DECISION-MAKING AND BEHAVIOR CHANGE IN RESIDENTIAL ADOPTERS OF SOLAR PV*

Varun Rai
LBJ School of Public Affairs
The University of Texas at Austin
Austin, TX 78712
e-mail: raivarun@gmail.com

Kristine McAndrews
W&T Offshore
Nine Greenway Plaza, Suite 300
Houston, TX 77046

* Working Paper Draft, 8 July 2012. Originally prepared for the World Renewable Energy Forum, Denver, Colorado, May 13-17, 2012.

ABSTRACT

We report results from a survey of residential owners of solar photovoltaic (PV) systems. Conducted during August-November 2011 in Texas, this first-of-a-kind survey seeks to understand the experience of PV adopters in selecting and installing a PV system. Specifically, we report descriptive findings on (i) aggregate socio-demographics of PV adopters in Texas, (ii) the decision-making process of adopters leading to PV installation, and (iii) the impact of PV adoption on the adopters' awareness of their electricity use, on their (perceptions of) changes in their electricity-usage pattern, and on their outlook towards the environment.

KEYWORDS: Residential solar PV, Diffusion of innovations, Energy use behavior change

1. INTRODUCTION

Largely due to a combination of attractive federal, state, and local financial incentives, over the last few years the adoption of solar photovoltaic (PV) technologies has dramatically accelerated in the residential sector in several states in the U.S., particularly in California, New Jersey, Colorado, and Texas. Yet, current adoption levels in this sector are below 2% of the market potential (Paidipati *et al.*, 2008).

Although the institutional context, including electricity rates, tax incentives and local rebates, greatly affects market development, social and communication networks are also key determinants in the decision-making of individuals who make up the technological system (Rogers, 2003). Perceived *uncertainties and non-monetary costs* (UNMCs) are key to understanding why social and communication networks are so important for the diffusion of technologies. In the context of PV, for example, the "value of PV" is a characteristic of the individual adopter and includes not only the monetary cost of the technology, which includes both equipment and installation costs, but also non-monetary costs, such as information search costs and uncertainty about the future performance, operations and maintenance requirements, and perceptions of quality, sacrifice, and opportunity cost (Zeimthaml, 1988; Faiers & Neame, 2006).

According to the diffusion of innovations framework (Rogers, 2003), to reduce their UNMCs people rely on the personal evaluation of the technology by those who have already adopted. As more people become adopters the observed performance of the technology spreads through the networks at a faster pace and further reduces the uncertainties associated with adopting the technology. In the same vein, it is important to understand whether the information gathered and expectations formed about a technology by adopters during the pre-adoption period holds true through the post-adoption period. If the post-adoption experience does not meet pre-adoption expectations— call it "post-adoption disconfirmation"— then there may be negative feedback in the market regarding the benefits of the technology, which could impact the rate of adoption by the next tranche of adopters.

Despite the clear importance (Margolis and Zuboy, 2006; Rai, 2011), there is little rigorous data and analysis of households' decision-making process, associated information channels, and post-installation consumer experience in the residential solar PV market. With that vacuum in mind, this paper reports some key descriptive findings of a survey-based research design to study the residential PV market. The data for the findings reported here were collected in Central and Northern Texas (in and around Austin and Dallas) during August-November 2011.

2. RESEARCH DESIGN

2.1 Research Questions

We are primarily interested in three broad-ranging questions. First, we are interested in the socio-demographics and the decision-making process of PV adopters. Specifically: what are the main motivations for people to adopt PV technologies? How do socio-demographic factors correlate with adoption of PV? What financial metrics (such as payback period or rate of return) do PV adopters use to assess the financial merits of PV-based electricity generation?

Second, we are interested in studying the information channels that PV adopters utilize to reduce the UNMCs associated with PV adoption. Specifically: what uncertainties and barriers do potential adopters face? What information sources (other PV owners, websites, etc.) do consumers use to inform their decision to install PV? How effective are these different information channels?

Third, we seek to understand the post-installation experience in comparison to pre-installation expectations from PV, including the operation and maintenance experience, customer satisfaction, and adopters' evaluation of financial benefits. Further, we also seek to study the impact that installation of PV systems have on adopters' energy usage and awareness and on their outlook towards the environment.

In Section 3 we report some key findings for the first ("decision-making process") and the third ("post-installation experience") of the above questions. Separate journal manuscripts are in preparation with more detailed presentation, analysis, and discussion of the findings of this research.

2.2 Data And Methodology

The research design hinges on a new household-level dataset we have built through a survey of households who have already adopted PV. By design, this dataset directly parallels the research questions outlined above. The survey seeks to understand the experience in selecting and installing a solar PV system by those who have installed PV at their homes. Only households that have already adopted PV are part of this survey. The survey consists of 60 questions, which are organized in the following seven sections: (i) system details (ii) decision-making process (iii) financial aspects (iv) sources of information (v) expectations/evaluation (vi) environmental attitude (vii) demographics.

The survey was administered electronically (online) in Texas during August-November 2011. The total number of complete responses received was 365, or 40% of the 922 PV owners contacted. In addition to complete responses, there were another 41 partial responses. Although we do not have the exact figures, we estimate from solar program data that our sample of received complete responses (365) represents about 20% of the entire target population (residential PV adopters) in the areas where we conducted the survey.

3. RESULTS AND DISCUSSION

3.1 Descriptive System Details And Demographics

The mean size of the PV systems installed by the respondents is 5.85 kW DC with a standard deviation of 2.68 kW DC. The installation period for the sample population ranges between 2003 and 2011, with 85% of the installations in 2009 or after. The increase in the number of installations starting in 2009 is largely due to the startup of solar rebate programs in service territories of several Texas electric utilities.

The median household income in 2011 of all respondents is between $85,000 and $115,000. The median household income in 2009 in Texas was $48,286 (Census, 2011), which is much lower than the average PV installing household. The median home value in 2011 for all respondents is $260,000 (the mean home value of the sample is $409,100 with a standard deviation of $469,302). The mean home area is 2,740 sq ft with a standard deviation of 1,140 sq ft.

Over 80% of PV adopters in our sample have a bachelor's degree or higher. The 2010 Census reports that only 25.4% of Texas residents hold a bachelor's degree or a higher level of education. The mean age of all respondents is 52 years, with a standard deviation of 11.4 years.

3.2 Decision-Making Process

3.2.1 Motivations To Install Solar

When asked how important five factors were in the decision to install PV, respondents considered three of the five equally important (Table 1). "General interest in energy and electricity generation", "Evaluation that solar PV is a good financial investment", and "Reducing the impact on the environment by using a renewable energy source" each had a mean response corresponding to "Very Important". Responses to an open-ended question on the motivations to install PV reveal that responders consider energy security and energy independence as part of the "general interest in energy." On the other hand, "Influence of others in the neighborhood with PV systems" and "Influence of a close acquaintance not from your neighborhood" were not considered important factors in the decision to install PV. This is mainly because the spatial distribution of these systems is sparse—these are largely "innovative" adopters. The picture is significantly different when we look at installations in only 2011, for which over 50% of the respondents report at least "moderate influence" of existing PV owners in their decision to install. This is a direct evidence of peer effects, which other authors have also reported recently (for example, see Bollinger and Gillingham, 2011), and the scale of which appears to be growing as the installed base increases.

TABLE 1: FACTORS IN THE DECISION TO INSTALL PV

Importance of Factor in Decision to Install PV	Mean Response	Standard Deviation	Number of Responses
General interest in energy and electricity generation	3.94	1.08	391
Evaluation that solar PV is a good financial investment	3.94	1.1	390
Reducing impact on the environment by using a renewable energy source	3.94	1.24	389
Influence of other in the neighborhood with PV systems	1.53	0.97	389
Influence of a close acquaintance not from neighborhood	1.45	0.99	388

Response options: Not important at all = 1, Somewhat important = 2, Moderately important = 3, Very important = 4, Extremely important = 5

3.2.2 Information Search Process: Time And Effort Spent

When asked to characterize the experience when trying to find dependable information while researching PV, the mean response is 2.52, between "easy" and "neither easy nor difficult", with a standard deviation of 0.95. Further, the respondents were asked regarding the state of their understanding of various aspects of the PV system after the information search was complete (that is around the time when they signed the contract to install the PV system). On average, the sample reported a good understanding of what to expect on nearly all aspects of PV—performance expectations, operations and maintenance requirements, and warranty. The statement, "I thought that the installation of PV systems was simple," has a mean response of 2.5 which lies between "agree" and "neither agree nor disagree", so respondents showed the most concern, although not very much concern overall, with the installation of PV. Overall, most respondents seemed to have had little uncertainty or concern about PV at the time of installation.

Respondents were asked to characterize the amount of time spent researching PV before deciding to install. The mean response to this question is 3.38 (standard deviation of 0.96), which lies between a "moderate" and a "large" amount of time. Respondents were also asked to rate how much time they spent learning about certain aspects during the process of deciding to install PV, such as changes necessary to the house, impact on home value to potential buyers, financial aspects, warranty, operation, maintenance, and performance. An answer of 1 corresponds to "negligible" and a response of 5 is a "very large" amount of time. Respondents spent the most time learning about "financial aspects of PV" with a mean response equal to 3.8 or close to a "large" amount of time, followed by the "performance of the system" with a mean equal to 3.6. Overall, the respondents felt they spent significant amount of time in the information search process, and most of that time was spent understanding the finances and performance of PV systems.

The respondents were asked to report the amount of time that passed between when they began to seriously consider PV and the date when they signed the contract to install a PV system. The mean response is 8.9 months with a standard deviation of 11.7 months. The long-tailed distribution is the result of some PV adopters who spent a disproportionately large amount of time during the decision period. This holds true across years. The median response is fairly constant at 6 months across all years.

3.2.3 Financial Aspects

An overwhelming majority, 87%, of the responding PV owners, used payback period to calculate the financial attractiveness of a PV system (Table 2). Internal rate of return (IRR) was the next most frequently used tool (36%) to calculate the financial attractiveness of a system. Some respondents used more than one method to calculate this attribute. 40% of respondents report not receiving or seeking any outside help with these calculations. Those who did receive help most frequently cited help by the PV contractor/installer (45%). Only 7% reported using online calculators for estimating the finances (Table 3). This is surprising given that there is no dearth of such online calculators. Answers to open-ended questions suggest that lack of trustworthiness might be a factor in why online calculators are not used more often. The calculation results varied widely. Reported payback period ranged from 1.5 to 35 years with the majority reporting a range between 7 and 10 years. Net present value (NPV) results ranged from $0 to $41,000, however only about 12% respondents used the

NPV method to value their PV system. The IRRs reported ranged from 2.57% to 34.5%. These variations in the financial evaluation by the respondents are not easy to explain. It is not apparent that the results of these calculations are accurate, especially in view that a majority (40%) of respondents report *only* self-calculating the finances, which are inherently very complicated.

TABLE 2: USE OF FINANCIAL METRICS

All Responders		
	Number	**Percent**
NPV	37	11.8%
IRR	113	36.0%
Payback Period	274	**87.3%**
None	23	7.3%
Number of Responders	314	

TABLE 3: HELP WITH FINANCIAL CALCULATIONS

	All Responders	
	Number	**Percent**
Neighbor	10	2.7%
Family	10	2.7%
Contractor	164	**44.7%**
Online	26	7.1%
Utility	17	4.6%
Non-profit	7	1.9%
Myself	212	**57.8%**
No Calculations	27	7.4%
Number of Responders	367	

As per their estimates of the financial evaluation of installing PV, 69% of respondents found the systems financially attractive or very attractive, while only 15% viewed the investment as financially unattractive or very unattractive. Those who calculated low IRRs or long payback periods chose to adopt because they were more strongly motivated by an interest in energy and/or their concern for the environment. In answer to an open-ended question about the financial attractiveness of PV, many respondents stated that the cost of electricity has increased and will continue to increase making PV a better investment with time.

Interestingly, 51 respondents (13% of total) reported that they took out a loan to pay for a PV system. In response to an open-ended question asking respondents why they did or did not take out a loan, most stated that they had the funds available and had wanted to see the best return possible, so they did not take out a loan.

3.4 Post-Installation Experience And Behavior Change

3.4.1 Post-Installation Experience

In a series of questions, respondents were asked to rate the performance, operation, maintenance, and financial attractiveness of their systems post-installation, where 1 is "a great deal better than expected", 3 is "same as before", and 5 is "a great deal worse than expected". The mean results are similar for each question at 2.6, 2.4, and 2.6, respectively. That is, most respondents feel that these attributes of their PV systems are delivering "as expected" or "better than expected" results. Overall, respondents report very strong satisfaction with PV ownership and nearly all consider that their decision to install PV was a wise one.

3.4.2 Perceptions Of Awareness And Behavior Change

As seen above, the decision to install a PV system is a resource-intensive process—it requires significant amount of both time and effort as well capital. Given this relatively intense decision-making process as compared to most other household decisions, one of the side effects of solar might be its impact on the awareness, attitude, and behavior of PV adopters as regards electricity use.

It might be expected that the adoption of PV would lead to a change in awareness of electricity use – when it is used, how it is used, and how much is used. This awareness change can occur for a number of reasons; some adopters install electricity monitors that provide more information, leading to increased awareness, while others attempt to maximize the financial attractiveness of the investment by adjusting consumption levels and timing. Additionally, as discussed above in Section 3.2, PV adopters spend a significant amount of time researching PV performance, which directly relates to electricity usage. The respondents were asked how their awareness of electricity used, awareness of their monthly electricity bill, and awareness of how electricity is used (when and what for) changed since PV installation compared to before the installation of PV. The mean result for all three questions is about the same at 3.9, 3.8, and 3.8, respectively, which corresponds to "awareness is higher than before PV installation". The standard deviation is 0.85 for all three questions. Over 70% of the sample reports that their awareness as regards their electricity use (amount used, bill paid, and purpose of use) is "higher or much higher" as a result of installing solar (Fig. 1, dotted line). Thus, most respondents believe that their awareness is higher post-installation in all three areas of electricity use.

We also asked PV adopters about the impact of PV installation on their environmental attitude. When asked about the "level of environmental concern pre-installation" 76% responded as being "concerned" or higher: "concerned" (18%), "fairly concerned" (24%), or "very concerned" (34%). For attitudinal changes post-installation, 62% of respondents reported that their level of environmental concern is "virtually unchanged" since PV installation, 31% answered that they are "more concerned", 5% answered "much more concerned", and 1% answered "much less concerned". Overall, PV adoption appears to raise the environmental concern of the subjects.

Finally, respondents were asked about the *change in total electricity consumption* compared to before the installation of their PV system. Total electricity consumption was defined as the sum of electricity consumption from both the PV system and the grid. Nearly 46% report that their total electricity consumption is "lower or much lower" post-installation and another 44% report no change (Fig. 1, solid line). Overall, a significant portion of the respondents *perceives* a reduction in their total electricity consumption post-installation of a PV system.

One of the potentially most beneficial aspects of PV systems is that they generate electricity during peak demand periods (typically associated with air conditioner usage in the afternoon, especially during the summer months), and thus can help to alleviate some of the congestion experienced by the grid when demand is at its highest. The respondents were asked if they had changed the timing in which they do any household activities to a time of day when the PV system is producing the most electricity, such as laundry, air-conditioning, dishwasher, and vacuuming. While 215 respondents (60%) reported no load-shifting behavior, 123 respondents (34%) did report load shifting *to match their consumption more closely to electricity production from their PV systems*. While our data does not allow us to accurately track the reason(s) for such changes, especially because the respondents subscribe to a range of electricity pricing structures (Texas has a deregulated electricity market), analysis of a related open-ended question sheds additional light on this behavior. Many who reported load-shifting *into* peak hours report doing so to "make better use of the electricity generation by the PV system". In some areas where we administered the survey the retail electricity providers do not provide any payment for outflows for the grid or do so at a lower rate than the rate for electricity inflows from the grid. While we cannot confirm a causal effect here, it is tempting to speculate that the price differential between inflows and outflows drives some PV adopters' load-shifting into peak hours. Indeed, several respondents note this and lament that the price differential deprives them of the "true value" of the electricity generated by their PV system.

4. CONCLUSION

We have reported descriptive findings from a survey of residential PV owners in Texas. As expected, the average PV adopter in Texas is more educated and has a higher income than the average Texan. General interest in energy, belief that PV is a financially prudent investment, and a desire to reduce environmental footprint were reported as equally important motivators for installing PV. Overall, most respondents seem to have experienced little uncertainty or concern about PV at the time of installation. This reflects, generally, the availability of plenty of information to the potential adopters of PV. However, responders also report spending a significant amount of time and effort sifting through all this information during their decision period. This suggests that while there is no dearth of PV-related information for potential adopters, the relevance and trustworthiness of information continues to be an issue. Most adopters use simple metrics like payback period to evaluate the finances of PV. Very few report using net present value (NPV) as a decision metric, even though rational decision-making (in the neoclassical sense) would suggest the use of NPV. Further, about 40% of the adopters perform these calculations without seeking outside help. Given the inherent complexity of reliably calculating a PV system's lifetime finances, it is likely that the majority of these estimates are not accurate. Interestingly, a majority of the respondents report system performance to be "as expected or better than expected". Overall, PV adopters appear to be highly satisfied with their decision to adopt. Post-installation, adopters' awareness regarding both the amount and end-uses of electricity is enhanced. A variety of factors, including the intensity of the information search during the decision-period and the use of monitoring devices post-installation, appear to function as awareness enhancers. A significant portion (46%) of PV adopters perceives that post-installation their *total* electricity consumption is lower than compared to pre-installation. Significantly increased awareness of their electricity usage and an enhanced concern for the environment in the process of PV adoption appear as tentative drivers of these perceptions. It would be interesting, and perhaps quite revealing, to analyze the actual electricity consumption patterns of PV adopters and compare with the reported perceptions. Finally, post-installation about one-third of the respondents report changing at least part of their electricity-consuming activities to more closely match electricity production from their PV systems—load-shifting *into* peak demand hours. We speculate that this might be because many deregulated retail electricity providers in Texas offer lower value for electricity outflows to the grid than the prices charged for electricity inflows to households. At least, that is how several PV adopters perceive the situation to be.

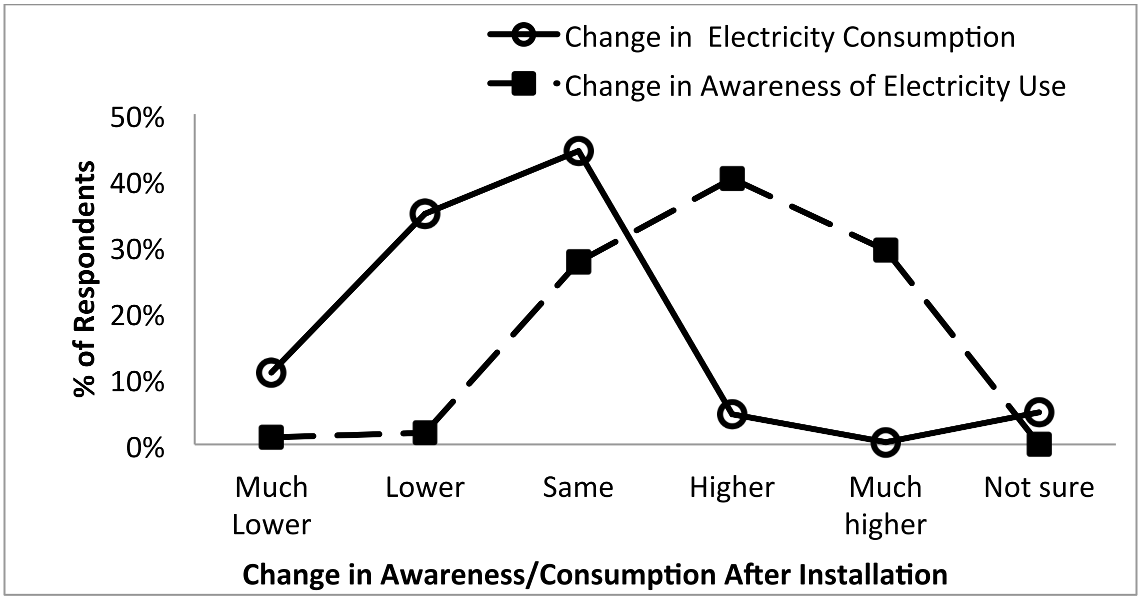

Fig. 1: Impact of PV installation on respondents' awareness of electricity use and on their electricity consumption as compared to their awareness and consumption prior to PV installation.

5. ACKNOWLEDGMENT

The authors would like to thank Leslie Libby, Chris Frye, and Tim Harvey of Austin Energy, Annie Castello, Jay Zarnikau, and Mark Kapner of Frontier Associates, and Steve Wiese of Clean Energy Associates for their helpful discussions and insights. Thanks are also due to Benjamin Sigrin, Pimjai Hoontrakul, and Scott Robinson—all graduate students at UT Austin—for help with different parts of the project. VR would like to acknowledge support from the Elspeth Rostow Memorial Fellowship and from the Center for International Energy and Environmental Policy at UT Austin. Any remaining errors are ours alone.

6. REFERENCES

(1) Paidipati, J., Frantzis, L., Sawyer, H., and Kurrasch, A., Rooftop Photovoltaics Market Penetration Scenarios, NREL Report, 2008 (2) Rogers, E. M., *Diffusion of Innovations*, 5th ed., New York: Free Press, 2003 (3) Zeithaml, V.A., Consumer Perceptions of Price, Quality, and Value: A Means-End Model and Synthesis of Evidence, *The Journal of Marketing*, 52(3): 2-22, 1988 (4) Faiers, A. and Neame, C., Consumer Attitudes Towards Domestic Solar Power Systems, *Energy Policy*, 34 (14): 1797-1806, 2006 (5) Margolis, R. and Zuboy, J., Non-technical Barriers to Solar Energy Use: Review of Recent Literature, NREL Report, 2006 (6) Rai, V., Solar PV Adoption in the U.S. Residential Sector: Decision-Making and Behavior Change, Paper presented at the *Behavior, Energy, and Climate Change Conference*, Washington D.C., 2011 (7) Census 2011, State and County Quick Facts, U.S. Census Bureau, 2011 (8) Bollinger, B. and K. Gillingham, 2011. Peer Effects in the Diffusion of Solar Photovoltaic Panels. Stanford University, December 2011