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New trends in solar: A comparative study assessing the attitudes towards the adoption of rooftop PV

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ABSTRACT

The factors affecting the adoption of conventional solar PV have been broadly addressed in the recent literature. However, it is still to determine the public's acceptance of innovations of the traditional solar PV architecture. Building applied photovoltaic technology (BAPV) is a technological innovation that can be installed over existing building surfaces. This study compares an evaluation of the conscious and subconscious attitudinal, control and normative beliefs of American homeowners when randomly primed with two brochures depicting the purchasing, installation, and commissioning of solar PV systems, developed according to the characteristics of conventional and an adhesive "plug and play" BAPV system. The survey instrument (N = 400 survey participants) was designed in consonance to the Theory of Planned Behavior (TPB).

When comparing the direct measures for each solar PV technology, no significant differences were found. This may indicate that for those unfamiliar with PV technology, placing an adhesive backing module on the roof is standard procedure and does not impact purchasing intentions. The evaluation further showed that unlike the subconscious control beliefs, social norms and attitudes have a significant impact on forming intentions to adopt solar PV. The implications of these findings for strategy, policy and future research are explored.

1. Introduction

For a residential homeowner, the process of "going solar" is an involved decision. Research on the diffusion of innovation suggests that individual decision-making significantly impacts the success of widespread technology deployment (Robinson et al., 2013; Rogers, 2003) and for the residential solar PV market, this proves especially true.

To encourage greater adoption of rooftop solar, past research has sought to understand better the motivations for and barriers to adopting solar PV (Faiers and Neame, 2006; Karakaya and Sriwannawit, 2015; Rai and Robinson, 2013). This research indicates that consumers see benefits from purchasing solar PV, which include a positive net energy life cycle (Faiers and Neame, 2006; Raugei et al., 2012), increased awareness of energy consumption (Truffer et al., 2001), visibility on the exterior of the home as a symbol of social status (Archer et al., 1987), bill savings (Herring et al., 2007), and environmental benefits such as decreasing local pollution (Luque, 2001; Pearce, 2002). In parallel, concerns about the quality of PV systems (Karakaya and Sriwannawit, 2015), uncertainty about bill savings due to changes in regulatory regimes (Borenstein, 2017) lack of understanding of the underlying technological details (Karakaya and Sriwannawit, 2015; Margolis and Zuboy, 2006), lack of trust in the contractor labor force (Rai and Robinson, 2013), and perceptions of technological risk and complexity (Karakaya and Sriwannawit, 2015) all stand to discourage homeowners from going solar. High actual (Margolis and Zuboy, 2006) and perceived total and upfront costs (Karakaya and Sriwannawit, 2015), poor perception of aesthetics on the roof (Faiers and Neame, 2006), and the unreliable and inadequate nature of the contractor workforce (Knudsen, 2002; Margolis and Zuboy, 2006) also deter homeowner purchases. Early research about solar PV adoption has often investigated barriers and motivations for purchasing rooftop solar without specifying details about the solar module itself (e.g. (Labay and Kinnear, 1981)). This most likely occurred since product options in the solar PV market limited consumer choice concerning features like panel and mounting type. In recent years, the industry has sought to address known barriers to adoption, which has resulted in new technological developments with regards to features such as panel type and mounting style, which expanded consumer choice.

Consumers can for example choose between different module materials, conventional rigid modules versus emerging lightweight flexible modules, or building-integrated photovoltaics (BIPV) and building-applied photovoltaics (BAPV), all with impacts on factors such as price and system efficiency. These new technological developments warrant further research into consumer beliefs, to confirm that the new products

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address the primary barriers to adoption and ensure that these solutions do not unknowingly create new barriers that, if unaddressed, would hinder deployment. This study focuses adoption of solar PV by US homeowners. A regionally balanced sample was used to obtain generalizable insights across geographic regions. Literature research, points to shared commonalities (Kebede and Mitsufuji, 2017), as concerns and motivations for going solar PV are shared across municipalities, and at National and International levels (Faiers and Neame, 2006; Labay and Kinnear, 1981; Simpson and Clifton, 2015).

However, regional differences such as government incentives (Kwan, 2012) or peer effects (neighborhood) (Graziano and Gillingham, 2015) could be responsible for a favorable attitude towards solar adoption from participants in different states.

1.1. Theory of Planned Behavior

The Theory of Planned Behavior (TPB) provides a framework to understand and predict human behavior in situations where people have incomplete volitional control (Ajzen, 2001). Per the TPB, the intention to perform the desired behavior precedes the execution of the desired behavior itself (Fishbein and Ajzen, 1975).

Behavioral intentions stem from attitudes, subjective norms and perceived behavioral control. Attitudes towards a behavior embody salient behavioral beliefs about the consequences of performing a behavior that is determined by an evaluation of instrumental beliefs (advantages or disadvantages) and affective beliefs (love or hate) (Fishbein and Ajzen, 1975). Subjective norms result from a combination of beliefs that evaluate the others' expectations and approval of one's decision, and of the strength of those beliefs, or how much one cares with the other's evaluation of self. The motivation to comply with expectations (Cialdini and Trost, 1998) and the perceived social pressure to engage in the behavior drive the strength of normative beliefs (Ajzen, 2011). Finally, perceived behavioral control reflects an evaluation of the factors that encourage or inhibit a behavior and determine their perceived behavioral control. Both internal and external factors influence perceived control over a target behavior.

Another aspect of the theory is the distinction between direct and indirect measures: the former is directly measured (e.g., by asking respondents about their overall attitude) and the latter is measured indirectly (e.g., by asking respondents about specific behavioral beliefs and outcome evaluations) (Francis et al., 2004). Direct and indirect measures have a different role in the theory. According to Montano and Kasprzyk (2008), direct measures of the TPB constructs are better predictors of intentions whereas indirect measures help understand the primary drivers of behavior (e.g., why people hold certain attitudes, subjective norms, and perceptions of behavioral control) (Ajzen, 2002).

This study compared conventional PV with BAPV technology, (hereto referred to as adhesive PV). The adhesive PV consists of flexible, lightweight solar PV panels that have an adhesive in the back, which can be placed directly over the roof. Interconnection with the electric grid is also simplified, via a utility socket positioned in the meter collar. A focus group (n = 6) was held to elicit predominant behavioral beliefs (Ajzen's guidelines in Francis et al. (2004)). Together with literature research and the coded results of interviews with the leaders of four Solarized Communities in Massachusetts (Brookline, Carlisle, Chelmsford, and Medford), the highly ranked beliefs (Appendix A), were incorporated in an online survey designed according to the Theory of Planned Behavior. Respondents were randomly assigned to one of two groups and primed by a brochure depicting either the process of purchasing, installing and commissioning the conventional solar PV array or the adhesive PV concept.

1.2. Research objectives and hypothesis

As discussed, research on consumer attitudes regarding rooftop solar has revealed numerous motivations for and barriers against the adoption of residential solar PV. As solar PV technology continues to develop, new module designs seek to address these barriers and make the decision to "go solar" more accessible. While new technological innovations could make solar PV more attractive and easy to purchase, they could be unearthing concerns that, if unaddressed could hinder adoption of the technology.

The study has two primary research objectives: a) to detect early in the development of the product whether the survey participants reveal more concern toward the adhesive technology, and b) to observe if the adhesive technology can address some concerns traditionally raised by solar adopters (e.g., reliability, attractiveness), and increase purchase intentions.

2. Methods

The salient belief elicitation process started with interviews with community leaders of the Solarize Mass campaign from four local communities (Brookline, Carlisle, Chelmsford, and Medford). Interviews with campaign leaders provided a perspective on the typical characteristics of homeowners in communities that install solar PV, mainly focused on uncovering the primary drivers and barriers to adoption. To supplement the information obtained from the interviews, the relevant literature was reviewed (for example (Faiers and Neame, 2006; Margolis and Zuboy, 2006; Rai and Robinson, 2013)). The target behavior was defined following the TACT technique (Ajzen, 2002): "the rooftop PV system" defines the *target,* "purchasing" the *action*, "for my home" the *context and* "in the next few years" defines the *timeframe*.

2.1. Survey design

The survey was designed according to Ajzen (1991, 2002) and Francis et al. (2004), to capture the intentions and the behavioral, normative and control beliefs (direct and indirect) of homeowners regarding the target behavior of purchasing residential rooftop solar (Appendix B). The semantic differential options were indicated on unimodal or bimodal scales ranging from 1 to 7, and − 3 to 3, respectively. To minimize biases, the order of the questions within blocks was randomized.

2.2. Technological concepts of solar PV

Before filling in the survey, participants were required to review a digital brochure showing what it looked and what it entailed, to purchase, install and commission solar PV for their homes. Participants were randomly assigned to two groups and primed with the conventional PV or the adhesive PV concepts. The differences between the conventional and the adhesive technologies had implications in installation (with or without perforations, and mounting rack versus adhesive mounting, respectively), commissioning, interconnection, and operation. However, both systems were depicted as if they were the standard for PV systems and both brochures were designed to look the same: if any differences in the survey responses occurred, they would be attributable to the technological concepts. These brochures are presented in Appendix C.

2.3. Participant recruitment

Participants (N = 400) were recruited by Qualtrics, with the following selection criteria: owners of a single family home, aged between 25 and 65 + years old, who did not previously own a PV system. The sample was balanced by gender and across four generic regions of the United States: Northeast, South, Midwest and West. Participants were randomly primed with one of the two solar PV concepts (Conventional; N = 205 and Adhesive; N = 195), after which they could complete the survey.

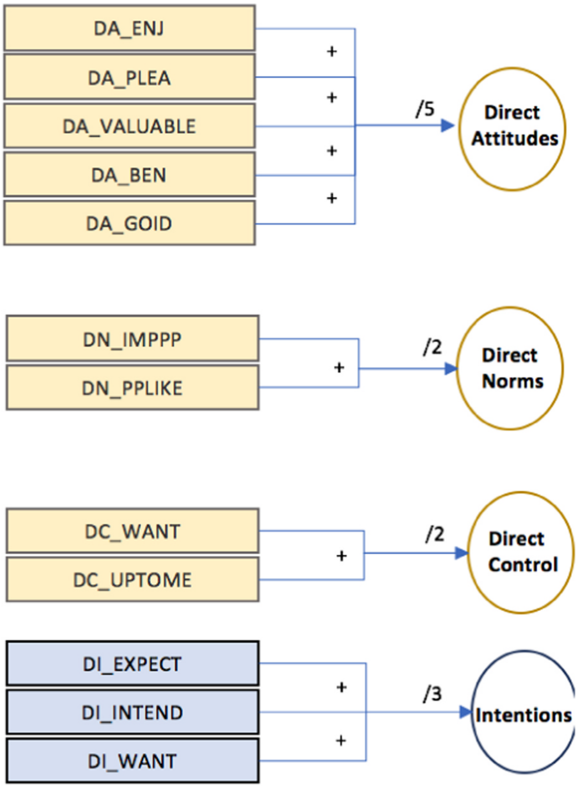

Fig. 1. Calculation of direct measures.

2.4. *Computation of direct and indirect measures*

2.4.1. *Direct measures*

Direct measures were calculated as an average of direct indicators (Fig. 1), scored in a 7 point scale. Direct intentions comprehended the items "I expect to…"; "I intend to …" and "I want to …". Direct attitudes were comprised of "purchasing solar PV would be…" "enjoyable/unenjoyable," "pleasant/unpleasant," "valuable/worthless," "harmful/beneficial"; "a good idea/bad idea." Direct social norms held the items "people who are important to me…" and "people who are like me…", "would approve of my purchase of…". Direct control included the items: "I am confident that I can…" and "It's up to me…". For a better understanding of the measures, please refer to the survey in Appendix B.

2.4.2. *Indirect measures*

Indirect measures are the result of the computation between pairs of variables that include both the elicited attitudinal, normative and control beliefs with the corresponding strength of the importance of that belief to the survey participant.

2.4.2.1. Indirect attitudes. This measure results from the participant's belief regarding the possible outcomes of performing a behavior in conjunction with the evaluation of those outcomes. For example, an attitudinal belief would be "*if I purchase solar PV, for my home, in the next few years, it will help me keep the environment clean,*" and the outcome evaluation would be "*I believe the environment needs to be protected.*" Eq. (1) shows how each attitudinal referent was computed, where (A_i) represents measure (i), (b_i) represents the behavioral belief and (e_i) the outcome evaluation.

$$A_i \approx b_i e_i \tag{1}$$

2.4.2.2. Indirect subjective norm. This measure is presumably influenced by one's beliefs regarding important referents (e.g., parents, friends) as well as one's motivation to comply with these referents in individual decision making. Indirect normative measures (SN_B) are the subjective norm beliefs (nb_j) multiplied by the motivation to comply with others (m_j) (see Eq. (2)).

$$SN_B \approx nb_j m_j \tag{2}$$

Indirect perceived behavioral control: accounts for the control an individual may feel over performing a behavior. Indirect perceived behavioral control measures (PBC) are the result of the multiplication of the control beliefs (c_k) multiplied by the belief strength (p_k). Formally, this is represented by Eq. (3).

$$PBC \approx c_k p_k \tag{3}$$

2.4.3. *Method of analysis of the latent relationships between TPB constructs and measures*

Following the guidelines of Hair et al. (2011), a variance-based Partial Least Square-Structural Equation Modeling (PLS-SEM) was selected and implemented using the software SmartPLS 3 (Ringle et al., 2015). In line with the decision rules of Coltman et al. (2008), the model is reflective. The structural model (Fig. 2), illustrates the relationships between latent exogenous and endogenous variables (Hair et al., 2009).

3. Results

3.1. *Demographic characteristics of the sample*

Table 1 shows the demographic characteristics of the sample. Participants were homeowners of single-family homes, whose age ranged from under 25 to over 65, with an income from under \$20,000 to over \$100,000 per year. 83% of the respondents are college educated, with no appreciable differences between groups. The sample was balanced for gender.

3.2. *Analysis of direct measures*

Following the guidelines of Petkova et al. (1995) and French et al. (2005), Cronbach's α was used to measure the reliability of the computed constructs, while the relationship between predictors (direct attitudes, direct control and direct norms, and technology: 0 = Conventional and 1 = Adhesive) and the dependent variable (direct intentions) were modeled using a multivariate regression technique (Ajzen, 1991). Table 2 illustrates that the degree of internal consistency among items for attitudes, intentions, and norms is high and medium for control. The internal consistency of the four constructs is high, for both groups αConv. = 0.845 = and αAdhs. = 0.882.

For the same group of items, the percent variance relative to the average, measured by the coefficient of variance (CV), has the same magnitude, in both groups. Means of the composite constructs are more favorable for the Adhesive group.

The Mann-Whitney test (Table 2) evaluated the statistical difference between groups for the dependent variable (intentions to purchase solar PV). Mann-Whitney is a non-parametric rank ordered test that compares the medians of two independent samples. It established that a statistically significant difference in the direct intentions variable exists, slightly more favorable to the Adhesive concept ((U(1) = 4.00, p = 0.047). This indicates that just in response to the questions "I expect to purchase solar PV for my rooftop in the next few years", "I intend to purchase solar PV for my rooftop in the next few years", and "I want to purchase solar PV for my rooftop in the next few years", responses were in median more favorable to the Adhesive concept.

To evaluate the level to which the direct variables (attitudes, perceived control and social norms) predict intentions, we applied a multivariate linear regression model. A dummy variable was added to represent each brochure (block score 0 = Conventional; block score 1 =

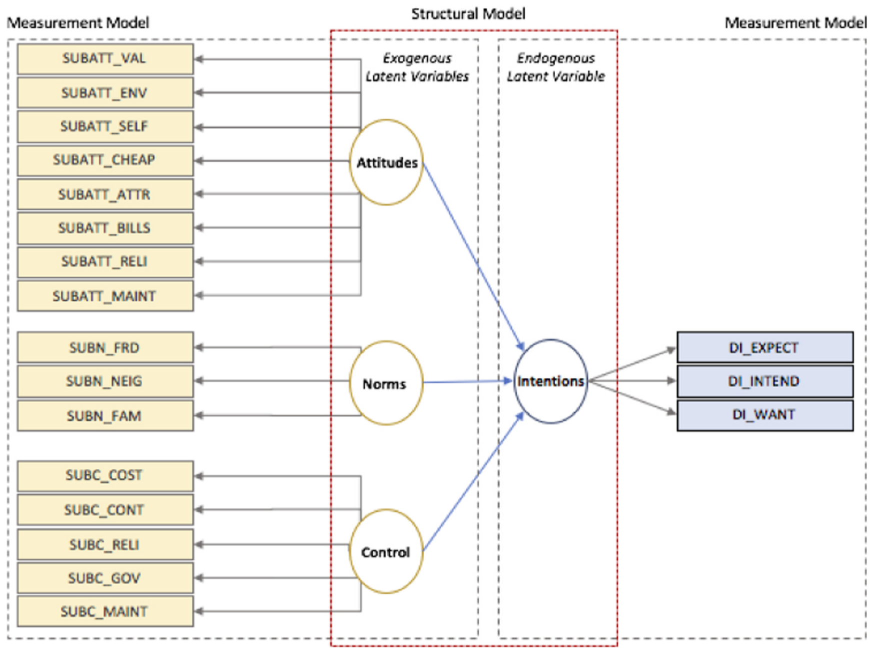

Fig. 2. PLS-Model overview.

Table 1
Demographic characteristics of the sample.

		Conventional PV	Adhesive PV
Income	Under $20,000	7	2
	$20,000 - $39,999	29	30
	$40,000 - $59,999	55	54
	$60,000 - $79,999	56	53
	$80,000 - $99,999	29	22
	$100,000 or more	44	49
Education	Less than high school	–	1
	High school / GED	41	41
	Some college/Associates degree	63	78
	4-year college degree	82	57
	Master's degree	27	28
	Doctorate or professional degree	7	5
Age	25 – 34	3	2
	35 – 44	43	39
	45 – 54	75	51
	55 – 64	92	115
	65 +	7	3

Table 2
Descriptive statistics of the main TPB constructs.

Technologies	Conventional			Adhesive		
	Mean (STD)	CV	C_α	Mean (STD)	CV	C_α
Direct intentions: 3 items	3.70 (1.77)	48%	0.921 0.914 0.900 0.505	3.83 (1.88)	49%	0.909
Direct attitudes: 5 items	4.90 (1.43)	29%	0.914	5.13 (1.51)	29%	0.944
Direct subjective norms: 2 items	5.12 (1.34)	26%	0.900	5.20 (1.43)	28%	0.882
Direct control: 4 items	4.64 (1.62)	35%	0.505	5.01 (1.50)	30%	0.528
Calculated intentions, norms, and control			0.845			0.882

Adhesive). The Durbin Watson test shows that the independent variables are not correlated (DW = 1.839 ≈ 2). The proportion of the dependent variable that is explained by the independent variables is high

Table 3
Summary regression model.

R	R^2	R^2_{adj}	Std. Error of the Estimate	R^2 Change	Durbin Watson
0.815	0.665	0.661	1.007	0.665	1.839

Table 4
Regression coefficients.

	Unstandardized Coefficients		Standardized Coefficients		
Model	B	Std. Error	ß	t	Sig.
Constant	− 1.451	0.215		− 6.759	0.000
DI_DA	0.748	0.057	0.638	13.014	0.000
DI_DN	− 0.005	0.061	− 0.004	− 0.076	0.940
DI_DC	0.317	0.037	0.289	8.563	0.000
Block Score[a]	0.074	0.102	0.021	0.725	0.469

[a] Block score → 0 = Conventional PV; 1 = Adhesive PV.

$R^2_{adj.}$ = 0.661 ($p < 0.01$; Table 3).

Regression coefficients in Table 4 below show that direct attitudes (DI_DA, ß = 0.638 p = 0.000) and direct control (DI_DC, ß = 0.289, p = 0.000) have a statistically significant positive influence on intentions to purchase PV. This could imply that if residents feel positive and in control, they are more strongly inclined to purchase PV. The effects of direct norms (DI_DN) and the block score were not significant. This indicates that whether the survey participants were exposed to one or the other brochure did not have a significant impact on the direct intentions to purchase solar PV. It also shows that direct norms had no significant direct impact on intentions.

3.3. Indirect measures: effect of attitudinal, normative and control beliefs

This section presents the results of the PLS-SEM modeling based on the Theory of Planned Behavior to understand why people hold certain salient beliefs (attitudes, subjective norms, and perceptions of behavioral control Ajzen, 2002), and their effect on the intentions to purchase solar PV.

3.3.1. Initial PLS SEM-Model

Reliability and validity of the overall PLS-SEM were tested[1] (Wong, 2013) and a bootstrapping technique[2] was used to test the accuracy of estimates of the structural model[3] (Hair et al., 2009) (Appendix D). Tests revealed that the reliability of a few indicators that form the latent Attitudes construct was low (outer loadings $\leq$ 0.4) and convergent validity for that construct was below the required threshold of 0.5. Therefore, an item trimming process was implemented to improve the consistency and stability of the model.

For illustration purposes, we observed how the attitude indicators loaded with direct attitudes. The method produced two significant eigenvectors, with the second grouping three variables that were excluded from the trimmed model. For interpretation purposes, we propose that the variables that highly correlate with direct attitudes have a positive influence in the intentions to purchase solar PV, while the ones that load in the second vector represent the barriers to the adoption of solar PV.

From this perspective, the drivers would include beliefs that “PV increases the value of a home”, “PV is clean”, “promotes self-sufficiency”, and that “spending on electrical bills is wasteful”. The second vector encapsulates barriers: “cost”, “reliability”, and “maintenance” (Fig. 3). This figure shows that the elements that the participants felt more positively or more negatively about were “automatically” split in two dimensions. Those elements are drivers or barriers (respectively) to the adoption of the PV technology that are typically referenced in the literature (Faiers and Neame, 2006). The overlay of the eigenvalues for both technologies, shows that despite its novelty, the adhesive system does not seem to be raising more issues than the conventional PV system.

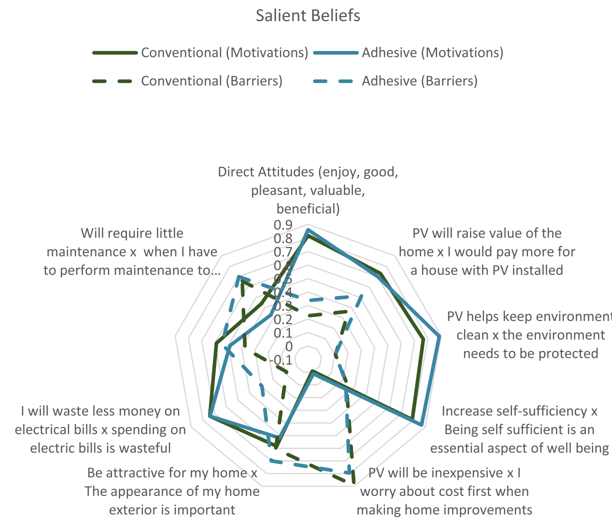

Fig. 3. Salient beliefs and how they load with direct attitudes.

3.3.2. Trimmed PLS SEM-Model

To increase indicator reliability,[4] the above identified measures “cost”, “reliability”, and “maintenance” with very low loadings were removed one at a time. Results of the reliability and validity tests for the trimmed model are displayed in Table 5 below.

All remaining indicators in the trimmed model showed reasonable factor loadings of at least 0.5 ($p < 0.05$)[5] and acceptable convergent validity[6] (AVE > 0.5) for Attitudes. Table 5 shows that except for Attitudes which correlate slightly with Perceived Behavioral Control, discriminant validity between all measures was ensured.[7] Composite reliability[8] was also well established between all measures (Bagozzi and Yi, 1988). It included the actual factor loading instead of equal weighting (Chin, 1998) and was more suitable for SEM-PLS evaluation than the Chronbach α previously reported to determine the model reliability for direct measures.

To explore the differences of belief structures of respondents primed with either adhesive or conventional PV, PLS SEM was calculated for each group (see Figs. 4 and 5), and a bootstrapping technique was again used to test the accuracy of estimates (Chin, 1998; Efron and Tibshirani, 1993).

3.3.2.1. Outer Loadings.

Outer loadings and t-statistics of the bootstrapping procedure for each group are presented in Appendix E. The two-tailed *t*-test shows that all indicators are highly significant in both groups ($p < 0.01$). The absolute contribution of each indicator to its latent variable is shown in Figs. 4 and 5. All indicators of Intentions and Subjective Norms highly loaded in both model calculations.

A few differences between technologies were observed. The indicator that measured the perception of the neighbor approval towards the adoption of solar PV, (IDN_NEIG), contributed more strongly to the variable Subjective Norms in the adhesive group. Similarly, “Will waste less on utility bills” (SUBATT_BILLS) and “keep the environment clean” (SUBATT_ENV”) contribute higher to Attitudes in the Adhesive PV group.

The PCB variable shows slightly different loadings in the two different model calculations, as the “requires little maintenance” (IC_MAINT) and “solar PV is reliable” (IC_RELI) contribute more to the latent variable in the Adhesive group.

3.3.2.2. Predictive power of the structural model.

The structural models for adhesive and conventional PV were evaluated to test the predictive power of the theoretical model and the stability of estimates.[9] With high R^2 values, Table 6 shows both models highly explain the variability in intentions to purchase PV (66.8% for Conventional and 63.5% for Adhesive PV).

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[1] Criteria for validating reflective constructs in literature include: indicator reliability, construct reliability, convergent validity and discriminant validity (Barroso et al., 2010; Chin, 1998; Hulland, 1999).

[2] For this procedure, 5000 subsamples (Hair et al., 2009) are taken from the original sample to give bootstrap standard errors and approximate T-values for significance testing of the structural path (Wong, 2013). The Bootstrap result approximates the normality of data.

[3] For extensive results of the reliability and validity tests and the bootstrapping procedure for the initial model please refer to Appendix D.

[4] Indicator reliability specifies which part of an indicator's variance can be explained by the underlying latent variable. A common threshold is to accept loadings of 0.707 or more (Summers and Bohrnstedt, 1970; Tenenhaus et al., 2005), however loadings of 0.4 − 0.5 can be acceptable for exploratory studies (Hulland, 1999).

[5] For significance of outer loadings see t-values, Appendix E. t-values > 1.96 imply significance level of 5%.

[6] AVE > 0.50, indicates that at least 50% of the indicator variance are accounted for (Barroso et al., 2010).

[7] Discriminant validity examines the extent to which a given construct differs from the other constructs (Barroso et al., 2010). Per Fornell and Larcker (1981) the square root of AVE for each latent variable can be used to establish discriminant validity, if the value is larger than other correlation values among the latent variables. Detailed results of the Fornell-Larcker criterion for discriminant validity can be found in Appendix E.

[8] Composite reliability evaluates the degree to which constructs are consistent with what they are intended to measure (Straub et al., 2004).

[9] Due to the assumption of distribution-free variance, the PLS method does not allow statistical tests to measure the model's overall goodness, but requires non-parametrical tests to evaluate the structural model's quality (Götz et al., 2010). Criteria include examining the R^2 measures to assess the predictive power of the endogenous constructs and the path coefficients’ directions and T-values for significance levels (Chin, 1998; Hair et al., 2009).

Table 5
Summary table for reliability and validity of the trimmed model.

Latent variable	Indicators	Indicator reliability (outer loadings)	Composite Reliability	Average Variance Extracted (AVE)
Attitudes	SUBATT_ATTR	0.79	0.87	0.56
	SUBATT_BILLS	0.62		
	SUBATT_ENV	0.73		
	SUBATT_SELF	0.81		
	SUBATT_VALUE	0.79		
Intentions	DI_EXP	0.94	0.95	0.86
	DI_INTEND	0.94		
	DI_WANT	0.89		
Perceived Behavioral Control	SUBC_CONT	0.70	0.84	0.51
	SUBC_COST	0.58		
	SUBC_GOV	0.78		
	SUBC_MAINT	0.77		
	SUBC_RELI	0.74		
Subjective Norms	SUBN_FAM	0.88	0.88	0.72
	SUBN_FRD	0.88		
	SUBN_NEIG	0.78		

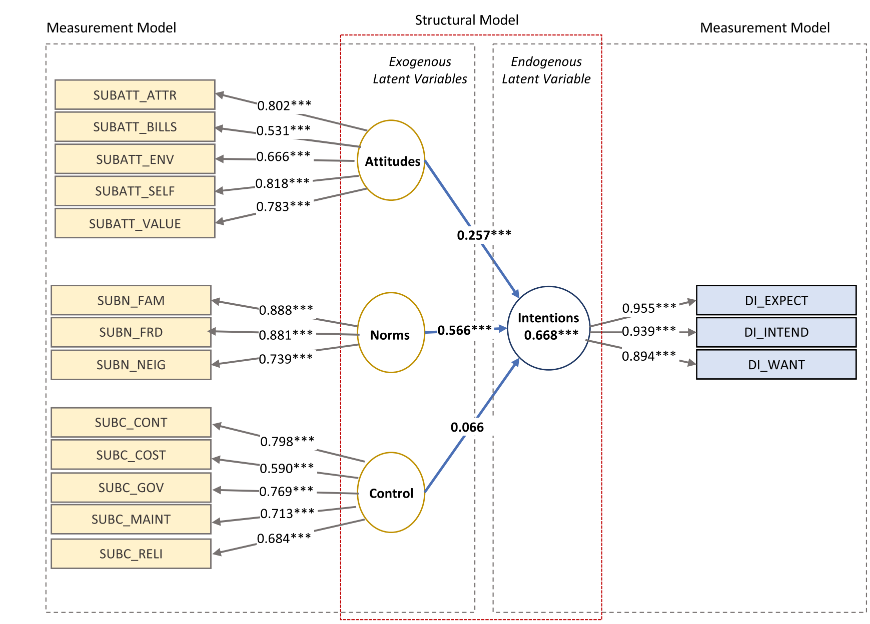

Fig. 4. Trimmed SEM model for conventional PV.

3.3.2.3. Path coefficients of the structural model. Table 7 below shows that Attitudes and Subject Norm strongly affect Intentions to purchase solar PV for both Adhesive and Conventional PV. The effect size of the path coefficients for both models suggest that Subjective Norms have the strongest effect on intentions to purchase solar PV. The effect of Social Norms is bigger in the Conventional PV group (0.53) than in the Adhesive PV group (0.48). Attitudes are significantly more influential in Adhesive group (Adhesive = 0.36; Conventional = 0.31). PBC does not predict participants' Intentions to purchase solar PV.

3.3.2.4. Multi-group analysis. Partial Least Squares Multi-group Analysis (PLS-MGS) was used to evaluate the group-specific parameter differences (Henseler et al., 2009). This method is non-parametric, with results being significant at the 5% error level if the p-value is < 0.05 for the difference between group-specific path coefficients. Table 8 reveals that the differences in the path coefficients are not statistically different between groups. Regarding the outer loadings, a difference is found in the variable "I will find a reputable contractor" (IC_CONT) indicator, which contributes significantly more to the to the PBC in the conventional group than in the adhesive group (see Appendix E).

4. Conclusion and policy implications

Individual decision making provides a key component to wide-spread diffusion of rooftop solar PV technology. As the market for

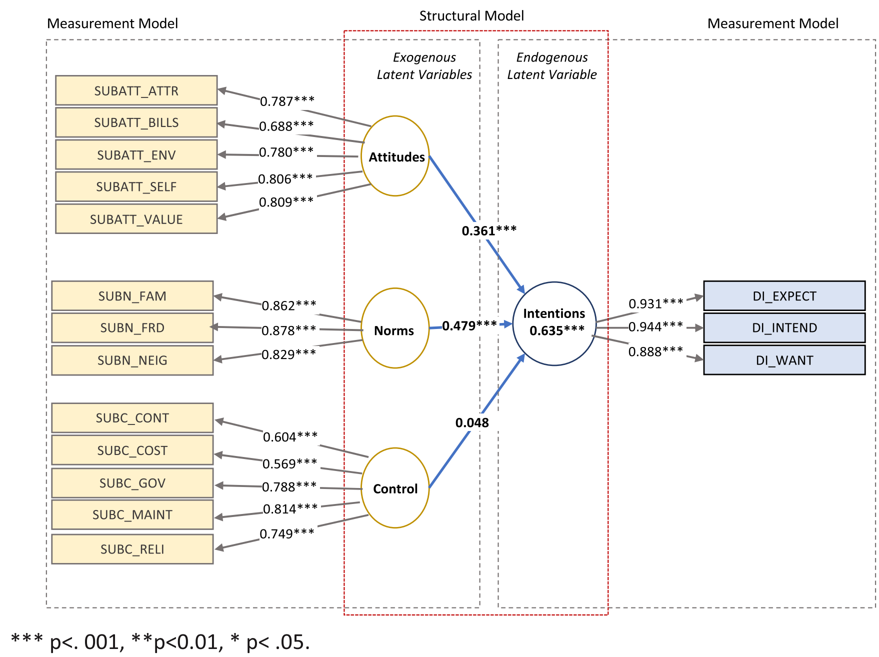

Fig. 5. Trimmed SEM model for adhesive PV.

Table 6
Variance of the explained for each Group.

	Original Sample (O; R^2)	*Sample Mean*	*Standard Deviation*	*t- Statistics (|O/STDEV|)*	*P Values*
Intentions Conventional PV	0.668	0.678	0.034	19.467	0.000
Intentions Adhesive PV	0.635	0.642	0.042	15.076	0.000

Table 7
T-statistics of path coefficients (inner model).

		Original Sample	*Sample Mean*	*Standard Deviation*	*T Statistics*	*P Values*
Conventional PV	*Attitudes - > Intentions*	*0.31*	*0.31*	*0.07*	*4.47*	*0.000*
	PCB - > Intentions	*0.05*	*0.06*	*0.06*	*0.95*	*0.343*
	SN - > Intentions	*0.53*	*0.53*	*0.04*	*11.96*	*0.000*
Adhesive PV	*Attitudes - > Intentions*	*0.36*	*0.36*	*0.10*	*3.64*	*0.000*
	PCB - > Intentions	*0.05*	*0.06*	*0.08*	*0.61*	*0.542*
	SN - > Intentions	*0.48*	*0.48*	*0.06*	*7.69*	*0.000*

Table 8
Path coefficients for the PLS-MGS test.

	Path Coefficients-diff Block(0.0) - Block(1.0)	**p-Value Block(0.0) vs Block(1.0))**
Attitudes - > Intentions	0.104	0.777
PCB - > Intentions	0.017	0.435
Subjective Norms - > Intentions	0.087	0.163

rooftop solar has grown in recent years, consumer choice has expanded with it. Consumers increasingly have the option between features such as conventional rigid or flexible panels, different mounting styles, and price. This study aimed to add a layer of depth to previous research by comparing the strength and nature of these factors between conventional solar PV and a new lightweight, adhesive PV technology. Designed for quick, easy, and safe installation with lightweight panels, we hypothesized participants would exhibit more favorable beliefs towards the adhesive PV concept. Further, we expected participants to indicate a stronger intention to purchase PV when exposed to the adhesive concept as compared to the conventional one.

The results of the study confirm the motivations and barriers to adopting solar discussed by previous research (for example (Karakaya and Sriwannawit, 2015; Margolis and Zuboy, 2006)) and lend initial support to two main conclusions. First, the results indicate the concept of placing an adhesive structure on the rooftop is generally well accepted and, despite its novelty, does not raise more issues than conventional PV. It represents a generally more attractive alternative to conventional PV, thus leading to a stronger intention of adopting adhesive PV and partially supporting the hypothesis that homeowners would react favorably to the adhesive PV concept.

While participants exhibited similar behavioral beliefs for both conventional and adhesive PV concepts, they indicated slightly more favorable normative beliefs and attitudes towards the decision to purchase adhesive PV: factors such as upfront cost, maintenance, and attractiveness, commonly perceived as disadvantages to the adoption of solar PV, were less impactful for adhesive PV-primed individuals in comparison with the conventional PV. In addition, survey participants primed with the adhesive BAPV indicated a stronger direct intention to purchase solar PV as compared to their survey counterparts receiving information about conventional PV.

Second, this research suggests that technology developers and practitioners should frequently assess the barriers and motivations associated with adopting new technologies and highlights the importance of continued awareness that new technological developments could unintentionally spur new barriers to adoption. While the motivation for adopting PV remained the same irrespective of the technology, during the focus groups participants raised new concerns about the adhesive system, concerning the reliability (“ability for the adhesive mount to withstand inclement weather”) or the lifetime of the system (“how long would the system remain durable”; “impact the adhesive would have on the roof”; “whether the panels would be removable”). These are issues that should be addressed by manufacturers during the design phase of the product.

The development of the adhesive technology was funded by a SunShot Grant of the U.S. Department of Energy (DOE), which supported technological innovations designed to reduce the costs and increase adoption of solar PV by residential homeowners. However, the scope of the present study was to evaluate if the innovation would raise new concerns that could hinder the adoption of the technology. From that perspective, the results indicate that the adhesive technology would not raise more issues than conventional technology.

The participants were not informed of the cost of purchasing or installing the solar PV technology by the study. If there was a reference point for what that cost could be, it was already on the minds of the participants, before partaking in the study, which could explain why the cost was not a "discriminant characteristic" between groups. Previous research (Faiers and Neame, 2006), documents that when it concerns the adoption of innovations, the cost is less worthy than other dimensions. The results indicate that the concerns regarding the adoption of solar PV are related with individual attitudes towards solar PV and social normative concerns. The reasons for intending to adopt PV are more subjective rather than rational. Thus, policies that favor community engagement and information dissemination seem to be adequate strategies to increase the local adoption of solar PV.

5. Limitations of the study

A limitation of the study is the lack of a control group that was not primed with a solar concept depicted by a brochure. For that reason, we suggest that future research should consider including such control to determine if the brochure design per se had any effect in the residents' responses. Another limitation of the study is that it ignores the effect of local State incentive policies, which is an aspect that has been reported in the literature, to affect the willingness to adopt solar PV (Kwan, 2012).

In addition, alternative methodologies could provide a better gauge for user acceptance. For example, a preference study where participants could compare the features of the two technologies at the same time and choose the one they prefer. Such a study would have added more detail to the results achieved in this study and would provide greater depth into the observation of the consumer's behavioral, normative and control beliefs about the intentions to adopt solar PV.

Acknowledgments

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Appendix A. Behavioral Beliefs

Salient Behavioral Beliefs

Focus group participants discussed the clean energy and environmental benefits of solar and the ability to save money on energy bills as the two dominant aspects of adopting solar they would like or see as advantageous. The initial investment required to install solar PV was the primary concern of participants when discussing what they would dislike or see as disadvantageous of adopting solar (Fig. A1). Other salient behavioral beliefs included concerns about finding a reputable contractor, the work to install and maintain the panels, reliability of the panels, and self-sufficiency from the grid (both as a positive and negative aspect; Table A1).

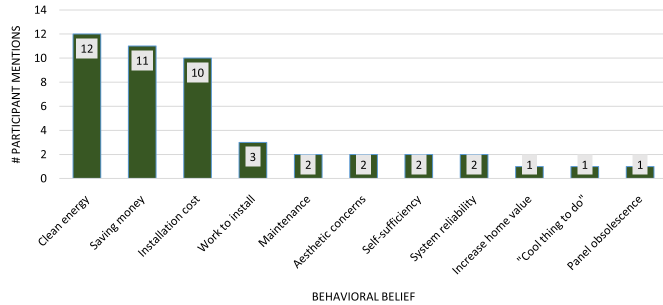


Fig. A1. Emergent salient beliefs.

Table A1
Top Emergent behavioral beliefs about conventional PV.

Emergent Theme	Example Participant Response
Clean Energy	• Reduce carbon footprint • Cleaner Energy • Keep environment clean • Good for the planet
Saving Money	• Long term cost saving • I would enjoy the savings on my utility bills • Generate cheaper heat and hot water and electricity
Installation Cost	• Initial investment, although I understand that anything worth doing has a price • I would dislike the cost but with tax rebates it all works out in the end • Unless it is a DIY thing, the only disadvantage to me is the cost initially

Salient normative beliefs

When considering which individuals or groups would approve or disapprove of their adoption of solar PV, participants predominantly mentioned three categories of referents: friends and family, neighbors, and other interest groups. Friends and family were by far the most commonly cited referent, both as an individual and a group. Most participants mentioned their friends and family would approve of adopting solar, while a small percent noted they would disapprove. Participants mentioned neighbors and other interest groups in roughly similar frequency, both as approving and disapproving of adoption. The "other interest group" category included sustainable energy groups, utility companies, members of historic districts, and local, state, and federal governments.

Salient control beliefs

Finally, participants were asked to note what they believed would make it easier or more difficult for them to acquire solar modules. Participants most frequently mention financing as a factor that would make it easier to adopt solar referencing access to low interest loans, grants, government subsidies, and tax credits. Similarly, participants mentioned the high cost as a factor that makes it more difficult to adopt solar. Contractor availability, time to recoup the cost of the investment, and getting permit approval by government agencies were also discussed as factors influencing the ease or difficulty of acquiring solar.

Additional beliefs specific to adhesive solar PV

After being introduced to the new concept of adhesive PV, participants again responded to the Theory of Planned Behavior questions to elicit any additional behavioral, normative, and control beliefs that may have emerged specifically about Adhesive PV. While the questions elicited no additional normative or control beliefs for plug and play PV, three additional, and noteworthy behavioral beliefs emerged: positive beliefs regarding ease of installations and initial cost and concerns regarding the adhesive mounting.

Table A2 below provides sample participant responses regarding these beliefs. When exposed to the adhesive concept, participants noticeably reacted positively to the easier, do-it-yourself approach to installations as this became the most frequently cited likeable or advantageous aspect of adopting the adhesive PV. Similarly, participants noted the cost as a positive aspect of adopting solar, whereas for conventional PV it had only been noted as something participants would dislike or see as disadvantageous.

Alternatively, concerns with the adhesive mounting system dominated participant responses regarding what they would dislike or see as a disadvantage of acquiring the adhesive PV panels.

Table A2

Additional emergent behavioral beliefs regarding the adhesive PV concept.

Emergent Theme	Example Participant Response
Ease of Installation	• I can do it myself / DIY • Easier to install • Easy, simple, convenient installations • Simpler system ~ easier maintenance
Cost of Modules	• Cost is lower • Cheaper to install • Cost effective • Save money
Reliability of Adhesive Mounting	• Adhesive unable to withstand weather conditions • That the backing is adhesive and they are not bolted down • Ease of removal for roof repair? • Worries about the panels[a] staying attached to the roof • Reliability, maintenance of adhesive

[a] The term panels, commonly used by target participants of the focus group is popular form for modules.

Appendix B. Survey questionnaire

This appendix describes the elements that were included in the questionnaire with the objective of evaluating direct and indirect attitudes, norms and perceived control (Table B1). The order of the questions was randomized.

Table B1

Survey questions developed to assess theory of planned behavior.

MEASURES	SURVEY QUESTIONS	SEMANTIC DIFFERENTIALS	CODES
DIRECT INTENTIONS	I expect to purchase solar PV for my home in the next few years.	Strongly agree = 7 / Strongly disagree = 1	DI_EXP
	I intend to purchase solar PV for my home in the next few years.	Extremely likely = 7 / Extremely unlikely = 1	DI_INT
	I want to purchase solar PV for my home in the next few years.	Strongly agree = 7 / Strongly disagree = 1	DI_WANT
DIRECT ATTITUDES	For me, purchasing solar PV for my home in the next few years would be …	Enjoyable = 7 / Unenjoyable = 1	DA_ENJ
		Pleasant = 7 / Unpleasant = 1	DA_PLS
		Valuable = 7 / Worthless = 1	DA_VAL
		Harmful = 1 / Beneficial = 7	DA_HRM
		A good idea = 7 / A bad idea = 1	DA_GOD
SUBJECTIVE ATTITUDINAL BELIEFS	If I purchase solar PV for my home in the next few years, it will	Raise the value of my home = 7 / Not raise the value of my home = 1	IDA_VAL
		Help me keep the environment clean = 7 / Not help me keep the environment clean = 1	IDA_ENV
		increase my self-sufficiency = 7 / not increase my self-sufficiency = 1	IDA_SELF
		be cheap = 7 / be expensive = 1	IDA_CHEAP
		be attractive = 7 / be unattractive = 1	IDA_ATTR
		waste less money on electric bills = 7 / waste more money on electric bills = 1	IDA_BILLS
		will be dependable for at least 15 years = 7 /will not be dependable for at least 15 years = 1	IDA_RELI
		will require low maintenance = 7 / will require high maintenance = 1	IDA_MAINT
STRENGTH OF SUBJECTIVE ATTITUDINAL BELIEFS	Rate how likely or unlikely this statement is you: I would pay a little more for a house that has solar PV already installed.	Very likely = 3 / Very unlikely = −3	IDAS_VAL
	I believe the environment needs to be protected.	Very likely = 3 / Very unlikely = −3	IDAS_ENV
	Please rate how much you identify with the following statement: Self-sufficiency is an essential aspect of well-being.	Just like me = 3 / Not at all like me = −3	IDAS_SELF
	Rate how likely or unlikely this statement is for you. I worry about cost first when making home improvement decisions.	Very likely = 3 / Very unlikely = −3	IDAS_CHEAP
	Please rate the importance of the following to you. The appearance of my home exterior is …	Extremely important = 3 / Extremely important − 3	IDAS_ATTR
	Please rate the importance of the following to you. Spending on electric bills is wasteful.	Very likely = 3 / Very unlikely = −3	IDAS_BILLS
	In general, I am concerned about long term reliability of my home infrastructure.	Very likely = 3 / Very unlikely = −3	IDAS_RELI
	Rate how much you believe in the following statement. When I have to perform maintenance to the home exterior I am …	Very displeased = −3 / Very pleased = 3	IDAS_MAINT

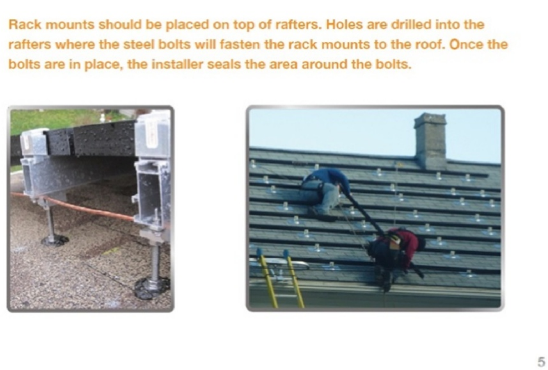
(*continued on next page*)

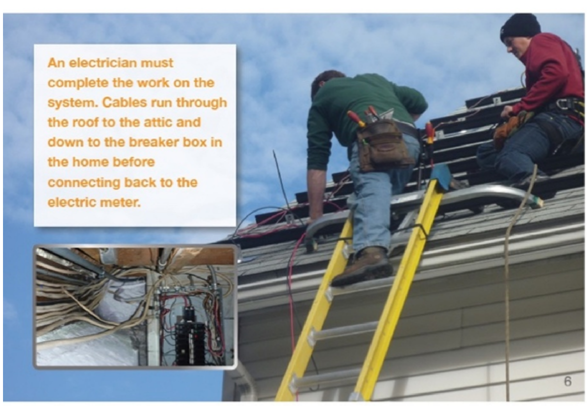
Table B1 (*continued*)

MEASURES	SURVEY QUESTIONS	SEMANTIC DIFFERENTIALS	CODES
DIRECT NORMS	Rate how much you agree or disagree with the following statement: Most people who are important to me would approve if I purchase solar PV in the next few years.	Strongly agree = 7 / Strongly disagree = 1	DN_PPL
	Rate how likely or unlikely you think the following statement is. People who are like me would approve of my purchase of solar PV in the next few years.	Very likely = 7 / Very unlikely = 1	DN_LIKE
SUBJECTIVE NORMATIVE BELIEFS	Rate how likely or unlikely the following statement is for you. Most of my friends who own homes will purchase solar PV in the next few years.	Very likely = 3 / Very unlikely = −3	IDN_FRD
	Rate how likely or unlikely the following statement is for you. My neighbors would approve if I purchase solar PV in the next few years.	Very likely = 3 / Very unlikely = −3	IDN_NEIG
	Rate how likely or unlikely the following statement is for you. My family thinks that I should purchase solar PV in the next few years.	Very likely = 3 / Very unlikely = −3	IDN_FAM
STRENGTH OF SUBJECTIVE NORMATIVE BELIEFS	When it comes to investing in your home, how important are the experiences of your homeowner friends?	Extremely important = 7 / Extremely unimportant = 1	IDNS_FRD
	Rate how much you agree or disagree with the following statement. My neighbors' approval of my home is important to me.	Strongly agree = 7 / Strongly disagree = 1	IDNS_NEIG
	Rate how much you agree or disagree with the following statement. What my family thinks I should do matters to me.	Strongly agree = 7 / Strongly disagree = 1	IDNS_FAM
DIRECT CONTROL	If I wanted to, I could purchase solar PV in the next few years.	Extremely confident = 7 / Not at all confident = 1	DC_WNT
	It is entirely up to me if I purchase solar PV in the next few years.	Completely agree = 7 / Completely disagree = 1	DC_UPTO
SUBJECTIVE PERCEIVED BEHAVIORAL CONTROL BELIEFS	I expect that the up-front cost of purchasing solar PV will not be an issue.	Strongly agree = 7 / Strongly disagree = 1	IC_COST
	I will be able to find a reliable contractor if I install solar PV in the next few years.	Extremely likely = 7 / Extremely unlikely = 1	IC_CONT
	I believe that solar technology is reliable.	Strongly agree = 7 / Strongly disagree = 1	IC_RELI
	I expect that government incentives will help my purchase of solar PV in the next few years.	Strongly agree = 7 / Strongly disagree = 1	IC_GOV
	I am confident that solar PV does not require much maintenance.	Extremely confident = 7 / Extremely unconfident = 1	IC_MAINT
STRENGTH OF SUBJECTIVE PERCEIVED BEHAVIORAL CONTROL BELIEFS	In general, do upfront costs make you more or less likely to make investments in your home?	Highly likely = 7 / Much less likely = 1	ICS_COST
	Being able to hire a reliable contractor makes it…	more likely that I will do home improvement projects. = 3 / less likely that I will do home improvement projects. = −3	ICS_CONT
	I am …	more likely to purchase electronic items if they are reliable. = 3 / less likely to purchase electronic items if they are reliable. = −3	ICS_RELI
	Government incentives will make it …	easier to purchase solar PV. = 3 / harder to purchase solar PV. = −3	ICS_GOV
	I am …	more likely to purchase equipment that will require little maintenance. = 3 / less likely to purchase equipment that will require little maintenance. = −3	ICS_MAINT

Appendix C. Brochures depicting the look and feel of installing conventional and residential solar PV

Conventional Technology Brochure Installation

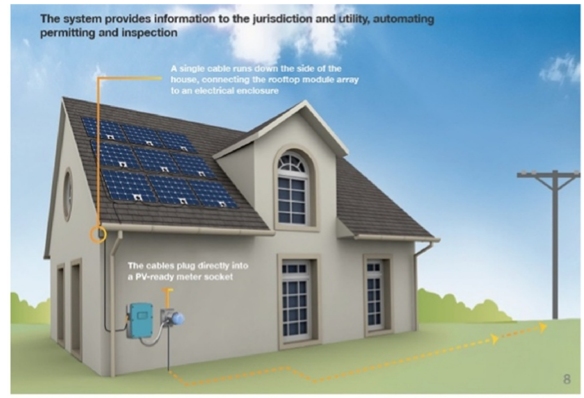


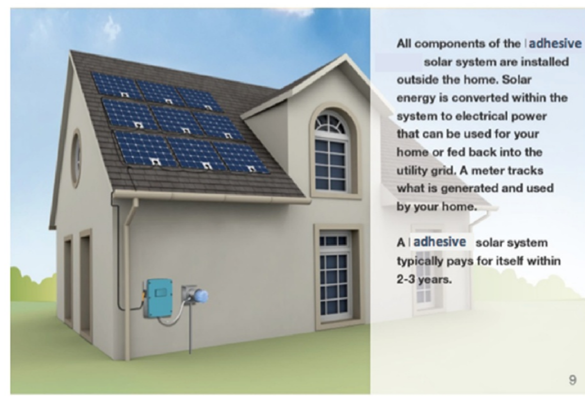


Adhesive Technology Brochure Installation

How does it work?

How does it work?





Appendix D. PLS SEM: Initial Model Results

See Fig. D1 and Tables D1–D4

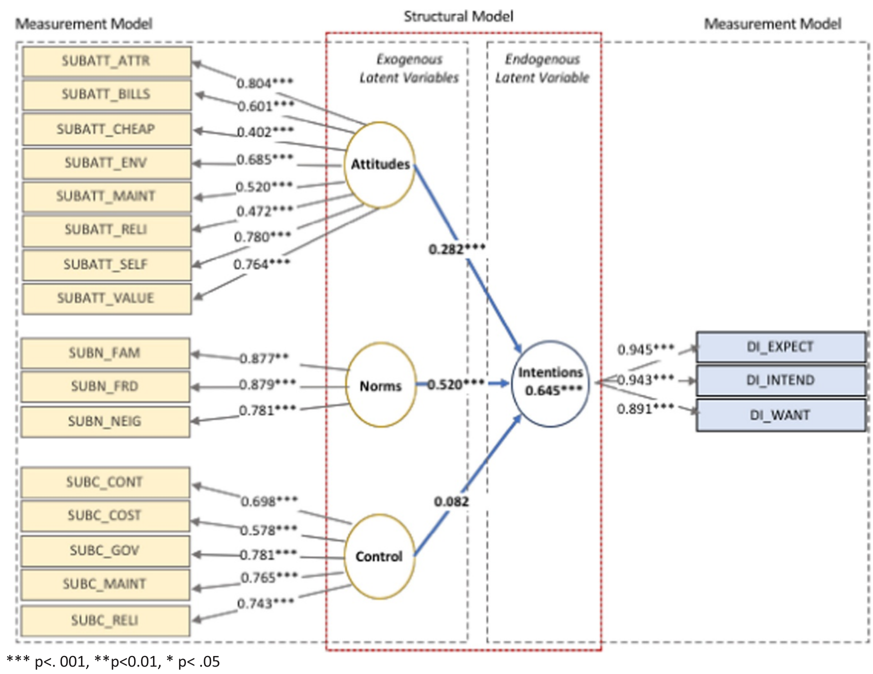


Fig. D1. Initial SEM-model.

Table D1
Results summary for reliability and validity of the initial model.

Latent variable	Indicators	Outer Loadings (indicator reliability)	Composite Reliability	Average Variance Extracted AVE (convergent validity)
Attitudes	SUBATT_ATTR	0.804	0.84	**0.42**
	SUBATT_BILLS	0.601		
	SUBATT_CHEAP	0.402		
	SUBATT_ENV	0.685		
	SUBATT_MAINT	0.520		
	SUBATT_RELI	0.472		
	SUBATT_SELF	0.780		
	SUBATT_VALUE	0.764		
Behavioral Intentions	DI_EXP	0.945	0.95	0.86
	DI_INTEND	0.943		
	DI_WANT	0.891		
Perceived Behavioral Control	SUBC_CONT	0.698	0.84	0.51
	SUBC_COST	0.578		
	SUBC_GOV	0.781		
	SUBC_MAINT	0.765		
	SUBC_RELI	0.743		
Subjective Norms	SUBN_FAM	0.877	0.88	0.72
	SUBN_FRD	0.879		
	SUBN_NEIG	0.781		

Table D2
Fornell-Larcker criterion for discriminant validity of the initial model[a].

	Attitudes	Control	Intention	Norms
Attitudes	**0.65**			
Behavioral Intentions	0.70	**0.93**		
Perceived Behavioral Control	0.79	0.61	**0.72**	
Subjective Norms	0.69	0.76	0.60	**0.85**

[a] Discriminant validity is established, if the AVE value for each latent variable is larger than other correlation values among latent variables (Fornell at al, 1981).

Table D3
Predictive power of the initial model.

	R^2 Original Sample	R^2 Sample Mean	Standard Deviation	T Statistics	P Values
Behavioral Intentions	0.645	0.650	0.026	24.3998	0.000

Table D4
Significance of path coefficients of the initial model[a].

	Original Sample	Sample Mean	Standard Deviation	T Statistics	P Values
Attitudes - > Intentions	0.28	0.28	0.07	4.06	0.000
PCB - > Intentions	0.08	0.08	0.05	**1.54**	0.120
Subjective Norms - > Intentions	0.52	0.52	0.05	10.84	0.000

[a] Two-tailed *t*-test. Critical t-value for significance level is 1.96 for 5% and 2.58 for a significance level of 1%.

Appendix E. PLS SEM: Trimmed Model Results

See Tables E1–E4

Table E1
Significance of outer loadings of the trimmed model[a].

	Original Sample	Sample Mean	Standard Deviation	T Statistics	P Values
DI_EXP < - Intentions	0.94	0.94	0.01	104.37	0.000
DI_INTEND < - Intentions	0.94	0.94	0.01	128.60	0.000
DI_WANT < - Intentions	0.89	0.89	0.01	67.77	0.000
SUBC_CONT < - Perceived Behavioral Control	0.70	0.70	0.04	15.88	0.000
SUBC_COST < - Perceived Behavioral Control	0.58	0.58	0.05	11.73	0.000
SUBC_GOV < - Perceived Behavioral Control	0.78	0.78	0.03	30.16	0.000
SUBC_MAINT < - Perceived Behavioral Control	0.77	0.76	0.04	18.51	0.000
SUBC_RELI < - Perceived Behavioral Control	0.74	0.74	0.05	15.13	0.000
SUBATT_ATTRACT < - Attitudes	0.79	0.79	0.02	37.96	0.000
SUBATT_BILLS < - Attitudes	0.62	0.61	0.04	14.19	0.000
SUBATT_ENV < - Attitudes	0.73	0.73	0.04	19.77	0.000
SUBATT_SELF < - Attitudes	0.81	0.81	0.02	39.22	0.000
SUBATT_VALUE < - Attitudes	0.79	0.79	0.02	40.24	0.000
SUBN_FAM < - Subjective Norms	0.88	0.88	0.02	56.31	0.000
SUBN_FRIENDS < - Subjective Norms	0.88	0.88	0.01	62.95	0.000
SUBN_NEIG < - Subjective Norms	0.78	0.78	0.04	18.06	0.000

[a] Two-tailed *t*-test. Critical t-value for significance level is 1.96 for 5% and 2.58 for a significance level of 1%.

Table E2
Fornell-Larcker criterion for discriminant validity of the trimmed model[a].

	Attitudes	Control	Intention	Norms
Attitudes	**0.75**			
Behavioral Intentions	0.70	**0.93**		
Perceived Behavioral Control	0.80	0.61	**0.72**	
Subjective Norms	0.66	0.76	0.60	**0.85**

[a] Discriminant validity is established, if the AVE value for each latent variable is larger than other correlation values among latent variables (Fornell and Larcker, 1981).

Table E3
Significance of outer loadings for conventional and adhesive PV, trimmed model.

	Conventional PV					Adhesive PV				
	Original Sample	Sample Mean	Standard Deviation	T Statistics	P Values	Original Sample	Sample Mean	Standard Deviation	T Statistics	P Values
DI_EXP < - Intentions	0.96	0.96	0.01	142.42	0.000	0.93	0.93	0.02	53.19	0.000
DI_INTEND < - Intentions	0.94	0.94	0.01	81.48	0.000	0.94	0.94	0.01	112.97	0.000
DI_WANT < - Intentions	0.89	0.89	0.02	49.73	0.000	0.89	0.89	0.02	43.05	0.000
SUBC_CONT < - PCB	0.80	0.80	0.04	20.36	0.000	0.60	0.60	0.08	7.75	0.000
SUBC_COST < - PCB	0.59	0.59	0.08	7.84	0.000	0.57	0.57	0.07	8.48	0.000
SUBC_GOV < -PCB	0.77	0.77	0.04	17.72	0.000	0.79	0.79	0.04	21.24	0.000
SUBC_MAINT < - PCB	0.71	0.72	0.08	8.85	0.000	0.81	0.81	0.03	23.61	0.000
SUBC_RELI < - PCB	0.68	0.68	0.10	7.09	0.000	0.79	0.79	0.03	25.39	0.000
SUBATT_ATTRA < - Attitudes	0.80	0.80	0.03	29.63	0.000	0.79	0.79	0.04	20.64	0.000
SUBATT_BILLS < - Attitudes	0.53	0.52	0.08	6.75	0.000	0.69	0.69	0.04	15.54	0.000
SUBATT_ENV < - Attitudes	0.67	0.66	0.08	8.84	0.000	0.78	0.78	0.03	22.95	0.000
SUBATT_SELF < - Attitudes	0.82	0.82	0.03	25.68	0.000	0.81	0.80	0.03	24.76	0.000
SUBATT_VALUE < - Attitudes	0.78	0.78	0.03	26.15	0.000	0.81	0.81	0.03	30.55	0.000
SUBN_FAM < - SN	0.89	0.89	0.02	41.54	0.000	0.86	0.86	0.02	40.16	0.000
SUBN_FRIENDS < - SN	0.88	0.88	0.02	39.14	0.000	0.88	0.88	0.02	48.07	0.000
SUBN_NEIG < - SN	0.74	0.73	0.08	8.88	0.000	0.83	0.83	0.03	26.31	0.000

Table E4
Outer loadings PLS-MGA test, trimmed model.

	Outer Loadings-diff (| GROUP_Block (0.0) - GROUP_Block (1.0) |)	**p-Value (GROUP_Block (0.0) vs GROUP_Block (1.0))**
DI_EXP < - Intentions	0.03	0.08
DI_INTEND < - Intentions	0.01	0.63
DI_WANT < - Intentions	0.01	0.42
IC_CONT_comb < - PCB	**0.19**	**0.01**
IC_COST_comb < - PCB	0.02	0.41
IC_GOV_comb < - PCB	0.02	0.63
IC_MAINT_comb < - PCB	0.10	0.89
IC_RELI_comb < - PCB	0.11	0.87
IDA_ATTRACT_comb < - Attitudes	0.01	0.38
IDA_BILLS_comb < - Attitudes	0.16	0.97
IDA_ENV_comb < - Attitudes	0.11	0.94
IDA_SELF_comb < - Attitudes	0.01	0.39
IDA_VALUE_comb < - Attitudes	0.03	0.74
IDN_FAM_comb < - SN	0.03	0.19
IDN_FRIENDS_comb < - SN	0.00	0.43
IDN_NEIG_comb < - SN	0.09	0.87

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