Energy 90 (2015) 351–358

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Using in-home displays to provide smart meter feedback about household electricity consumption: A randomized control trial comparing kilowatts, cost, and social norms

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ARTICLE INFO

Article history:
Received 2 March 2015
Received in revised form
5 June 2015
Accepted 22 June 2015
Available online 1 September 2015

Keywords:
Smart meters
Feedback
In-home displays
Social norms
Message frame
Demand management

ABSTRACT

A randomized control field experiment is reported using in-home displays to reduce household electricity consumption. Custom-coded in-home displays (IHDs) were created to provide real-time household electricity consumption feedback, and were framed as either (a) simple kW consumption, or (b) kW consumption and the corresponding cost, or (c) kW consumption and a dynamically-derived social normative frame. Analyses focused on household electricity consumption in the first week following deployment, and again over a 3-month time span. Findings showed that households receiving simple feedback, and feedback framed as cost did not differ significantly from the randomized control at either the 1-week or the 3-month time points. Similarly, results showed that educational materials alone did not reduce electricity consumption. However, significant effects were found for households receiving the normative frame, which consumed 9% less than control households during the initial 1-week evaluation period, and 7% less during the full 3-month evaluation period. Yet despite these findings, residents reported more positive experiences and more obligations to conserve electricity with the cost and feedback IHDs. The results suggest that in-home displays offer promise for encouraging energy conservation, but careful consideration should be given to the way that the feedback is framed.

1. Introduction

Recent advances in metering infrastructure have afforded new opportunities for communications and feedback aimed at promoting energy efficiency. While high resolution metering has been available for many decades, it is only recently that this technology has been widely deployed. AMI (Advanced Metering Infrastructure)—commonly referred to as smart meters—monitor and record electricity consumption at a high-frequency resolution, most commonly in 1-hour intervals, but resolutions of 15-minute and even near-real-time are also possible. AMI technology is being widely deployed around the world, but surprisingly there are few peer-reviewed reports testing the impact of smart meter enabled feedback on residential electricity consumption. This paper reports a randomized control trial using in-home displays (IHDs) that provide smart meter enabled feedback in a near-real-time context. The experiment also compares the impact of feedback alone, with feedback framed as cost, or as a social norm comparison.

1.1. Background

As of 2012, there were an estimated 36 million smart meters deployed in the United States, with a projection of 65 million by the end of 2015 [1]. Worldwide, deployment of smart meters has grown sharply since 2010, and industry estimates suggest that in 2014 there were 100 million smart meters shipped, up from 87 million in 2013 [2]. Among the justifications for purchasing and deploying smart meters are reduced labor costs associated with automated

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http://dx.doi.org/10.1016/j.energy.2015.06.130
0360-5442/

billing, improved billing accuracy, increased energy efficiency, and increased customer engagement [2,3].

This paper focuses on the role of smart meters in promoting more efficient uses of electricity that ultimately reduces consumption. Smartgrid technologies allow for a range of communication opportunities that encourage consumers to modify their behavior, including enhanced demand response programs, time of use pricing, smart automation, and high resolution energy feedback [4]. Feedback in particular is often cited as a gateway to efficiency and reduced consumption, and real-time feedback is typically viewed as more influential than less granular forms of feedback such as monthly utility bills (even when the monthly bills are enhanced using AMI data; [5,6]).

1.2. Feedback

Research on feedback has clearly established that it can promote changes in behavior and assist an individual in achieving a goal [7,8]. With regard to residential electricity consumption, there is considerable evidence showing that feedback can play a role in reducing consumption [9–12]. However the effectiveness of feedback to reduce consumption varies widely across studies, and a number of researchers have concluded that feedback alone is generally not sufficient to induce conservation [13–15]. In fact, in some cases feedback can lead to boomerang effects, resulting in increased levels of consumption [16–18].

Given that feedback can result in a variety of outcomes, it is useful to examine the conditions under which it works best. Froehlich [19] offered a framework for designing effective feedback designs, which included:

- Higher frequency feedback systems to allow the individual to connect their actions with the consequences;
- Meaningful units;
- Highly granular with regard to time, space, source, or category;
- Always available, rather than only upon request.

In addition to these practical recommendations, feedback theory suggests that it is more effective at changing behavior when it is accompanied by a goal. In essence, feedback can help an individual to achieve a goal, but in the absence of a goal, feedback is unlikely to motivate a change in behavior [8,14]. Goals provide a motivation for action and can originate from the attitudes or values of the person, from a stated commitment, or a social obligation, among others. Two goals in particular have been studied in the context of energy efficiency: saving money, and social norm comparisons. With regard to saving money, many feedback strategies show consumption paired with the cost of the consumption. In fact, the energy efficiency area is replete with examples of cost message frames, but there is some evidence to question their effectiveness [20]. Note that the lack of evidence in this case pertains to the framing of the feedback regarding the behavior's cost, and not changing the cost itself. The latter—changing the cost—has a considerable amount of evidence showing the effects of price elasticity on electricity consumption [21,22].

In recent years, social norms have emerged as a promising alternative message frame. Here, feedback is presented in comparison to similar others, or nearby households, and consumption rates above the norm are identified as deviant, whereas consumption rates below the norm are praised. The basic approach emerged from behavioral science research [17], and has become an industry standard through large-scale applications such as OPOWER [23]. However to date, normative comparisons have been provided based on monthly consumption rates, and to our knowledge, no published papers have examined the potential for a normative feedback message frame in the context of smart meters.

The current study tested the impact of real-time feedback on residential electricity consumption. In recent years, there have been a large number of utility-based pilot programs to study the impact of IHDs, although only a few have used a randomized control design. Faruqui, Sergici, and Sharif [24] reviewed the findings from 12 utility-based pilot programs. Across the 12 pilots, IHDs were associated with reductions in consumption by 7%, but the effects were heterogeneous, and several moderating variables were identified. Most relevant to the current study is a pilot program by Canada's Hydro One. The pilot compared households that received an IHD with households that were switched to a time-of-use (TOU) pricing plan, households that received both, and households that received neither (control group). The results showed a reduction of 5.5% for households with the combined IHD and TOU pricing, but only 1.8% reduction for households with only the IHD.

In the current study, we focus on how the message frame impacts the effectiveness of feedback provided through IHDs. Feedback was provided to households using an IHD, and a custom coded interface. The devices were provided to a sample of utility customers for free, and households were randomly assigned to receive one of three message frames: kilowatts, cost, or norm comparison. Based on prior research, we hypothesized that the kilowatt feedback alone would not be sufficient to reduce consumption, relative to a randomized control group. Similarly, we hypothesized that the cost message frame would not produce less consumption, compared to a randomized control. Third, we hypothesized that households in the norm message frame would significantly reduce their consumption. We further hypothesized that the norm frame effect would be largest for high-consuming households. Finally, based on prior research [20], we hypothesized that participants would report liking the cost frame more than the kilowatt frame, and that they would report liking the norm frame less than the kilowatt frame. An additional set of analyses was conducted to test for moderating variables of the three message frames.

2. Method

This study was conducted in cooperation with a large local investor-owned utility in Southern California. Recruitment for the study was conducted in October 2012, the materials were deployed in June 2013, and household electricity consumption was monitored through the following October of 2013. Prior to the launch of the study, smart meters had been installed in all homes for approximately one year.

2.1. Participants

Participants in this study were residents of 431 single-family households. On average, each household had 3.43 residents with a length of residency in the home of 11 years. Regarding income, 80% reported earning more than $55,000 per year (the identified regional median). Politically, 34% of participants self-identified as Republican, 39% Democrat, and 27% other. The single-family homes ranged from 870 to 4400 square feet, with an average size of 2127 square feet. Households with electricity producing solar panels were excluded from this study due to variability in the energy used from the utility. During the two weeks prior to the intervention, the 431 households used an average of 23.83 kWh per day.