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Bridging the gap between sustainable technology adoption and protecting natural resources: Predicting intentions to adopt energy management technologies in California

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ABSTRACT

To achieve energy savings, emerging energy management technologies and programs require customer adoption. Although a variety of models can be used to explain the adoption of energy management technologies and programs, they overlook the seemingly unconventional element of level of affiliation with nature. In fact, connectedness to nature has been identified as an important driver of many pro-environmental behaviors, but its role in pro-environmental technology adoption is also not well understood. Can affiliation with nature help to bridge the apparent gap—and complex chain of events—between sustainable technology adoption and protecting natural resources? Based on survey data from 856 southern California residents, this study investigated the influence of connectedness to nature and other factors on intentions to adopt five energy management technologies and programs: using three platforms to monitor home energy use (website, mobile phone application, in-home display); signing up for a time-of-use pricing plan; and participating in demand response events. Regression results showed that nature connectedness was the strongest predictor of all outcomes such that higher nature connectedness predicted greater likelihood of technology and program adoption. These findings suggest that connectedness to nature may facilitate "bridging the logic gap" between sustainable innovation adoption and environmental protection.

1. Introduction

A great deal of energy research focuses on technology fixes, with a much smaller portion (i.e., 2.2%) dedicated to understanding end user behavior [57]. For instance, global investment in smart grid technologies was $14.9 billion in 2013 [19]. Among other hardware and software upgrades, electricity meters that collect near real-time consumption data ("smart meters") are key components of smart grid systems. In 2015, over 622 million smart meters were installed, a 15% increase from 2014 [27].

Despite their prevalence, smart meters alone will not save energy. However, they have expanded the variety of technologies and programs that utilities can offer directly to residential customers. Hence, to maximize energy savings, smart grid technologies require customer adoption and proper use [26]. Although utilities already use a variety of approaches to involve customers in power systems, as has been pointed out previously [55], customers are often not the central consideration in technology or program design. Resonating with a key lines of inquiry in the field of energy research and social sciences as highlighted in Sovacool [57], we argue that a better understanding of how people make decisions about energy use and energy technologies is urgently needed.

Focusing on end user decision-making, the present study investigates novel factors that influence decisions to adopt smart grid-enabled energy management technologies. Addressing additional key research themes, specifically, ways of leveraging energy technologies in new communication strategies and behavioral change approaches [57], findings can help practitioners to plan strategic rollouts of new programs using targeted marketing approaches, improve framing of energy feedback, and enhance adoption rates of such technologies and programs to maximize energy savings.

1.1. Smart grid-enabled energy management technologies and programs

Although in isolation, smart meters alone will not generate savings, smart grid infrastructure enables two-way data communi-

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cation between utilities and customers. This ability to interact with customers in real time offers one key route for engaging customers. Additionally, the savings that can be achieved via new voluntary pricing (e.g., time of use) and demand response programs depends in part on program enrollment, and hence customer adoption of such programs. Below we review select smart grid-enabled energy management approaches commonly offered by electric power utilities and factors relevant to their adoption.

1.1.1. Demand response programs

The United States (U.S.) Federal Energy Regulatory Commission (FERC) characterizes demand response as a "bottom-up process. . .driven by changes in customer behavior" [64]. Although demand response forecasting models predict when, where, and how much energy will be used, solving the key problem of managing peak demand requires programs that encourage electric customers to make behavioral changes. Such programs can be effective in promoting overall energy conservation, with home energy savings as high as 21% [15].

The most common type of demand response program is voluntary curtailment, which involves appealing to customers to temporarily curtail consumption by changing behavior in real time in response to alerts. However, program enrollment is a critical barrier to participation in both direct control and voluntary curtailment programs. Overcoming this barrier is not trivial. Current demand response program participation rates are estimated at less than 10%, and actual compliance rates are likely lower [64]. Achieving the load reduction objectives of the coming decades will require increasing levels of customer engagement. Toward this end, utility-customer connectivity must be enhanced. Identifying customers who are more willing to participate in these programs is a key step in tailoring marketing efforts.

1.1.2. Time-of-use pricing

Another method utilities can use to reduce peak demand is variable pricing plans. For instance, time-of-use pricing plans aim to discourage energy use during peak times of the day by charging higher rates during high-use periods (typically mid-afternoon hours) and lower rates during off-peak hours. Under time-of-use pricing programs, energy consumption tends to shift to off-peak hours, but the total consumption generally does not decrease [36]. Using financial (dis)incentives as a form of stimulus control, these programs attempt to shape customers' peak energy use, specifically by punishing (with higher prices) on-peak use and reinforcing (with lower prices) off-peak use [56]. A large body of research has shown that rewards can be effective in promoting behavior change, especially while incentives are in place, and rewards have been effective in reducing home energy consumption below baseline use levels [71,74] as well as below levels of information-only and control groups [44,74]. Currently, most time-of-use pricing plans in the U.S. are voluntary, and similar to demand response voluntary curtailment programs, adoption rates remain low. As indicated by a nationwide survey conducted among utility providers in 2010 [65], only about 1% of residential consumers have enrolled in time-of-use pricing rate programs.

1.1.3. Energy feedback

With the high-resolution data recorded by smart meters, utilities have advanced from providing energy feedback as part of monthly (or even annual) billing to providing near real-time data that can enhance relatability. Such energy feedback can be quite effective in changing residential energy use behavior. A wealth of research on residential electricity conservation interventions, including a meta-analysis of 156 field studies leveraging feedback and information [11], has shown that households can use 5–10% less direct energy without adversely impacting occupant comfort or well-being [12]. Considering that these direct energy savings do not reflect the obviation of upstream power losses at the power plant (∼60–70% loss) or transmission and distribution (up to 10% loss) levels, they are actually conservative estimates—meaning changing household behavior can result in even higher savings. In addition, as noted above, smart meters can offer high resolution (15-min interval) feedback, which better enables customers to connect their usage data to their behaviors, and to make more informed decisions about their actions. This also encourages conservation, and higher resolution feedback has been associated with greater levels of energy conservation [15].

Smart meter data can be made available to customers through a variety of platforms, including websites, mobile phones, and in-home displays. Ford and Karlin argued that the large variation of range of energy savings for different studies could partly be due to the difference in how the information is presented to customers [16]. Though each interface can generally display the same content, users may be more likely to adopt and use different interfaces for different reasons. Froehlich found that ambient displays, a type of in-home display, require less attention, but also provide less information compared to websites or mobile phone applications [17]. Varying preferences for different displays could stem customer preferences surrounding accessibility, mobility, or usability of the information provided. However, few studies have explored the relationship between the display preferences and customer characteristics. Such systems are costly to develop, market, and deploy, making it critical to understand customer preferences around these differences.

1.2. Theoretical underpinnings of smart grid technology adoption

In the following section, we discuss several key theories that inform sustainable technology adoption decisions. These include Diffusion of Innovations Theory, the Technology Acceptance Model, and Value-Belief-Norm Model.

1.2.1. Diffusion of Innovations Theory

Presently, smart grid technology is regarded as an early-stage innovation. According to the Diffusion of Innovations Theory [50], innovations are adopted in waves or stages throughout a given population. Under this theory, a given population consists of five categories of adopters differentiated on the basis of characteristics of the innovation itself, communication channels, time, and the given social system or context in which the innovation manifests. The five groups, in sequential order of adopters, are: innovator, early adopter, early majority, late majority, and laggard. The adopter distribution curve is assumed to be normally distributed.

What is interesting about smart grid technologies, particularly smart meters, is that while they are an "early stage" innovation, more than 50 million smart meters had been installed nationwide in the U.S. by the end of 2013, representing 37.6% of U.S. electricity customers [66]. According to Diffusion of Innovations Theory, the first 2.5% of a given population are innovators, the subsequent 13.5% are early adopters and the next 34% are the early majority. However, smart meters have been rapidly deployed in part because of the availability of American Recovery and Reinvestment Act funds for such smart grid projects. The true "voluntary" adopters, or people with intention to actually use these innovations, may be significantly fewer than one third of the U.S. population, effectively converting those who may be more appropriately categorized as late majority or laggard into "involuntary" early adopters. Actual early adopters differ from later adopters in how they perceive new technologies. For instance, in a survey-based study of factors impacting the intention to adopt electric cars among 2974 Dutch participants conducted in June 2012, results showed that earlier adopters evaluated the symbolic attributes of an electric car