2 days. The timely resolution of this plot is 0.2 Hz (one value per five seconds), corresponding to the frequency of the power measurement at the household site. The dashboard shall provide an intuition on how much users currently consume and how the power-on of a particular appliance adds to this value.

The *consumption overview*, lets the users see how much they are consuming over the course of a day, week, or month. Average consumption (in kW) is plotted. The actual consumption of the respective period is indicated in red and half transparent, and the historic average of the user's consumption for the period is plotted unobtrusively in gray

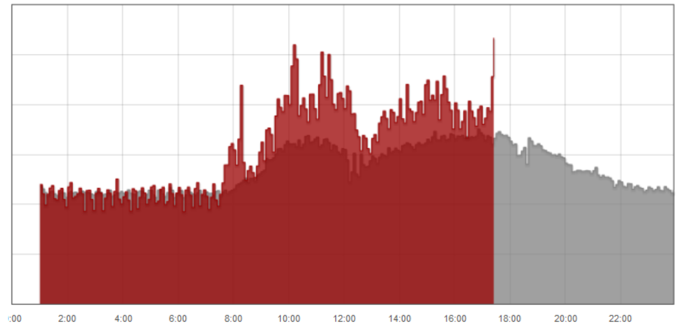

Figure 1. Consumption view as presented to the user, daily consumption, aggregation: 5 minute intervals, red: actual consumption, grey: historic average consumption

in the background (cf. Fig. 1). This enables an instant comparison between actual current and average consumption and enables users to evaluate their current behavior (benchmarked against their own historic average). The timely resolution is 5 or 15 minutes for the day view, 30 minutes for the week view, and 180 minutes for the month view.

The *appliance overview* is an experimental feature and serves as an indicator for users, which of their appliances that are currently active, and how much power these appliances consume. Note, that it is a difficult task to determine when specific appliances are switched on or off, since power signals are noisy, occur simultaneously and interfer with each other. Appliance recognition has been subject to extensive research in the past decades [12] [13]. However, even though progress has been made in this area, most current solutions for disaggregating appliances use highly specialized hardware that is hard to scale to the number of households that could benefit from this feedback [14]. This part of our website functionality addresses this gap and is intended to give users a more intuitive sense of their electricity consumption.

Finally, the *social ranking* lets the users see, how much energy they use compared to their peer group. Thereby, users are ranked not according to their absolute, but relative consumption referred to their own floating historic average. This means that participants, which consume less than usually will occur on top—but find it harder to be on top in the consecutive weeks, since a low consumption naturally decreases the reference value. Each peer group consists of about 5 households, with similar demographic characteristics (see Section V for a more detailed description).

IV. Technical Approach

Our hardware approach to measuring electricity consumption comprises two components, based on the openenergymonitor project (www.openenergymonitor.org). The first component consists of a battery powered sensor, that is attached to the main power lines in the fuse box of the household. The measurement is non-invasive, meaning that

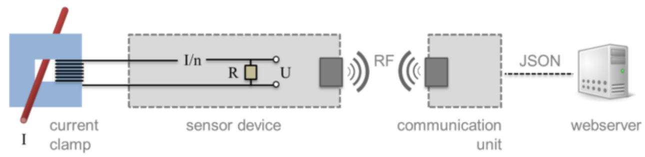

Figure 2. Measurement System Overview: power line (single phase), current clamp sensor, sensor device, communication unit, web server

participants will be able to install the device at home themselves, no expert knowledge or certification is required. However, a student assistant checks on the installations manually to assure reliability. The entire process usually takes not more than 10 minutes.

The German grid provides alternating current on 3 phases, 50 Hz and a nominal voltage of 230V. At the fusebox each phase corresponds to one of the main wires. We attach a ferrite split-core current transformer (CT) with $n = 2000$ turns and a maximum current restriction of $I_{max}^{in} = 100A$.

The data consumption data then is processed on an Atmega micro-controller. It is fed by voltage at $3.3V$, restricting the incoming signal to the analog-to-digital converter (ADC) to a voltage up to this value. This means that the incoming current from the CT must be limited, in order not to put the integrated circuit at risk of an overvoltage. Since most of the fuses in German households have a trigger threshold of $50A$ or less, we chose the on-board burden resistor accordingly. Supposing an ideal transformer ($I_1/I_2 = n_2/n_1$) and using Ohm's law ($U = R \times I$) we deduce the burden resistance to be 66Ω. By using a 60Ω-resistor we leave room for a $5A$ overshoot without sacrificing too much resolution.

The micro controller processes the voltage information from the CT and the burden resistor on a 10-bit scale (2^{10}), which results in a resolution of 8.7 VA/bit. Note that only current—not voltage—is measured. A more detailed analysis of real and reactive power is thus unavailable. However, the hardware can easily be extended to include this measurement, which has been confirmed in initial testing.

The second component (base unit) handles the communication with the central web-server. The sensor and base unit communicate via radio at 868 MHz frequency. The base unit is connected to the router of the household via ethernet and pushes the data objects to our central server using JSON elements. The entire system scheme is depicted in Figure 2.

V. Experimental Design

We aim to assess consumption behavior in a field experiment. Therefore, 45 voluntarily participating households, selected from a mutually comparable student milieu with 2 through 4 residents per household are equipped with the sensor system. Participants are invited to the Institute and are elaborately briefed about the project, use of the hardware, etc. The actual experiment is then carried out in two stages. In the initial calibration phase (2 weeks), the metering devices are installed and consumption is monitored. The participants fill out forms asking for perceived energy consumption knowledge, personal characteristics and general demographic factors. There is no feedback to the households whatsoever in this phase and the website functionality is limited. The calibration phase serves to establish a base level of consumption and to classify the households' consumption profiles. Participants also sign the general terms of use and agree that consumption data is stored and published anonymously.

In the treatment phase, the actual experiment begins. This phase lasts 8 weeks. As stated above, we use a between-subject design. The 45 households are partitioned into two groups, the control group ($n_0 = 20$ and the treatment group ($n_T = 25$). From then on, the participants of the different groups face different website functionalities. The control group can access the dashboard, and the consumption overview, whereas the treatment group can, in addition to that, access the social feedback, which is basically a ranking. The 30 treatment households are partitioned into peer groups of about 5—based on consumption-relevant characteristics such as number of residents, square meters of the apartment, type of the stove (gas/ electric), and consumption profile as indicated in the calibration phase. Every peer group has its own social ranking. The decisive value for the position in this ranking is the current week's aggregated consumption, referred to the own average weekly consumption during the preceding weeks. This ranking value $r_t = c_t/(\frac{1}{t-1}\sum_{i=1}^{t-1} c_t)$ is a percentage value where c_t denotes the electricity consumption in week t. With the beginning of every new week, all ranking values are set to 0. Note that the way the ranking is computed inherently balances the game play of the experiment. A household with a particular low consumption in one week will thereby lower its reference value and thus be less likely to achieve a top position in the ranking—and vice versa. In respect of participant motivation, this is a preferable design characteristic, since the best chances to achieve a high rank vary from week to week.

There are several different approaches for evaluating participants behavior. First, total consumption as the most obvious measure will be analyzed. Second, the idle consumption levels (e.g. during nights or absence of residents) can be used as indicators of how consistently lights, laptops, monitors, standby appliances etc. are switched off. This is suitable for analyzing whether users *care* about their consumption and consciously alter their behavior. Third, the total number and frequency of peak loads potentially explains whether high-load appliances such as water-boiler, vacuum cleaner, or electric heating were replaced by other, less wasting alternatives (broom, gas stove, warm pullover). Also variance, timely distribution, and load quantiles are interesting points of reference in order to explain what the experiment participants actually do.

Note that, for the participants, there is no monetary incentive to be on top of the social ranking. Nevertheless, we expect the mere presence of the comparison to have an effect on consumption behavior—lowering total consumption. Also, we expect total consumption to differ between the initial calibration and experimental phase for all subjects—irrespective of the treatment.

VI. Conclusion

Academic research on real-life consumption behavior under systematically manipulated conditions is sparse. Lab experiments put participants outside their natural environment, which appears to be crucial for studying consumption behavior, since it is inherently and closely linked to the own home, particular habits and routines. Our project addresses this gap. We are developing an easily installable and flexible platform to enable and evaluate the effects of social feedback and collaboration in the context of energy consumption. We expect that this will lead to a more general knowledge and awareness, and eventually a lower total consumption. It will be crucial to maintain a high level of participation and interest during the experiment.

Beyond the social feedback context we also anticipate other studies within the same framework. For example, communication among the members of a peer group can be introduced in order to foster peer effects like internal collaboration, e.g. sharing of tips for efficient usage. Also competition *between* different peer-groups appears conceivable. Eventually, the provision of applications for mobile devices brings consumption feedback even closer to the users and their daily routines—which ultimately may be a substantial contribution to a more appropriate dealing with electrical energy—and thus welfare and sustainability.

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References

[1] C. Swanson, M. Blasnik, and E. Calhoun, “Measuring public benefit from measuring public benefit from energy efficient homes,” prepared by Advanced Energy for the U.S. EP, 2005.

[2] S. Roberts, “Consumer preferences for improving energy consumption feedback,” prepared by the Center for Sustainable Energy for Ofgem, May 2004.

[3] H. Wilhite, A. Hoivik, and J. G. Olsen, “Advances in the use of consumption feedback information in energy billing: The experiences of a norwegian energy utility,” in *Proceedings from the ACEEE 1998 Summer Study on Energy Efficiency in Buildings*, European Council for an Energy Efficient Economy. Paris: ECEEE 1999 Summer Study on Energy Efficiency in Buildings, 1999.

[4] T. Philippine and N. Devernois, *Promoting Energy Efficiency Investments: Case Studies in the Residential Sector*. Paris: International Energy Agency, Agence française de développement Organisation for Economic Co-operation and Development, 2008.

[5] S. Darby, “The effectiveness of feedback on energy consumption: A review for DEFRA of the literature on metering, billing, and direct displays,” Environmental Change Institute, University of Oxford, Tech. Rep., April 2006.

[6] T. Ueno, R. Inada, O. Saeki, and K. Tsuji, “Effectiveness of an energy-consumption information system for residential buildings,” *Applied Energy*, vol. 83, no. 8, pp. 868 – 883, 2006.

[7] M. Weiss, “emeter: Stromverbrauchsfeedback auf basis eines pervasive energy monitoring systems,” in *Energieinformatik 2010*, 2010.

[8] T. Dietz, G. T. Gardner, J. Gilligan, P. C. Stern, and M. P. Vandenbergh, “Household actions can provide a behavioral wedge to rapidly reduce us carbon emissions,” *Proceedings of the National Academy of Sciences*, vol. 106, no. 44, pp. 18 452–18 456, November 2009.

[9] H. Staats, P. Harland, and H. A. M. Wilke, “Effecting durable change: A team approach to improve environmental behavior in the household,” *Environment Behavior*, vol. 36, no. 3, pp. 341–367, 2004.

[10] C. Grevet, J. Mankoff, and S. Anderson, “Design and evaluation of a social visualization aimed at encouraging sustainable behavior,” in *2010 43rd Hawaii International Conference on System Sciences*, January 2010.

[11] P. Petkov, F. Köbler, M. Foth, and H. Krcmar, “Motivating domestic energy conservation through comparative, community-based feedback in mobile and social media,” in *Proceedings of the 5th International Conference on Communities and Technologies*, ser. CT ’11. New York, NY, USA: ACM, 2011, pp. 21–30.

[12] L. Norford, S. Leeb, D. Luo, and S. Shaw, “Advanced electrical load monitoring: A wealth of information at low cost,” Massachusetts Institute of Technology, Tech. Rep., 1999.

[13] S. Patel, T. Robertson, J. Kientz, M. Reynolds, and G. Abowd, “At the flick of a switch: Detecting and classifying unique electrical events on the residential power line,” in *UbiComp 2007*. Springer Berlin / Heidelberg, 2007, pp. 271–288.

[14] H. Pihala, *Non-intrusive appliance load monitoring system based on a modern kWh-meter*. Espoo, Finland: Technical Research Centre of Finland (VTT), 1998.