Diffusion of Feedback: Perceptions and Adoption of Devices in the Residential Market

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Abstract. Providing households with energy feedback is widely promoted as a conservation strategy and its effectiveness has been established in field studies. However, such studies actively recruit participants and little is known about naturalistic consumers. Despite hundreds of products emerging, few have taken hold in the market. Diffusion of innovation is a theory of technology adoption that details both the general process by which innovation spreads as well as the individual process of technology adoption. The current study analyses survey data from 836 individuals through a diffusion framework to assess the current and potential market of energy feedback. Questions related to knowledge and perceptions of feedback reveal important insights about customer acceptance and statistical comparison of adopters and non-adopters identify key characteristics related to adoption. Implications for the design and marketing of feedback technologies are discussed.

Keywords: Sustainability · Feedback · Energy · Usability user experience

1 Introduction

Residential energy feedback has been highlighted as a promising strategy to promote energy conservation. Over 100 empirical studies testing feedback have been conducted over the past 40 years, with reviews finding average energy savings of 8-12 % [4–6, 17]. Effectiveness has been found to vary based on both on the way feedback is provided as well as to whom it is provided [11], yet there has been little investigation

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into the ideal consumer of residential energy feedback or differences in the adoption, experience, and outcomes of different types of feedback.

Stern [27] observes that the impact of any climate-related action can be expressed by the equation $1 = tpn$, where I is total impact (carbon reduction); t is technical potential (reduction per single action); p is the plasticity of the action (proportion of individuals that can be induced to act); and n is the total number of individuals in the population. Research has been building a case for the technical potential of feedback, but largely neglecting the issue of its behavioral plasticity.

This paper examines the plasticity of residential energy feedback using a diffusion of innovation framework. We will introduce the framework, along with relevant literature on each step of the innovation-decision process and present findings from an online survey of active feedback adopters. Finally, implications of this research for the design and marketing of residential energy feedback will be discussed.

2 Literature Review: The Innovation-Decision Process

Diffusion of innovation is a theory of technology adoption that details the general process by which an innovation spreads and the personal process by which an individual learns about, assesses, and adopts or rejects an innovation, called the innovation-diffusion process [24]. An innovation is an idea, practice, or object perceived as new by an individual or community. It matters little if the innovation is "objectively"; the perceived newness determines its innovativeness. Groups of items or products can also be considered an innovation. A *technology cluster* consists of one or more distinguishable elements of technology that are perceived as being closely interrelated (e.g., residential energy feedback).

The innovation-decision process describes how an individual (or other decision-making unit) passes from first knowledge of an innovation (knowledge stage) to forming an attitude toward the innovation (persuasion stage), to a decision to adopt or reject (adoption stage), to use of the innovation (implementation stage), and finally to continue or discontinue use (confirmation stage). Individual characteristics and communications channels influence each of these five stages. Individual characteristics include personal and household demographics and general attitudes and values. Communication channels are interpersonal or mass media sources by which consumers learn about, receive evaluative messages about, or acquire the technology. Diffusion of Innovation has been discussed with regard to energy conservation [26], yet has not been systematically evaluated. This section will review literature related to the stages of the innovation-decision process for energy feedback.

2.1 Knowledge

Lack of consumer awareness and knowledge is cited as a barrier to feedback adoption [29]. However, there is little empirical research on knowledge and awareness of feedback among consumers, let alone systematically investigates this barrier. A recent market-scoping study found that just 10 % of individuals are very familiar with smart home products and 62 % are not familiar at all [19].

2.2 Persuasion

Since most energy efficiency studies actively recruit participants to receive feedback, little is know about active adopters (i.e., individuals who have actively and independently adopted feedback) and their attitudes toward feedback products. Liikenan [14] identified three types of motivation for adopting a load monitor: (1) determining the "truth" about home energy use; (2) identifying energy-intensive appliances; and (3) acquiring information on a single new or suspicious appliance. Other studies that inquired about motivations for using feedback among recruited participants found environmental concern ranked second to financial savings [9, 20].

2.3 Decision

The speed with which an innovation is adopted is called the rate of adoption. Rogers [24] specifies five categories of adopters: (1) innovators, (2) early adopters, (3) early majority, (4) late majority, and (5) laggards. Few studies have characterized these categories in terms of individual characteristics. Research suggests that the feedback adopters are largely male and belong to a two-adult household; education and age varied widely [9, 14]. Positive attitudes toward energy conservation [13] and past conservation behavior [2] have been found to predict feedback use among recruited study participants, but another study found no significant differences between study participants and a control group in terms of energy conservation awareness, commitment, or behavior [28]. No study to-date has systematically investigated trends in where feedback products are acquired (communication channels) or which products are adopted and many of these studies involve products that are not even commercially available.

2.4 Implementation

Problems with usability have been reported, mostly pertaining to the display of information. Mail/email feedback was reported to be unclear and not useful [23], in-home display users reported difficulty reading and interpreting numerical information and graphs provided [1, 9], and users of load monitors reported accessibility issues with certain appliances (e.g., refrigerator) whose size would block information displayed by the device [14]. Additional comments mentioned difficulties with installation, general loss of interest, and a lack of desire to change behavior [22].

2.5 Confirmation

User satisfaction has been high across feedback types. Participants report that feedback improves both their knowledge about and behavior towards energy conservation. Knowledge gains include a general increase in awareness of energy use patterns [1, 8]; learning that their energy use was either more [16] or less [9] than expected; and specific knowledge about how to reduce energy use [11, 18].

2.6 Limitations of Feedback Adoption Research

Almost all studies to-date have recruited participants to use feedback. Since widespread use requires market adoption, analysis of active adopters is vital to understanding the diffusion of this technology cluster. While over 200 feedback products are commercially available [10], less than a dozen have been tested in published studies and few have compared different product types, leaving gaps in our understanding of actual use in the market. Critical data, such as how and where users have learned about and acquired feedback, cannot be collected in experiments.

The literature review sheds light on several aspects of energy feedback diffusion, but not comprehensively or systematically linked to the innovation-decision process in a way that can broadly advance our understanding of how feedback technology is adopted in the wider marketplace. The current study, which reports results of a survey of naturalistic adopters and non-adopters of feedback, investigates multiple aspects of the adoption process in a diffusion of innovation framework.

3 Method

Data were gathered through an online survey of 838 individuals in 2010. The survey took approximately 15 min to complete and respondents were entered into a raffle for a $50 gift certificate to Amazon.com. A purposive sample of potential feedback users was recruited online via email, Facebook, and listservs. About half (53 %) found out about the survey through a personal email and the rest were recruited via listserv, website, or newsletter. Respondents were identified as *adopters* if:

1. The individual responded that s/he every used feedback
2. At least one open-ended question concerning feedback was answered.
3. The reported product was used in the home.[1]

Among the 836 survey respondents, 86 respondents met our inclusion criteria. The remainder of the sample constitutes the comparison group, *non-adopters.*

3.1 Measures

Data were collected as part of a residential energy survey, which was designed to address energy conservation behavior and its predictors and use of residential energy feedback devices. The current paper presents results from analyses of the last part of the survey (i.e., use of residential energy feedback devices) as well as demographic and psychological data. The variables examined in this study are described below:

- **Feedback Awareness and Perceptions.** Participants were presented with a definition of feedback and asked if they were aware of feedback in general and/or any specific products and their general impressions of feedback. Fixed option items inquired after reasons for not adopting feedback (e.g., *too expensive; did not know*

[1] If the product was unrecognizable or unspecified, subsequent responses related to energy use.

they existed) and communication channels that might influence their likelihood of feedback (e.g., *available at my local drugstore or supermarket*; *provided by my utility company*).

- **Feedback Adopters.** Participants were asked whether they had used a feedback device. If they said yes, they were asked a series of open-ended questions about the product and their experiences with it. These questions were designed to inquire about the product(s) used and address three general topics of interest: adoption (how, where, and why they obtained feedback), usability (likes and dislikes about the use of feedback), and outcomes (changes in knowledge and/or behavior due to use of feedback). If the respondent had used more than one feedback product, s/he was asked to answer these questions separately for each product.
- **Individual Characteristics.** Demographic, housing, and psychological variables were included in the survey to characterize the general sample and to compare adopters with non-adopters. Demographic items included gender, age, race, marital status, political affiliation, education, and income. Housing characteristics included housing type (detached house vs. apartment/other) and homeownership (own vs. rent). Psychological variables included: (1) a three-item environmental concern scale; a single item to assess bill consciousness; a two-item social norm scale; and three sets of two-item scales to assess motivational factors (environmental, financial, and social motivation) related to energy conservation.

4 Results

Data were analyzed using a mixed-methods approach. Individual characteristics of adopters ($n = 86$) and non-adopters ($n = 749$) were compared quantitatively via independent t-tests. Descriptive statistics and qualitative analysis (open coding followed by axial coding and derivation of common themes) were used to analyze responses related to innovation-decision stages and communication channels.

4.1 Knowledge Stage

Looking at responses about respondents' awareness of energy feedback products, they were about equally split between being completely unaware that feedback existed (37 %), being generally aware of the existence of feedback, but not aware of a specific feedback (35 %), and being aware of at least one specific product (27 %). Of those who were aware of one or more specific feedback products, 38 % had actively adopted or uses one, constituting approximately 10 % of the overall sample. We remind the reader that this sample is likely over-representative of feedback awareness and adopters due to our sampling strategy (see above).

When asked where they "found out" about each product, 24 feedback adopters indicated social means, including friends and family (17) and environmental groups (4); 21 indicated utilities; and 15 indicated a work/professional context. Additional sources of exposure included online, retail stores, magazine and newspaper articles, and

displays at energy fairs/events. Environmental, or "green" sources were reported across exposure categories; these included environmental groups (5), renewable energy events (e.g., conference, fair) (3), energy audit (3), and "green" stores (2).

4.2 Persuasion Stage

When asked about general impressions of energy feedback, 42 % reported positive impressions (e.g., *wonderful idea*). 48 % responses were coded as ambivalent (e.g., *assume they make sense since utilities are promoting them*), and 10 % reported negative impressions (e.g., *doesn't seem necessary*). Many participants responded with conditional statements, stating that feedback may not be valuable *unless it is* cheap, easy to use, effective, available everywhere, etc. Non-adopters were prompted about reasons for not adopting and factors that might influence adoption. The top three reasons for not adopting were related to knowledge; additional responses included those related to time or not seeing personal benefits (Table 1). When asked about factors likely to influence adoption, the most frequent response was "available at my local drugstore or supermarket", followed by "provided by my utility company" and "somebody to help me install/use the device".

Feedback adopters were questioned further regarding their reasons for adopting. The most common reasons pertained to desire for knowledge about energy use. Analyses revealed a distinction between *tracking* and *learning*. Those motivated by *tracking* reported an interest in ongoing information about home energy use (*track energy use and compare over time more easily*). Those motivated by learning reported an interest in acquiring discrete, static facts about energy use (*trouble shoot inefficient devices*; *see what energy use was on a plug load*). Other reported motivations included curiosity (15), work-related reasons (9), saving energy (5), saving money (4), and because the product was free or on sale (6). None of the responses noted environmental motivations.

Table 1. Reasons for not adopting residential energy feedback

Reason	Percentage
Did not know that they existed	44 %
Did not know where to buy them	27 %
Did not know how to install/set up	18 %
Already conserving energy	16 %
Never got around to it	15 %
Too expensive	11 %
No time to install/set up	9 %
No benefit in using	5 %
Conserving energy is not a priority	2 %

4.3 Decision Stage

Type of Feedback Used. The 86 respondents reported using a total of 99 feedback products (12 reported using more than one product). They are categorized by the feedback types introduced in Karlin, Ford, & Squiers [10], as follows.

The most frequently reported type of feedback (55) were *load monitors*. Specific products reported include *Kill-A-Watt (42)*, *Watts Up (4),* and *Square D PowerLogic (1).* Five did not specify a product and three indicated *self-monitoring* their meter. Fifteen people reported using *in-home displays*. Specific devices reported include *The Energy Detective (TED, 9)*, *PowerCost Monitor (2), Home Energy Cost Monitor (1), Wattson (1)*, *ampere meter* (1) and a computer display of his wind turbine. Twelve people reported receiving feedback via an *information platform*. Specific reported products include *utility website (*6), *utility bill* (3), *Google PowerMeter* (1) and estimated feedback [4, 17] via a *online carbon footprint calculator* and a *Wattbott*. Two people reported using *energy-management networks*. Specific devices reported include *Plugwise (1)* and *Green Switch (1)*.

An additional category for *HVAC* was included in this analysis. Although they do not meet the definition of *energy* feedback, respondents reported them as feedback and referred to information provided on other home parameters (e.g., temperature) in their responses. Since we are interested in subjective user experience, they were included in the sample. Specific products reported include *automated thermostats* (5), *thermal sensors* (4), *Hobo Data Loggers* (3), and *home thermometers (1)*. Specific type of feedback used was unidentifiable for two respondents. One reported being unsure of the device was and the other indicated using a prototype.

Individual Characteristics. Independent sample t-tests revealed several differences between feedback adopters and non-adopters. Table 2 presents descriptive statistics for demographic variables. Feedback adopters were significantly more likely than non-users to be male ($t = 4.14$, $p < .001$), married ($t = 2.52$, $p = .013$), and homeowners ($t = 5.73$, $p < .001$). Feedback adopters were also significantly older ($t = 3.34$, $p = .001$), more liberal ($t = 2.36$, $p = .019$), higher-income ($t = 2.64$, $p < .01$), and more educated ($t = 1.96$, $p = .05$) than non-users. The only demographic variable that was not associated with feedback adoption was race ($t = 1.38$, $p = .170$).

Feedback adopters were significantly higher than non-adopters on environmental concern ($t = 3.74$, $p < .001$) and bill consciousness ($t = 2.09$, $p = .020$). Adopters were *less* motivated by financial considerations ($t = 3.40$ $p = .001$) and more motivated by environmental considerations ($t = 3.36$ $p = .001$). No significant differences were found for social norms ($t = 1.36$ $p = 176$) or social motivation ($t = 1.05$ $p = .295$).

Communications Channels. The most prevalent source of feedback acquisition was the Internet (29 %), followed by friend or family (14 %) and utility (14 %), then store (13 %), other (12 %), and manufacturer (11 %); 7 % did not recall. A recurring theme of borrowing devices emerged across acquisition categories. Two thirds of products obtained via social means (10) were borrowed. Respondents also reported borrowing devices from utility companies (2), the library (1), and the workplace (1). The most commonly borrowed products were less expensive real-time plus devices (e.g. Kill A Watt, which currently costs about $20) (Table 3).

Table 2. Demographic/housing characteristics of adopters and non-adopters

	Adopters	Non-adopters
Gender***	46 % female 54 % male	70 % female 30 % male
Age**	45.5 years	39.9 years
Race	80 % Caucasian	82 % Caucasian
	1 % Hispanic	7 % Hispanic
	8 % Asian	6 % Asian
	1 % African-American	2 % African-American
	10 % Other/Decline	3 % Other/Decline
Marital status*	65 % married	51 % married
	35 % not married	49 % not married
Political affiliation[a]*	3.96	3.67
Education	18.0 years	17.4 years
Income*	$106,000	$88,000
Homeownership**	83 % own	57 % own
	17 % rent	43 % rent

*$p < .05$. **$p < .01$. ***$p < .001$.
[a] Scale ranged from 1 = Extremely Conservative to 5 = Extremely Liberal.

Table 3. Psychological characteristics of adopters and non-adopters

	Adopters		Non-adopters	
Psychological Variables	*M*	*SD*	*M*	*SD*
Environmental				
Environmental concern[a]*	4.40	0.51	4.18	0.67
Environmental motivation[b]	3.18	1.03	2.80	0.98
Financial				
Bill consciousness[c]*	0.70	0.46	0.59	0.49
Financial motivation[b]	2.67	1.01	3.07	1.03
Social				
Social norms[a]	3.04	0.80	2.92	0.77
Social motivation	1.95	1.05	1.83	1.01

*$p < .05$. **$p < .01$. ***$p < .001$.
[a] Scale ranged from 1 = Strongly Disagree to 5 = Strongly Agree.
[b] Scale ranged from 0 = Not at All to 4 = A Great Deal.
[c] Binary variable normalized to a maximum of 1.

4.4 Implementation Stage

Respondents reported overall positive experiences across feedback. 65 mentioned that they were happy or satisfied with the product; when asked what they *disliked* about the product, 15 said "nothing" and others emphasized ease of use (34) and the quality

of information presented about energy use (29): "*Educational to my husband and other people that are not as interested in conserving energy*" (TED), "*ease of use and quick comparison information*" (load monitor). A few noted having fun using feedback: "*it was fun to see graphical info*" (Data Logger), "*very cool to see the number change when using appliances*" (TED). Additional features praised across products included multi-functionality, comparative feedback, and interactivity.

Negative responses mentioned both hardware (e.g., installation, accessibility) and software (information displayed) issues. Five responses mentioned difficulties with installation: "*totally difficult/hazardous*", "*much more difficult to install than I thought*" (*TED*). Eight responses discussed the physical design of the product, primarily with regard to plugging in load monitors: *"have to get behind large appliances to plug it in" (Kill A Watt).* Adopters of both whole-home and appliance-specific feedback reported feeling as though they received an "incomplete picture" of energy use. Whole-home feedback adopters reported a desire for isolating end uses (e.g., *would be more effective if it could tell you specifically which appliance was using the most*). Adopters of appliance-specific feedback expressed a desire for whole-home information (e.g., *hard to implement for long term or whole house*).

4.5 Confirmation Stage

When asked about continued use, over half (54) responded that they still use feedback. Reasons provided included continued usefulness (5), saving energy (4), saving money (3), and because it is hard to remove (1): "*I like to check myself and make sure I'm on track*", "*still useful, especially for measuring long-term usage on an appliance*", "*it's become a habit.*" Nine responded that they still use feedback, but to a lesser degree: "*only once in a while if I'm chasing down a draft*" (Kill A Watt).

These statements suggest a potential diminished utility of feedback as they are used over time, which was reinforced by the nearly half (46) who reported that they no longer use feedback. When asked why, 25 indicated that they are no longer in possession of the product because they borrowed it, it was removed by the company, or they moved away. Four mentioned that they no longer used feedback because they had all the information they needed: *"it's served its purpose."*

5 Discussion

This study extends previous energy feedback research by analyzing the characteristics and user experience of active adopters (and non-adopters). Both quantitative and qualitative analyses reveal patterns that can be integrated into future design, marketing, and research of residential energy feedback, as follows.

Market Segmentation. The present study revealed demographic characteristics related to the adoption of feedback products including gender, age, marital status, income and homeownership, supporting previous findings that men tend to engage more with feedback technologies [9] as well as research on demographic variables related to general energy conservation behavior [7, 18, 25]. These findings suggest

market segmentation strategies should be useful in promoting residential energy conservation. Further research into the perceived barriers and benefits of energy feedback for different demographics would further inform marketing strategies.

Results also indicate difference based on motivation and attitudes. Findings support previous research that feedback adopters have high pro-environmental attitudes [13]. Adopters reported lower financial motivation than non-adopters, countering past research that found that significant financial motivation among feedback users [9, 14, 19]. However, they did not compare adopters to non-adopters. The implications of these findings are unclear; they may suggest that messages concerning financial benefits of feedback are less effective among early adopters or, conversely, greater use of financial messaging may expand the market. Further research is needed to elucidate the motivations of early adopters and non-adopters.

Feedback Acquisition. Respondents were more likely to learn about feedback though social networks and utilities than mass-media sources. It is not clear if social networks afford more effective dissemination strategies or if media sources contain little coverage of feedback (or a combination thereof). Social contacts and utilities were also significant sources of acquisition of feedback, along with both online and brick and mortal retail. Findings support social-network and utility-based marketing programs as influential dissemination venues, but also suggest the importance of developing additional diffusion strategies.

The prevalence of borrowing suggests another promising avenue for dissemination of feedback devices. Current borrowing programs are primarily through utility companies and local libraries. The findings that many feedback users report diminishing returns over time and that over half no longer use their feedback products further supports continued investigation into temporary lending programs.

Importance of Product Testing. Users reported positive experiences overall, but several usability issues were noted, including difficulty with installation, low voltage detection, and difficulty reading and interpreting displays. If a product does not undergo thorough reliability testing, early adopters will have inferior experiences and dissemination will be inhibited. This is an important concern as energy-feedback technologies are not yet widely known by the public and, therefore, product usability issues could severely diminish the likelihood of adoption by a wider population if feedback technologies acquire negative connotations early on.

Rebound Effects. Some users reported adjusting consumption upwards upon discovering they used less energy than anticipated, reflecting past research that suggests a rebound effect for gains in energy efficiency of products [3]. This is an important reminder of the need for feedback designers to acknowledge unintended consequences and also extends the potential rebound effect to not just efficiency gains, but also information sources. Further research into message-framing and motivational aspects of feedback is needed to understand ways to counter rebound effects.

6 Conclusions

This study has both practical and theoretical applications, as understanding the market for energy feedback can increase energy conservation and also contribute to our understanding of the diffusion of new technologies across sectors. By focusing on active adopters of energy feedback and collecting both quantitative and qualitative data about the user and their experiences, this study was able to address previously neglected questions about how to best to design and market feedback technologies to the public. In doing so, we found that males, homeowners, and individuals with high environmental concern were among those most likely to purchase and use feedback, which is consistent with research on other energy-conservation behaviors. Users indicated generally positive impressions of feedback devices, and their experiences revealed great promise for novel approaches to the design and marketing of feedback, including the provision of both aggregate and disaggregate energy-use information and dissemination through utility and social-network channels. Design and usability issues identified in this study indicate that this technology, despite great potential, still has some hurdles to overcome before being marketed to the general American public. Further research testing use across devices, distinguishing among non-adopters (e.g., unaware of feedback, aware but not knowledgeable, knowledgeable but have not adopted) to ascertain a more differentiated understanding of the innovation-decision process, and isolating key features of feedback will greatly enhance our understanding of its use and potential for energy conservation.

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