Public perceptions and information gaps in solar energy in Texas

2015 Environ. Res. Lett. 10 074011

(http://iopscience.iop.org/1748-9326/10/7/074011)

Environmental Research Letters

OPEN ACCESS

RECEIVED
5 June 2015

REVISED
26 June 2015

ACCEPTED FOR PUBLICATION
29 June 2015

PUBLISHED
17 July 2015

LETTER

Public perceptions and information gaps in solar energy in Texas

Varun Rai[1,2] and Ariane L Beck[1]

[1] LBJ School of Public Affairs, The University of Texas at Austin, Austin, Texas, TX 78712, USA
[2] Mechanical Engineering Department, The University of Texas at Austin, Austin, Texas, TX 78712, USA

E-mail: raivarun@utexas.edu

Keywords: solar PV, residential energy, information barriers, Texas emissions, technology adoption, distributed generation, decision-making

Supplementary material for this article is available online

Abstract

Studying the behavioral aspects of the individual decision-making process is important in identifying and addressing barriers in the adoption of residential solar photovoltaic (PV). However, there is little systematic research focusing on these aspects of residential PV in Texas, an important, large, populous state, with a range of challenges in the electricity sector including increasing demand, shrinking reserve margins, constrained water supply, and challenging emissions reduction targets under proposed federal regulations. This paper aims to address this gap through an empirical investigation of a new survey-based dataset collected in Texas on solar energy perceptions and behavior. The results of this analysis offer insights into the perceptions and motivations influencing intentions and behavior toward solar energy in a relatively untapped market and help identify information gaps that could be targeted to alleviate key barriers to adopting solar, thereby enabling significant emissions reductions in the residential sector in Texas.

1. Introduction

The Texas electricity sector faces a range of issues including increasing demand, shrinking reserve margins, constrained water supply, and challenging emissions reduction targets under proposed regulations. Rapid population growth in Texas is increasing demand for both electricity and water resources, while persistent drought in many parts of the state compound the constraints on water needed to operate power plants (Malewitz 2015). In 2012 Texas generated 50% of its electricity from natural gas and 32% from coal, but only 7.5% from wind (EIA 2014). The resulting emissions leave Texas with a 38% CO2 emissions reduction goal from the U.S. EPA Clean Power Plan (CPP) (US EPA 2014b). With Texas already stretching to meet growing demand, (ERCOT 2013, 2014) it will have to reach beyond traditional, carbon-intensive sources to meet its energy needs under new environmental constraints and priorities. The EPA CPP suggests that 20–25% of Texas' reduction goal could be met by renewable energy production (US EPA 2014a, Vaughan 2014).

While there is an increasing expansion in renewable energy at the utility scale in Texas, the range of efforts do not appear to fully tap into the significant potential in distributed solar generation in the residential sector that could help meet demand and reduce peak energy usage while also reducing emissions and contributing to an aggregation market for distributed energy resources (Burr *et al* 2014, SEIA 2014, St. John 2015). Current penetration rates of residential solar photovoltaic (PV) in Texas are less than 2% of potential market penetration (Paidipati *et al* 2008; Authors' estimates[3]). This suggests that there is significant room for growth in residential PV in Texas. However, there is little systematic understanding of customer perceptions, expectations, and

[3] In Austin (TX), where the installed density of residential solar is among the highest in Texas, the penetration level is about 2% of technical potential, which accounts for residential rooftops not suited at all for PV installations due to very poor roof orientation/structure or excessive tree shading. Average estimates for the ERCOT system, which covers most of Texas, are around 0.5% (authors' estimate using ERCOT data). We thank Steve Wiese and Chad Blevins for help with these estimates.

readiness toward adopting solar PV technology across Texas.

This paper aims to address this gap through an empirical investigation of data collected through a theoretically designed survey instrument. Specifically, we apply the theory of planned behavior (TPB) framework (Ajzen 1991, 2002) to investigate attitudes, norms, and perceived behavioral control (PBC) surrounding solar energy adoption in Texas. Identifying the beliefs that guide intentions and behavior in energy conservation and solar adoption is necessary for designing successful interventions to facilitate these behaviors. Establishing the degree to which attitudes, norms, PBC, and environmental concern influence solar adoption intentions is informative as to which types of information will be most useful and effective in interventions intended to increase solar penetration rates in low penetration communities. To the best of our knowledge this study represents the first systematic application of the TPB framework to study barriers in the adoption of residential PV.

2. Background and related literature

TPB asserts that the behavior of individuals is determined by intentions, the antecedents of which are the attitude toward the behavior, subjective norms, and PBC (Ajzen 1991, 2002). *Attitude* toward a behavior is formed from beliefs about the likely positive or negative consequences of a behavior. *Subjective norms* are the perception of how a particular behavior will be viewed by others important to the subject. *PBC* measures a person's perception of her/his ability to perform the behavior. In addition to these three primary TPB constructs, we also add descriptive and personal norms to our analysis. Ajzen and Fishbein (2005) updated TPB to consider *descriptive norms*, i.e., the perception of how others typically behave, in addition to subjective norms. Thus, we included descriptive norms as a component of this study. *Personal norms* describe self-expectations or obligations based on internalized values and have the potential to impact intentions and behavior, particularly when motivation stems from closely held beliefs, values, and convictions, such as environmental responsibility (Harland *et al* 1999). Gardner and Abraham (2010), in a TPB study of car use, found both personal norms and descriptive norms to enhance the TPB model.

TPB has proven an effective tool in understanding the intentions and behavior surrounding the adoption of new technologies. A meta-analysis of nearly 200 TPB studies by Armitage and Conner (2001) found that 39% of variance in intention and 27% of variance in behavior could be explained through TPB. Bamberg *et al* (2003) apply TPB in a study on travel-mode choice going beyond understanding behavior and leveraging the theory to evaluate the effectiveness of a behavioral intervention. They also find that past behavior has limited effect on future behavior if the conditions or context of the behavioral decision change. This is particularly relevant to fast-changing technologies such as solar, for which prices have dropped rapidly and the technology has improved significantly just in the last few years. Communicating this changing context to potential adopters becomes critical to the process of reassessing the decision to adopt or reject a technology as it evolves.

Residential PV adoption faces many challenges, such as high upfront cost, extensive time and effort associated with information acquisition, high discount rates, inaccurate estimates of benefits, and perceived uncertainties about the performance and benefits of the technology (Faiers and Neame 2006, Jager 2006, Margolis and Zuboy 2006, Denholm *et al* 2009, Shih and Chou 2011, Bollinger and Gillingham 2012, Drury *et al* 2012, Rai and McAndrews 2012, Rai and Robinson 2013, Rai and Sigrin 2013, Davidson *et al* 2015). The installed price and upfront costs of solar PV have a particularly strong influence on adoption, due to influences on both perceived and actual behavior (Rai and Sigrin 2013). Peer effects have also proven influential in the adoption of residential solar, while uncertainties and non-monetary costs, such as perceived complexity or the time commitment necessary to filter through a glut of information from a variety of sources, can also act as barriers to adoption (Bollinger and Gillingham 2012, Rai and Robinson 2013). When applied in the context of diffusion of innovation studies (Rogers 2003), the impact of the three TPB constructs—attitude, norms, and PBC—can uncover barriers to adoption. Uncovering the most important factors related to adoption of a specific technology can inform the focus of a targeted intervention and its potential effectiveness. Likewise, discovering that a highly influential construct has a low rating within a population of interest can inform what information might be most useful or beneficial for increasing adoption.

3. Data and methods

Using the TPB framework, this study investigates the behavioral, normative, and control factors affecting intentions and behavior related to residential solar PV. Further, descriptive norms, personal norms, and environmental concern act as potential moderating factors to adoption of 'green' technologies as discussed above and are included as well. Specific hypotheses to test the factors driving intentions toward solar energy are listed below. The Texas regions studied have a low solar penetration rate, thus we focus on predictors of intention, measured by respondents' consideration to install a solar system and the likelihood of calling a solar installer for a quote. In an early stage market, we need to first understand the factors influencing this initial interest and openness to a new technology. Thus the intention of considering a solar installation was selected because it is the first step in the process of solar adoption and signals attention and thoughtfulness toward information about a new technology. Calling a solar installer for a quote was selected as a specific, concrete action necessary for solar adoption that signifies moving beyond initial interest and onto serious consideration of solar.

3.1. Hypotheses

Following directly from TPB (Ajzen 1991, 2002), we postulate that:

Hypothesis 1. Solar energy (a) attitude, (b) subjective norms, and (c) PBC will predict intentions to consider installing solar.

Hypothesis 2. Solar energy (a) attitude, (b) subjective norms, and (c) PBC will predict intentions to call a solar installer for a price quote.

Since 'considering' solar (H1) is an earlier step compared to requesting installer quotes (H2) on the path to solar adoption, it is informative to investigate motivational influences at the consideration stage in a low penetration market.

Given the novelty, potential complexity of installation, and cost of solar PV, adoption requires both the knowledge *and* financial means to act (Drury *et al* 2012, Rai and Sigrin 2013, Liu *et al* 2014). Thus, we anticipate that the decision to adopt will be heavily influenced by PBC, as measured through the perception of affordability. Accordingly, we hypothesize:

Hypothesis 3. PBC will be the strongest predictor of (a) considering installing solar and (b) intentions to call a solar installer.

Trusted information channels, and peer effects in particular, have proven a significant factor in overcoming non-financial barriers to solar adoption (Bollinger and Gillingham 2012, Rai and Robinson 2013, Graziano and Gillingham 2015, Noll *et al* 2014). Given the lack of experience with new technologies like solar, adopting such technologies is characterized by heightened perceptions of risk. Observing neighbors install solar can allay uncertainties related to perceptions of risk (e.g., maintenance and performance of the system) and provide motivation and confidence (Rai and McAndrews 2012). These observations of others' behavior can form perceptions of which behaviors are typical behaviors, thus establishing descriptive norms. Given the known relative importance of peer effects in the decision to adopt solar, we hypothesize that:

Hypothesis 4. Descriptive norms will be the most influential norm on the likelihood to (a) consider installing solar and (b) call a solar installer.

It is also important to explore beliefs that drive attitudes and intentions. Gardner and Abraham (2010) explored the relationship between environmental concern, attitudes, and personal norms in travel mode decisions. They found that personal norms significantly predict intentions, and, in turn, are significantly impacted by environmental concern. Environmental concern is a known salient motivating factor underpinning solar adoption behavior (Kollmuss and Agyeman 2002, Rai and McAndrews 2012). However, the effect of environmental concern on behavior is indirect, flowing through its impact on personal norms, which in turn impact intentions to perform the behavior (Klöckner and Matthies 2004). Accordingly, we hypothesize:

Hypothesis 5. Personal norms will predict intentions to (a) consider installing solar and (b) call a solar installer.

Hypothesis 6. Environmental concern will predict personal norms toward solar energy.

Installed cost of solar, particularly the upfront cost, has been a significant barrier to adoption (Drury *et al* 2012, Rai and Sigrin 2013). The value of incentives combined with declining PV prices significantly reduces that upfront cost (SEIA 2014), but awareness of these factors is necessary for lowering those cost barriers to adoption. Thus, incentive awareness was explored here as a moderating factor on attitude and PBC, due to its prevalence as a policy tool for driving residential solar demand (DSIRE Solar 2014). Accordingly, we hypothesize:

Hypothesis 7. Awareness of incentives for solar PV will predict (a) the monetary components of attitude and (b) PBC toward solar energy.

3.2. Survey

The survey instrument was developed following the guidelines for a TPB questionnaire (Ajzen 2014) using a 7-point bipolar Likert scale with 'agree' written by 7 and 'disagree' written beside 1, unless otherwise noted. Intermediate rankings were labeled numerically. The goal of the survey was to collect measures of attitudes, norms, PBC, intentions, and behavior with respect to solar energy. Demographic data was also collected. Environmental concern was included as an additional factor to investigate potential effects specific to solar energy intentions (Bamberg 2003, Carley *et al* 2013).

In some cases, the survey uses multiple questions to assess the relevant factors. Pearson correlation and factor analysis were used to eliminate questions that offered little additional information. In the case where multiple questions remained to assess a single TPB construct, an index variable was calculated as the mean of responses to the questions used. The full list of questions and discussion of the variables are available in the supplemental information (SI) available at stacks.iop.org/ERL/10/074011/mmedia[4], sections SI-1 and SI-2. The resulting variables were used to develop logit

[4] Supplemental information consists of survey questions, summary and table of demographic data.

models for dependent variables with binary (yes/no) responses and ordered logit models for dependent variables measured using a Likert scale.

3.3. Survey respondents

As mentioned above, our objective is to study perceptions, intentions, and behavior regarding solar energy adoption. Accordingly, in selecting the geographical focus of the study we considered three criteria: (1) areas with significant solar incentives, (2) urban areas, and (3) competitive retail regions of Texas. In the absence of local incentives, the (weak) economics of solar would dominate outcomes, making it hard to uncover attitudinal, social, and information-related drivers. Criterion 1 increases the likelihood that the economics of adopting solar would be more favorable, providing a better setting to study behavioral and informational aspects. We wanted to focus on urban areas (criterion 2) because in the current (low) stage of solar market penetration, we expect the supply-side factors (primarily access to installers) to be extremely weak in rural areas due to poor economies of scale and scope for installers, leading to little variation in outcomes of interest (e.g., installer quotes). Finally, our focus on the competitive retail areas of Texas (criterion 3) was driven by two factors: first, these areas represent the largest portion of the residential market in Texas; second, the main non-competitive areas in Texas (such as the municipally owned utilities in Austin and San Antonio) have had strong fully subscribed solar programs for many years. As such, in these areas, the awareness of and interest in solar are generally already quite high. Based on these criteria we decided to focus on three cities in Texas: Corpus Christi (2013 population: 316 381), Abilene (2013 population: 120 099), and San Angelo (2013 population: 97 492). To recruit respondents to the survey we used a direct mail (postcard) advertisement[5] for a randomly selected list of single-family residential addresses in the three cities, approximately in proportion to population (50% to Corpus Christi and 25% each to Abilene and San Angelo). A $10 Amazon gift card for completing the survey and entry into a prize drawing for one $500 and two $150 Amazon gift cards were offered.

This process led to a sample of 522 completed responses that is closely representative of the underlying population along most observable socio-economic demographics, with the exception of education (see SI-3 for additional details). On education, the sample—with nearly 60% of respondents having a bachelor's degree or higher—ranks above average compared to the general population of Texas (26.3% with bachelor's degree or higher). Education is typically associated with better information and higher awareness (Donohue *et al* 1975, Rogers 2003). Accordingly, to the extent that we identify information and awareness gaps below, we believe that those gaps would be even more significant for the underlying population from which our sample is drawn. Additionally, higher educational attainment is associated with earlier adoption groups in the diffusion of innovation model (Rogers 2003). Thus, this sample is likely in or near the 'chasm' group, which is a core group where a technology either fails or crosses to the mainstream (Moore 1991).

Table 1. Descriptive statistics of TPB constructs, intentions, behavior, and environmental concern ($n = 522$ except where noted).

	Mean	SD
Attitude	5.31	1.34
Subjective norms	5.28	1.70
Descriptive norms	3.75	1.59
Personal norm	5.47	1.74
Perceived behavioral control	3.15	1.65
Environmental concern	5.94	1.24
Intention—considering solar (Y/N)	14% (71)	54% (283)
Intention—call installer	3.11	1.61
Behavior—call installer (Y/N)	6% (27)	94% (453)

4. Results

4.1. Descriptive findings

Table 1 shows the descriptive statistics for both index and single-item variables for the TPB constructs, intentions, behavior, and environmental concern, with question-level detail available in the SI (sections SI-1, SI-2). Solar energy attitudes were measured using four questions to address financial, aesthetic, and environmental attitudes toward solar. On finances, most respondents agreed that solar energy will save money and increase home value. Regarding aesthetics, the mean response of 4.27 (sd = 2.08) indicated a relatively neutral attitude. When asked if 'solar is good for the environment,' 80% selected 6 or 7.

Subjective and personal norms both had a mean greater than 5, indicating positive norms with regard to solar installations. However, descriptive norms[6] were rated lower with a mean of 3.75 (sd = 1.59). The highest rated descriptive norm with a mean of 4.51 (sd = 1.89) was in response to, 'People who are important to me think solar energy is important.' When asked to rate, 'Solar energy is a topic of interest in my neighborhood,' the mean of responses was only 2.81 (sd = 1.68). The perceived lack of community interest[7] combined with a low penetration rate of residential solar in this area limits the opportunity to establish

[5] The postcard promoted a research project on energy use. The survey asked a variety of questions about energy use, energy conservation, and solar energy. This, in addition to monetary incentives, was done to minimize self-selection bias toward those already specifically interested in solar.

[6] Descriptive norms here include elements of injunctive norms, as well. There is a nuanced difference between the two, which is discussed further in the SI (section SI-1.2).

[7] The *perception* that solar is not a topic of interest is the key here, though that perception could stem either from an actual lack of community interest or a lack of connection to the community. In either case, the perception indicates the potential for normative influences on adoption decisions.

descriptive norms or peer effects that, through visible rooftop installations, positively influence solar adoption at this early stage.

PBC was measured from responses to, ‘a solar system is affordable for my household[8].’ The mean response was 3.15 (sd = 1.65). Thus, in the studied population the perceived affordability of solar was low and is likely to be a barrier to adoption.

An additional question asked respondents to characterize the expected financial return of solar energy on a 7-point Likert scale from ‘very low’ to ‘very high’ with an option for ‘do not know.’ Of the 520 respondents, nearly 20% ($n = 98$) selected ‘don’t know.’ The mean of the remaining respondents was 4.4 (sd = 1.59). This indicates that while attitudes toward solar energy were positive and solar energy is expected to save money, the *expected* savings are not particularly high.

Intentions regarding solar energy were measured with two questions: (1) Are you considering installing a solar system on your house? (2) How likely is it that you will call a solar installer for a quote? For the first question, of the five possible responses offered, only two were used in the models, creating a binary variable: 71 responding, ‘Yes, I am currently considering,’ and 283 responding, ‘No, I am not considering.’ Only one of the 520 respondents that answered this question had already installed solar (the first response option). The options, ‘Previously considered, but decided not to install’ and ‘other’ were included to provide a more complete set of options for respondents, but neither indicates a current intention. Thus, these two latter response categories were not included in the models for considering solar[9]. The second question was measured on a 7-point Likert scale from ‘Very likely’ to ‘Very unlikely’ with a mean of 3.11 (sd = 1.61). Knowing in advance that the region of focus had low solar penetration, we measured solar-related behavior by asking, ‘Have you ever called a solar installer for a quote?’ rather than relying on solar installations as a measure of behavior. Only 6% ($n = 27$) of respondents had called a solar installer. So even this measure for solar-related behavior does not provide sufficient variation to build a TPB behavior model for solar PV adoption, for which we only report TPB intention models.

[8] See SI-1.3 for more details on the choice of this measurement.

[9] Those who considered solar, but decided not to install, cannot be used in the ‘not considering’ group because considering solar seriously at some point indicates they likely share many of the same characteristics as the considering group. However, we do not know the reason or at what point in the adoption process they rejected solar, e.g. financial, shading from a tree or neighboring building, etc. On the other hand, someone who is ‘not considering’ solar may not be interested enough in solar to think about it at all. These are fundamentally different decisions, thus we include only considering or not considering in the final model.

4.2. Models of intentions toward solar PV adoption

Table 2 provides the results of TPB models for these two solar intentions: (1) a logit model for considering a solar installation, SIconsider and (2) an ordered logit model for likelihood to call a solar installer, SIquote. These models used the main TPB constructs—attitude, subjective norms, and PBC—as well as demographic and house-related variables as controls: age, gender, income, education, and home area. Home value and home area had a high correlation (0.74); thus only home area was used in the models, because the data set was more complete ($n = 486$) compared to home value ($n = 439$). A second set of models, SIconsider2 and SIquote2, added descriptive norms and personal norms to the models SIconsider and SIquote, respectively.

For those considering solar (SIconsider), the TPB constructs attitude and PBC proved significant at the 0.05 and 0.001 levels, respectively, whereas subjective norms were not significant (Hypothesis 1b not supported). With an OR of 1.73, attitude showed most influence, thus supporting Hypothesis 1a. The OR for PBC is 1.64, which supports Hypothesis 1c, but falls short of supporting Hypothesis 3a, since attitude, not PBC, had the greater influence on the likelihood of considering a solar installation. However, the SIconsider model focuses on the likelihood of considering solar—a relatively early stage in the decision process leading to a final adoption/rejection decision. In TPB, PBC impacts both intention, an immediate antecedent of behavior, and behavior itself directly. Thus, the importance of PBC is amplified by influencing behavior both directly and indirectly (Ajzen 1991). As such, the relative prominence of PBC may be greater in later stages of the decision process (discussed below). Table 3 presents a summary of all hypotheses and results.

For the model SIconsider2, the inclusion of descriptive norms and personal norms improved the model fit (χ^2 (2 304) = 13.72, $p = 0.001$), but removed the significance of attitude. This is attributed to the high correlation of attitude (0.57 and 0.79, respectively) with these two variables. PBC remained strongly significant as in SIconsider. Descriptive norms were significant to the 0.001 level, increasing the odds of considering solar by 75% for each one-point increase, confirming Hypothesis 4a. Personal norms were not significant for considering solar, thus Hypotheses 5a was not supported. These results indicate that at this stage (i.e., low levels) of solar penetration individuals with a positive attitude toward solar, with a generally strong perception that they are able to pursue solar (PBC), and who receive informational cues or confirmation of their decision through the behavior of others (descriptive norms) are more likely to consider adopting solar.

In the model SIquote both attitude and PBC were significant at the 0.001 level. Each one-point increase in the solar attitude index increased the odds of

Table 2. Models for solar energy intentions[a].

	SIconsider	SIconsider2	SIquote	SIquote2
n	304	304	417	417
AIC	227	217	1335	1326
Pr (>Chisq)	<2.2e-16	<2.2e-16	<2.2e-16	<2.2e-16
Pseudo *R*-square[b]	0.38	0.41	0.24	0.24
	OR	OR	OR	OR
Attitude	1.73*	1.34	1.56***	1.28*
	(0.23)	(0.28)	(0.09)	(0.11)
Subjective norm	1.25	0.91	1.13	0.98
	(0.18)	(0.21)	(0.07)	(0.08)
Perceived behavioral control	1.64***	1.44**	1.66***	1.59***
	(0.13)	(0.14)	(0.07)	(0.07)
Descriptive norm		1.75***		1.21*
		(0.17)		(0.08)
Personal norm		1.33		1.27**
		(0.24)		(0.09)
Age	0.96**	0.96**	1.00	1.00
	(0.01)	(0.01)	(0.01)	(0.01)
Gender	0.26***	0.25***	0.94	0.92
	(0.39)	(0.4)	(0.16)	(0.16)
Income	1.18	1.25	1.12	1.14
	(0.13)	(0.14)	(0.07)	(0.07)
Education	0.81	0.83	0.90	0.89
	(0.14)	(0.14)	(0.07)	(0.07)
Home area	1.00*	1.00	1.00	1.00
	(0)	(0)	(0)	(0)

[a] Odds ratios (OR) and standard errors in parentheses. Intercepts are not reported, as there are many, but are available on request.

[b] Maximum Likelihood was the lowest of a several metrics for SIconsider models, thus is reported as the most conservative estimate. McFadden's *R*-square is reported as the conservative estimate for SIquote models.

Significance 0.001***, 0.01**, 0.05*, 0.1 '.'

intending to call a solar installer for a quote by 56%, supporting Hypothesis 2a. A one-point increase in PBC had a corresponding increase of 66% on the odds of intending to request a solar quote, supporting both Hypotheses 2c and 3b, as PBC had the greatest influence on intentions to request a solar quote. Subjective norms were significant only at the 0.1 level, weakly supporting Hypothesis 2b.

The model SIquote2 included both personal and descriptive norms and improved the model fit (χ^2 (2, 417) = 12.99, $p = 0.0015$). The addition of these two variables diminished the influence of attitude ($p < 0.05$), which is attributed to the high correlation of attitude with descriptive and personal norms as in the SIconsider2 model discussed above. Among the three norm-related variables in this model, personal norms showed the most influence on intentions to call a solar installer. A one-point increase in personal norms increased the odds of requesting a quote by 27% ($p < 0.01$), while a one-point increase in descriptive norms increased the odds by 21% ($p < 0.05$). Thus, while this supports Hypothesis 5b (influence of personal norms), Hypothesis 4b (descriptive norms most influential) is not supported.

Furthermore, personal norms were modeled as a function of environmental concern and the five demographic control variables included in the above models. Environmental concern was significant at the 0.001 level with an OR of 2.13, thus supporting Hypothesis 6. This indicates a strong relationship between personal norms (for solar energy) and environmental concern. However, note that personal norms were only significant in the SIquote2 model, not the SIconsider2 model. Together, these findings indicate that the influence of environmental concern acting through personal norms becomes significant later in the process of solar adoption, while the initial step of considering solar is more influenced by informational cues from others, i.e., descriptive norms.

4.3. Financial aspects and information gaps

Since both attitude and PBC include financial components and, together, are the most influential constructs

Table 3. Summary and confirmation of hypotheses.

# Hypothesis		Supported
Hypotheses 1. Solar energy… will predict intentions to consider installing solar.		
H1a	(a) attitude,	Yes
H1b	(b) subjective norms, and	No
H1c	(c) PBC	Yes
Hypotheses 2. Solar energy… will predict intentions to call a solar installer.		
H2a	(a) attitude,	Yes
H2b	(b) subjective norms, and	Yes
H2c	(c) PBC	Yes
Hypothesis 3. Perceived behavioral control will be the strongest predictor of		
H3a	(a) considering installing solar and	No
H3b	(b) intentions to call a solar installer.	Yes
Hypothesis 4. Descriptive norms will be the most influential norm on the likelihood to		
H4a	(a) consider installing solar and	Yes
H4b	(b) call a solar installer.	No
Hypothesis 5. Personal norms will predict intentions to		
H5a	(a) consider installing solar, and	No
H5b	(b) call a solar installer.	Yes
Hypothesis 6. Environmental concern will predict		
H6	*personal norms for solar energy.*	Yes
Hypothesis 7. Awareness of incentives for solar PV will predict… toward solar energy.		
H7a	(a) the monetary components of attitude and	No
H7b	(b) *PBC*	No

to both variations of solar intentions considered here (SIconsider and SIquote), the perceived cost of solar emerges as the most significant barrier to adoption for this sample. Furthermore, both attitude and descriptive norms had a weaker influence on calling for a quote than on considering solar, while the relative significance of PBC increased for SIquote. Presumably, considering solar is an earlier stage in the adoption process than calling for a quote. Thus, our findings indicate that attitudinal components play a stronger initial motivating role and that the financial component becomes increasingly dominant through the progression of the decision-making process.

Given the prevalence of solar incentives (DSIRE Solar 2014) to address the financial barriers of solar, it is important to consider the effect of incentives on the monetary components of attitude and on PBC. Awareness of solar incentives was assessed with the question, 'Are you aware of any incentives (federal, state, or local) to install solar?' The response options were 'Yes' or 'No', with only 16% responding in the affirmative. The effect on attitude was measured by creating a dependent variable from the two monetary components of attitude (see SI), and modeling it as a function of awareness of incentives and the five demographic control variables used in previous models. Awareness of incentives as a predictor of attitude was highly insignificant ($p = 0.95$), thus Hypothesis 7a was not supported. Similarly, solar PBC was modeled as a function of awareness of incentives and the same five demographic control variables[10]. Awareness of incentives as a predictor of PBC was not significant either ($p = 0.49$); thus, Hypothesis 7b was also not supported. This indicates that the overall financial picture of solar is important for driving solar intentions (as confirmed by the significant effect of PBC in the TPB intention models), but knowledge of any particular rebate or incentive is not. As noted previously, only 16% of the respondents in a group with above average educational attainment (i.e., typically more informed) were aware of incentives and nearly 20% were unsure of the financial returns from solar. Thus, expectations about financial returns from solar appear to be formed independently of available incentives. Put another way, a technology like solar that is perceived to be expensive may still be perceived as expensive even with a 30% price reduction (Federal Investment Tax Credit) and additional available local incentives. As such, the relative cost may be less important than the *perceived* overall financial picture, which is currently a negative (adverse) perception. Any additional incentives and rebates appear to be a wash, as individuals are either not aware of that information or do not appear to be filtering that new information to rightly update their perception. This finding may be related to the 'ostrich effect' that Karlsson *et al* (2009) identify, whereby individuals avoid additional information given adverse prior news. Overall, these findings point to an inaccurate, and perhaps outdated, understanding of solar costs and benefits, suggesting the existence of an information gap that decreases the potential effectiveness of incentives for reducing the cost barrier to solar adoption.

5. Conclusion

Given the importance of solar energy in meeting emissions reductions targets amid growing electricity demand in Texas, in this paper we studied individual-level perceptions and information gaps associated with the adoption of residential solar PV. Specifically, we collected and analyzed a new survey dataset of households in Texas to better understand existing attitudes, norms, and PBC and their impact on intentions and behavior regarding the adoption of solar PV. Our analysis sheds light on the nature of behavioral and informational barriers in the adoption of residential

[10] It is plausible that home ownership could also impact PBC. We specifically targeted single-family homes, but information on actual ownership (owner or renter) was not available for all respondents. We feel that living in a single family home provides the perspective and experience with electricity use and expense that would inform decisions on solar. Home ownership was not included in the PBC model because responses were only available from a smaller sample of respondents ($n = 173$), with just over 85% as homeowners. Within that smaller sample we note that there is no significant difference between PBC for homeowners and renters, $p = 0.61$ (t test).

PV in Texas and offers insights for designing potential interventions to alleviate those barriers.

Survey respondents demonstrated positive attitudes, which were significantly associated with intentions to consider the adoption of solar PV. PBC was also highly significant in every model we tested for intentions toward considering solar installation or calling installers for quotes, though it was rated low (3.15). Low PBC toward solar may indicate why descriptive norms play such an influential role in considering solar. Since respondents do not feel particularly knowledgeable or confident with solar, a new and complex technology, looking to others for information and/or confirmation has relevance and benefit. This finding is consistent with recent findings in the literature confirming the importance of peer effects in solar adoption (Bollinger and Gillingham 2012, Rai and Robinson 2013, Graziano and Gillingham 2015, Noll *et al* 2014). Thus solar incentive programs should strive to leverage the beneficial impacts of peer effects (reflected in descriptive norms) to address underlying informational barriers in the adoption of PV. The internalization of the positive externality associated with peer effects could take different forms, ranging from the purely economic (e.g., higher incentives for early adopters (Bollinger and Gillingham 2012)), to more informational (e.g., online peer-exchange platforms (Rai and Robinson 2013)), or more instituational instruments (e.g., non-profit, community organizaions (Noll *et al* 2014)).

The relationship between environmental concern and solar energy is nuanced. Environmental concern —as operating through personal norms—was not a significant factor in considering solar, but became a significant factor for the intention to call for a solar quote, a later stage intention (compared to considering solar). As discussed above, we also see a diminishing role for attitudes and descriptive norms as respondents move through the decision process, as evidenced by the relative influence of the TPB constructs in the models. In contrast, perceived affordability and personal norms play an increasingly influential role as the decision process progresses. Thus, attitude and descriptive norms may spark initial interest before financial considerations take stronger hold during the later stages in the decision process with an added boost to action from personal norms (Bamberg and Möser 2007). Quite possibly, since environmental concern (acting through personal norms) does not appear to be a key spark for considering solar, influencing attitude and PBC through targeted information regarding the financial benefits could provide the necessary impetus at the early stages of the decision process regardless of environmental concern.

But information alone, especially if not targeted, may not be sufficient to overcome adoption barriers. Survey respondents had the option of leaving a comment. The most frequent sentiment (57%) of those that did was that they would install solar if they could afford it, which is consistent with the reported high (positive) attitude but low PBC survey scores. This indicates a market ready for solar PV *when* systems become more affordable. For many, growth in the availability of solar loans and leasing options creates those affordable conditions and potentially opens new market segments in residential PV (Rai and Sigrin 2013). However, despite the presence of federal (30% investment tax credit) and local incentives ($1.20/W) and leasing options, respondents generally expected low financial returns from solar. This suggests that customer awareness of the cost of solar has not caught up with available incentives and rebates, declining prices, and lease options that are quickly increasing the affordability of solar PV. This is a valuable insight, in light of the fact that our models show that perceived affordability of solar is the strongest predictor of intentions associated with adopting solar. That a population with higher than average educational attainment—a factor generally indicative of more informed respondents—showed such low awareness of solar costs, options, and investment potential, points to a substantial information gap that is likely feeding the low observed PBC in the sample. One implication of these findings is that incentives to encourage solar PV adoption would be more effective if accompanied by relevant information that enables the targeted population to assess how the incentives actually impact key criteria, such as affordability, and to update their perceptions accordingly.

Acknowledgments

We thank Erik Funkhouser and Cale Reeves for research assistance and Jay Zarnikau, Jim Fowler, and Steve Mutiso for several rounds of helpful discussions. We thank the anonymous reviewers for their helpful suggestions. Funding support from the US Department of Energy under its Solar Energy Evolution and Diffusion Studies (SEEDS) program within the SunShot Initiative (Award Number DE-EE0006129) is gratefully acknowledged. The study was conducted in the service territory of American Electric Power (AEP) Texas, which provided support for participant recruitment and incentives for the survey participants. VR acknowledges support from the Elspeth Rostow Memorial Fellowship. All remaining errors are ours alone.

References

Ajzen I 1991 The theory of planned behavior *Organ. Behav. Hum. Decis. Process.* **50** 179–211

Ajzen I 2002 Perceived behavioral control, self-efficacy, locus of control, and the theory of planned behavior *J. Appl. Soc. Psychol.* **32** 665–83

Ajzen I 2014 Constructing a Theory of Planned Behavior Questionnaire (http://people.umass.edu/aizen/pdf/tpb.measurement.pdf) (Accessed 1 January, 2014)

Ajzen I and Fishbein M 2005 The influence of attitudes on behaviore *The Handbook of Attitudes* ed D Albarracín, B T Johnson and M P Zanna (Mahwah, NJ: Erlbaum) pp 173–221

Armitage C J and Conner M 2001 Efficacy of the theory of planned behaviour: a meta-analytic review *Br. J. Soc. Psychol.* **40** 471–99

Bamberg S 2003 How does environmental concern influence specific environmentally related behaviors? A new answer to an old question *J. Eng.* **23** 21–32

Bamberg S, Ajzen I and Schmidt P 2003 Choice of travel mode in the theory of planned behavior: the roles of past behavior, habit, and reasoned action *Basic Appl. Soc. Psychol.* **25** 175–87

Bamberg S and Möser G 2007 Twenty years after Hines, Hungerford, and Tomera: a new meta-analysis of psycho-social determinants of pro-environmental behaviour *J. Environ. Psychol.* **27** 14–25

Bollinger B and Gillingham K 2012 Peer effects in the diffusion of solar photovoltaic panels *Mark. Sci.* **31** 900–12

Burr J, Hallock L and Sargent R 2014 Shining cities: harnessing the benefits of solar energy in America *Environment Texas* (www.environmentamericacenter.org/sites/environment/files/reports/EA_ShiningCities2015_scrn.pdf)

Carley S *et al* 2013 Intent to purchase a plug-in electric vehicle: a survey of early impressions in large US cites *Transp. Res.* D **18** 39–45

Davidson C, Steinberg D and Margolis R 2015 Exploring the market for third-party-owned residential photovoltaic systems: insights from lease and power-purchase agreement contract structures and costs in California *Environ. Res. Lett.* **10** 024006

Denholm P *et al* 2009 Break-even cost for residential solar water heating in the United States: key drivers and sensitivities *Technical Report* NREL/TP-6A2-46909 National Renewable Energy Laboratory (www.nrel.gov/docs/fy10osti/46909.pdf)

Donohue G A, Tichenor P J and Olien C N 1975 Mass media and the knowledge gap: a hypothesis reconsidered *Commun. Res.* **2** 3–23

Drury E *et al* 2012 The transformation of southern California's residential photovoltaics market through third-party ownership *Energy Policy* **42** 681–90

DSIRE Solar 2014 Database of State Incentives for Renewables & Efficiency (http://dsireusa.org/solar/index.cfm?ee=0&RE=0&spf=1&st=1)

EIA U 2014 *Texas Electricity Profile 2012* Washington, DC (http://eia.gov/electricity/state/texas/)

ERCOT 2013 Striking a reliable balance: 2012 state of the grid report *Electric Reliability Council of Texas* (http://ercot.com/content/news/presentations/2012/2012 ERCOT State of the Grid_Web.pdf)

ERCOT 2014 Report on the capacity, demand, and reserves in the ERCOT region *Electric Reliability Council of Texas* (http://ercot.com/content/gridinfo/resource/2014/adequacy/cdr/CapacityDemandandReserveReport-Dec2014.pdf)

Faiers A and Neame C 2006 Consumer attitudes towards domestic solar power systems *Energy Policy* **34** 1797–806

Gardner B and Abraham C 2010 Going green? Modeling the impact of environmental concerns and perceptions of transportation alternatives on decisions to drive *J. Appl. Soc. Psychol.* **40** 831–49

Graziano M and Gillingham K 2015 Spatial patterns of solar photovoltaic system adoption: the influence of neighbors and the built environment *J. Econ. Geography* **15** 814–39

Harland P, Staats H and Wilke H A M 1999 Explaining proenvironmental intention and behavior by personal norms and the theory of planned behavior *J. Appl. Soc. Psychol.* **29** 2505–28

Jager W 2006 Stimulating the diffusion of photovoltaic systems: a behavioural perspective *Energy Policy* **34** 1935–43

Karlsson N, Loewenstein G and Seppi D 2009 The ostrich effect: selective attention to information *J. Risk Uncertain.* **38** 95–115

Klöckner C A and Matthies E 2004 How habits interfere with norm-directed behaviour: a normative decision-making model for travel mode choice *J. Environ. Psychol.* **24** 319–27

Kollmuss A and Agyeman J 2002 Mind the gap: why do people act environmentally and what are the barriers to pro-environmental behavior? *Environm. Educ. Res.* **8** 239–60

Liu X *et al* 2014 Purchasing versus leasing: a benefit-cost analysis of residential solar PV panel use in California *Renew. Energy* **66** 770–4

Malewitz J 2015 Water ruling cuts state's power in droughts *The Texas Triubune* (http://texastribune.org/2015/04/02/huge-water-ruling-court-sides-ranchers/)

Margolis R and Zuboy J 2006 *Nontechnical Barriers to Solar Energy Use: Review of Recent Literature* NREL/TP-52(September) National Renewable Energy Laboratory.

Moore G A 1991 *Crossing the Chasm: Marketing and Selling Technology Products to Mainstream Customers* (New York: HarperBusiness)

Noll D, Dawes C and Rai V 2014 Solar community organizations and active peer effects in the adoption of residential PV *Energy Policy* **67** 330–43

Paidipati J *et al* 2008 *Rooftop Photovoltaics Market Penetration Scenarios* NREL/SR-581-42306 National Renewable Energy Laboratory (www.nrel.gov/fy08osti/42306.pdf)

Rai V and McAndrews K 2012 Decision-making and behavior change in residential adopters of solar PV *Proc. of the World Renewable Energy Forum* (Denver, CO)

Rai V and Robinson S A 2013 Effective information channels for reducing costs of environmentally- friendly technologies: evidence from residential PV markets *Environ. Res. Lett.* **8** 014044

Rai V and Sigrin B 2013 Diffusion of environmentally-friendly energy technologies: buy versus lease differences in residential PV markets *Environ. Res. Lett.* **8** 014022

Rogers E M 2003 *Diffusion of Innovations* (New York: Free Press)

SEIA 2014 *Solar Market Insight Report 2013 Year in Review* Solar Energy Industries Association (www.seia.org/research-resources/solar-market-insight-report-2013-year-review)

Shih L H and Chou T Y 2011 Customer concerns about uncertainty and willingness to pay in leasing solar power systems *Int. J. Environ. Sci. Technol.* **8** 523–32

St. John J 2015 Texas mulls new grid markets for aggregated distributed energy resources *Green Tech Media* (http://greentechmedia.com/articles/read/texas-looks-to-distributed-energy-resources-as-market-players)

US EPA 2014a *Carbon Pollution Emission Guidelines for Existing Stationary Sources: Electric Utility Generating Units* Washington, DC (https://federalregister.gov/a/2014-13726)

US EPA 2014b *Clean Power plan—Proposed State Goals* US Environmental Protection Agency (20140602-state-data-summary.xlsx) (Accessed 1 January, 2014)

Vaughan T 2014 EPA's clean power plant proposed rule and its impact in Texas *Center for Global Energy, International Arbitration, and Environmental Law* (https://utexas.edu/law/centers/energy/blog/2014/07/epas-clean-power-plant-proposed-rule-and-its-impact-in-texas/)