Understanding the Role of Visual Appeal in Consumer Preference for Residential Solar Panels

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Abstract

Appearance is often key to the success of consumer-oriented products. However, few studies have been conducted to understand the role visual appearance plays in the adoption of renewable energy systems. This paper investigates the influence of visual appeal of renewable energy systems on consumer preference with a case study of residential solar panels. Two surveys of US residents were conducted with 194 and 350 responses, respectively. The first focused on aspects of solar panel appearance, including color, surface pattern and frame, while the second examined the tradeoffs between solar panel appearance, functional performance and price. Respondents were presented with two types of visual representations: solar panel images alone or solar panel images shown in the context of use. Results suggest that consumers in general prefer black solar panels with rounded-cornered and even-surfaced solar cells, and prefer the color of solar panels to match the color of the roof. It was also found that respondents were willing to pay a higher price for better-looking solar systems. This effect was found to be stronger with contextualized images of solar panels on roofs.

Keywords

Residential Solar Panels, Solar System Adoption, Product Appearance, User Preference Modeling

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1. Introduction

Renewable energy systems such as solar panels offer many potential benefits for users, including reduced energy bills, energy independence, and the opportunity for individuals to make a statement about their environmental beliefs [1]. Traditional strategies for increasing adoption of renewable energy systems have centered on performance and pricing. Much current research focuses on improving technical performance such as energy conversion efficiency [2,3] and system reliability [4,5] of renewable energy systems. At the same time, substantial monetary incentives such as rebates and loans are offered widely by public agencies to increase adoption [6,7]. Motivations and barriers for consumer adoption are widely studied [8–11], as well as the broader topic of social acceptance of the technologies [12,13].

In the past, renewable energy systems have often been thought of as performance-driven rather than driven by styling. However, studies have suggested that their visual appearance is also important. A survey of 138 California solar panel installers found that the aesthetics of solar panels was mentioned by 40% installers as a key factor when selecting a panel to recommend to homeowners [14]. Aesthetics was found to be a limiting factor to the adoption of solar power in the UK [15]. A US survey reported that 17% of respondents who were not interested in installing solar panels because they found the panels were not attractive [16].

Our study aims to examine the role that a solar panel's visual appearance plays in consumer preferences from a product design point of view. This study was conducted in two phases to reveal attributes that characterize solar panel appearance and evaluate how appearance is linked to user preferences for a solar system. The study poses three questions about consumer preference for solar panel visual appearance:

Q1: *What design elements are most important to consumers regarding the visual appearance of a solar panel?*

The visual appearance of a solar panel can be characterized in part by its color, surface pattern, and type of frame that are selected by the design and engineering team. We are interested to see which elements have the bigger impact on preferences of consumers.

Q2: *How do preferences change when a consumer is shown a solar system with and without context?*

Manufacturers of solar panels often show photographs of their products in marketing literature and specification sheets. Typically, these photographs are of the solar panel alone or installed on a roof. Recent research [17,18] has demonstrated that the way a product is visually presented can influence consumers' opinion of the product. In this study, two types of solar panel images, with or without context, were used to identify any potential differences in user response to different types of images.

Q3: *Does the visual appeal of solar panels influence consumer preference for functional attributes and price of the product?*

Performance and price are common factors that previous research has considered in solar panel adoption. They are also key factors that homeowners consider when shop for solar panels. This paper investigates how consumers balance tradeoffs between a solar panel's visual appeal with performance and price.

A widely used method known as conjoint analysis [19] was applied to study users' preference for solar panel designs. A particular form of conjoint analysis known as visual conjoint [20–22] was employed to evaluate product appearance.

This paper begins with a literature review of the roles of product appearance in product adoption and conjoint analysis in product preference, followed by an introduction to the survey design and modeling tools used in the study. Details of the survey data and modeling results are presented and discussed. The paper concludes with a summary of findings and future work.

2. Related Work

2.1 Product Appearance and Visual Representation

Appearance is core to the success of consumer-facing as well as technical products [23]. Product appearance conveys performance and emotional information to users [24] and helps define the product-person relationship [25]. Studies have shown evidence of interactions between users' judgment of product forms and product function [26]. Consumers have been found to perceive different levels of environmental friendliness based on a vehicle's silhouette [27]. User interface designs that were perceived as more attractive were considered better, whether or not they actually were more effective [28]. A study of industrial products, including multimeters and motors, suggests that the appearance of these products can be as strong an influence on user preferences as a product's functional performance and price [29]. Taken together, our research points to the value of product appearance in terms of consumer desirability.

Studies addressing the visual appearance of renewable energy systems are limited. Ladenburg and Dubgaard [30] studied the willingness to pay for reduced visual disamenities from offshore wind farms in Denmark. However, they considered only the visibility of wind farms and proposed to reduce the visual impact by building wind farms further away from the shore rather than change the appearance of the farm itself. Torres-Sibille, et al. developed a quantifiable indicator considering the visibility, color, fractality and continuity of the energy generation units, to evaluate the aesthetic impact of large renewable energy systems, including wind farms [31] and solar plants [32]. However, these two studies considered only the configurations of wind turbine or solar panel arrays, but not the appearance of the single energy generation unit nor attributes such as functionality and consumers' willingness to pay. In our study, we investigate the appearance of a renewable energy system, using residential solar panels as an example, and further study users' tradeoffs among product appearance, functionality and price.

The particular form of visual representation presented to users must be carefully considered. In the field of product design, designers use visual representations such as sketches and Computer-Aided Design (CAD) models to communicate design ideas to stakeholders [33]. It has been shown that different visual representations of the same product can evoke different perceptions of its appeal. Realistic, finished hand sketches were more appealing when compared to rough hand sketches or CAD models [17]. Computer sketches, silhouettes, and renderings generated inconsistent perception of the stylishness and even the dimensions of a product [18]. Our study takes this into consideration and tested two kinds of images of solar panels to investigate the potential differences of users' perception for solar panel appearance.

2.2 Conjoint Analysis in Preference Study

User preference can be driven by many aspects of a product, such as appearance, price, functional performance, sustainability and brand. Accurately capturing consumers' preference is key to the formulation of comprehensive design requirements and features, thus plays a critical role in the success of a product. Conjoint analysis, or discrete choice analysis, is a specific method that addresses the cumulative effect of various features of an individual product [19]. Users are presented with varying combinations of attributes, traditionally in text form, to elicit preference information [34]. Responses to these combinations can be transformed into models that enable quantification of the user preferences.

Conjoint analysis has been widely used in studying consumer preferences for renewable energy products and systems. Álvarez-Farizo and Hanley [35] conducted a conjoint survey to study the public's preferences for the environmental impacts of wind farms in Spain. Bergmann, Hanley, and Wright [36] ran a choice experiment in Scotland to investigate people's perceptions of renewable energy projects' impact on the landscape, wildlife, air quality, and job market. Scarpa and Willis [37] conducted a choice experiment in the UK to investigate households' willingness-to-pay for renewable energy micro-generation products including solar photovoltaic, micro-wind and more. Kaenzig, Heinzle and Wüstenhagen [38] studied consumer preference for electricity in Germany using a conjoint survey and found that in general people were willing to pay a significant premium for environmental friendly electricity production. Islam and Meade [7] conducted a conjoint survey to study consumer preferences for the initial investment, energy cost savings, and government subsidies of residential solar panels in the Canadian market.

To capture preferences for product appearance that is hard to express through text descriptions, the method of visual conjoint analysis was developed. In visual conjoint, elements such as dimensions [20], colors [21], and shapes [39] can be controlled and has been applied to product forms such as coffee pots [18] and vehicles [40], among others. This method has been used to investigate consumer tradeoffs between product attributes such as form, function [41], as well as environmental impact [42].

In our study, the conjoint analysis method was utilized to reveal consumer preferences for functional attribute, price and appearance of residential solar panels. Visual conjoint was employed to capture user preferences for solar panel appearance.

3. Methods

Two surveys were conducted. Survey I investigated consumer preferences for solar panel appearance. Survey II examined consumer preferences for a solar panel's functional performance and price, as well as the interaction between preferences for solar appearance and non-appearance attributes. Preference models were constructed with the survey results.

The surveys were distributed to US residents over the age of 18 via Amazon Mechanical Turk, a human intelligence crowdsourcing platform. The target population of the surveys were solar users as well as interested non-users. Respondents received one US dollar as compensation for completing a 15-minute survey. Response quality assurance strategies, including: 'correct answer', screening for double responses, a minimum time requirement, and participant restrictions [43], were applied to identify valid responses.

3.1 Survey I - Solar Panel Appearance

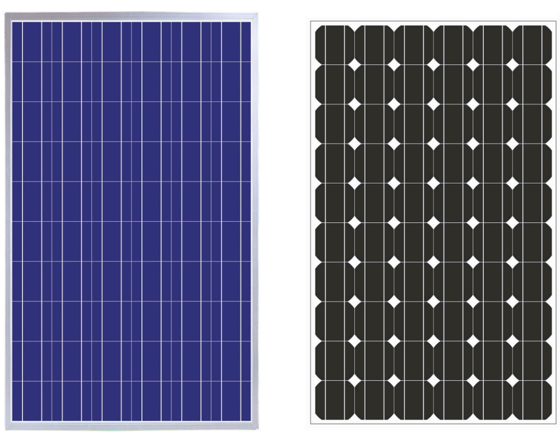
Four attributes that had impact on solar panel appearance were identified based on analysis of datasheets of 265 models of residential solar panels from 37 popular brands in the US market from 2007-2011 collected from the California Solar Initiative in a previous study [44]. Attributes were defined as having three or four levels, summarized in Table 1.

Table 1 Solar Panel Appearance Attributes and Their Levels

Attributes	Definition	Levels
Color	Color of solar cells	Black Blue Red Green
Shape	Shape of individual solar cells	Big rounded corner cell Small rounded corner cell Square cell
Pattern	Pattern of contact wires on solar cells	Even, no contact wires Uneven A, with two main contact wires Uneven B, with three main contact wires
Frame	Frame style of solar panel	Black frame Silver frame No frame

Solar images with combinations of these four attributes were custom made using Adobe Illustrator and Photoshop. Each respondent was presented with 27 pairs of choice questions of the images. Orthogonal fractional factorial design was generated for the pairwise choices using the statistical software package R [45]. Each question included a null option to allow participants to choose neither of the two choices. An example of the pairwise choice questions can be found in Figure 1.

Only considering the appearance, which of the solar panels would you prefer?



○ A ○ B ○ None of the two

Figure 1: Example pairwise question from Survey I

In addition, the survey collected demographic information such as age, gender, type of housing and ownership of housing [46].

3.2 *Survey II – Tradeoffs among solar panel attributes*

Four attributes that were not related to the appearance of a solar system were determined based on characteristics of panels already on the market. Their definitions and levels are summarized in Table 2.

Table 2: Solar Panel Non-appearance Attributes and Their Levels

Attributes	Definition	Levels
Reliability	The life span of a solar panel, given by a years-of-warranty.	10 years (low) 20 years (medium) 30 years (high)
Efficiency	A panel's solar-to-electricity energy conversion rate. The higher the efficiency, the fewer solar panels needed to meet the electricity demands of a home.	10% (low) 20% (medium) 30% (high)
Price	The price per Watt of energy of a solar panel system	1 $/watt (cheap) 2 $/watt (medium) 3 $/watt (expensive)
Grid-tying Service	A solar panel system can be independent of community's electricity grid, or it can be connected. Being tied to the utility grid enables a homeowner to potentially sell excess electricity to the grid, which is often desirable to the homeowner.	On-grid Off-grid

Based on the results of Survey I, six panels were chosen (Appendix I). These panel images had a front view of a solar panel on a blank background, thus were referred to as **Non-contextualized** images. An additional set of images was constructed with solar panels installed on the roofs of houses, called **Contextualized** images. Contextualized images provided a more realistic sense of what a panel might look like once installed. Twelve contextualized images of these panels were created, with four common roof colors: black, blue, green and red (Appendix II).

There were two versions of Survey II, each with one style of solar images. *Version N* of survey II had non-contextualized images, and participants who responded to it will be called *group N*. The other version using contextualized images and participants of it will be referred to as *version C* and *group C*. The respondents to each survey version were asked to evaluate non-contextualized and contextualized images on 1~7 Likert scales.

Two pairwise choice questionnaires with 12 questions each were presented in the survey. The first one included only non-appearance attributes (Reliability, Efficiency, Price and Grid-tying services). The second one included non-appearance attributes together with solar panel images. Example conjoint questions with images from both survey versions are shown in Figure 2.

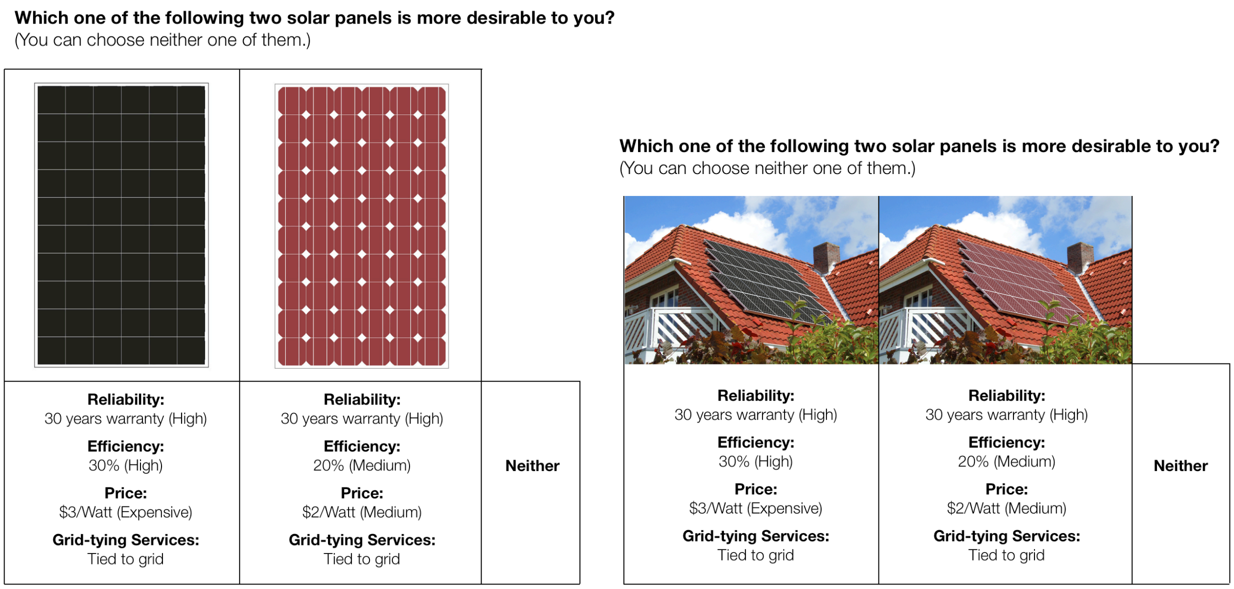


Figure 2: Example Survey II Pairwise Choice Questions
(left - group N with Non-contextualized images, right – group C with Contextualized images).

Before being presented with conjoint questions, participants were asked to list the three most important attributes of solar panels that they would consider the most if they were going to install solar. In this way, their perceptions of the attribute importance would not be primed with the pre-determined conjoint attributes. After finishing the conjoint questions, they were asked about the importance of different solar panel attributes again, this time ranking all the attributes (including appearance) introduced in the pairwise choice questions. In the end, demographic questions same to Survey I were asked.

3.3 Preference Modeling

The user preference for different attributes of a solar panel were modeled using the mixed logit model [47, 48]. The utility of alternative i was specified as:

$$U_i = \beta x_i + \varepsilon_i \quad (1)$$

x_i were observed variables relating to solar panel i; β was a vector of coefficients that represents people's preference corresponding to each variable; and ε_i was a random term that was iid (independent and identically distributed) extreme value.

Here, the utility was a measure of preferences over different alternatives. According to the choice theory, the larger the utility of an alternative, the more likely it would be chosen. Under the mixed logit model, the probability that alternative i being chosen over other alternatives was:

$$P_i = \boldsymbol{P}\left[U_i > U_j \quad for\ all\ \ j \neq i\right] = \int \frac{\exp(\beta x_{ni})}{\sum_j \exp(\beta x_{nj})} f(\beta) d\beta \quad (2)$$

Here coefficient vector β was not fixed, but followed a certain distribution. This study assumed a multinomial distribution. The conditional logit model [49], which is the foundation of the mixed logit model, assumes the coefficients to be constant and homogeneous among the population. However, in the real world, tastes and preferences are usually different from person to person and thus cannot be fully captured by constant coefficients. Mixed logit models overcome this issue by assuming the coefficients to be random variables with distributions that vary over individuals. The parameters of the coefficient distributions can be estimated by maximizing the log-likelihood of the probability of observed choices [47, 50].

The preference models across survey versions were compared to show the difference between the effects of contextualized and non-contextualized images. However, the coefficients of mixed logit models were not estimated on an absolute scale. Therefore, it would be incorrect to compare the coefficients directly. To address this issue, the *Attribute Importance,* an normalized measurement of the weight of each attribute was estimated [51]. In the analysis, a hypothetical marketplace with solar panels of any combinations of the attributes that we studied was created. I_ζ, the importance of attribute ζ, was defined as:

$$\mathrm{I}_\zeta = \sum_{\omega}\left(\sum_{i} P_{i\zeta\omega} - \mathrm{n}_\zeta{}^{-1}\right)^2 \quad (3)$$

where ω was the level of attribute ζ; $\sum_i P_{i\zeta\omega}$ was the summed probability of any alternative i with level ω of attribute ζ being chosen; and n_ζ was the number of levels of attribute ζ.

The importance of an attribute described the divergence of the summed probability being chosen for different levels of that attribute. The more divergent the chosen probability of different levels of an attribute were, the more important that attribute would be. In contrast, if levels of an attribute had similar probability being chosen, then the importance of that attribute would be small, which indicated respondents didn't have significant preference for one level over another.

4. Results

In total, 227 and 485 responses were collected for Survey I and Survey II, respectively. After applying quality control screening rules, there were 194 valid responses for Survey I and 350 valid responses for Survey II. The sample sizes of Survey I and Survey II provided 7% and 5% margin of error, respectively, with 95% confidence level for the US adult population. Among the valid responses of Survey II, 180 were from group N (no context) and 170 were from group C (with context). A rule-of-thumb for the minimum sample size of choice based conjoint study is $nta/c > 1000$, where n is the number of respondents, t is the number of choice questions, a is the number of alternatives per question, and c is the largest number of levels for any attributes when estimating the main effects [52]. The sample sizes of our valid surveys guaranteed each level of any attributes in the conjoint questions to be displayed more than 1,000 times collectively, and this is considered sufficient to estimate the attribute main effects in the preference models.

The demographic distributions of the respondents are summarized in Table 3. About 2% of the respondents were solar adopters, which is close to the 1% US solar adoption rate at the time when the surveys were conducted (2013 - 2014) [53]. Over half of all respondents reported that they would like to install solar in their home, citing a range of reasons such as "to save money on electricity" or to be "green." About 15% of respondents said they might not install solar, mostly because they didn't own their home or didn't think they could afford it. The remaining respondents were not sure whether to install solar or not.

Table 3: Demography of survey respondents

Demography	**Survey I**		**Survey II**	
	# Respondents	**Percentage**	**# Respondents**	**Percentage**
Age				
<= 30	94	48.5%	189	54.0%
30 ~ 50	79	40.7%	131	37.4%
> 50	20	10.3%	30	8.6%
Gender				
Female	84	43.3%	142	40.6%
Male	110	56.7%	206	58.9%
Housing ownership				
Own	86	44.3%	159	45.4%
Rent	96	49.5%	171	48.9%
Other	12	6.2%	20	5.7%
Housing style				
High-rise apartment	28	14.4%	34	9.8%
Multi-family town house	36	18.6%	39	11.1%
Single family house	123	63.4%	243	69.4%
Other	7	3.6%	27	7.7%

4.1 *Preferences for Appearance of Solar Panels*

4.1.1 Mixed Logit Model for Appearance Preference

Using the data collected from the pairwise choice questionnaire of Survey I, a Mixed Logit model was generated and summarized in Table 4. The last level of each attribute was treated as baselines with coefficient 0, thus was excluded from the table. An attribute level with a larger coefficient indicated that it was more preferred over other levels. A larger standard deviation of an attribute level represented more diversity of preference among the surveyed population. The z-values and p-values tested the significance of the coefficients. A small p-value would reject the null hypothesis that a parameter equaled 0.

Table 4: Mixed Logit Model of Solar Panel Visual Appeal

Coefficients Estimation	Mean (se)	Z-value (p-value)	St Dev (se)	Z-value (p-value)
Constant	3.749*(0.502)	7.472 (<0.001)	3.878*(0.300)	12.920 (<0.001)
Color: Black	1.694*(0.159)	10.662 (<0.001)	1.660*(0.191)	8.693 (<0.001)
Color: Blue	0.841*(0.100)	8.432 (<0.001)	1.339*(0.103)	12.974 (<0.001)
Color: Red	-0.226 (0.110)	-2.045 (0.041)	0.366 (0.206)	1.780 (0.075)
Shape: Big rounded corner cell	0.414*(0.065)	6.339 (<0.001)	0.399*(0.073)	5.490 (<0.001)
Shape: Small rounded corner cell	0.346*(0.102)	3.399 (0.001)	1.527*(0.111)	13.707 (<0.001)
Pattern: Even	0.937*(0.084)	11.216 (<0.001)	0.967*(0.081)	11.931 (<0.001)
Pattern: Uneven A	0.117 (0.069)	1.688 (0.091)	0.005 (0.086)	0.063 (0.950)
Frame: Black	0.125 (0.064)	1.946 (0.052)	0.037 (0.074)	0.500 (0.617)
Frame: Silver	-0.031 (0.067)	-0.462 (0.644)	0.059 (0.074)	0.791 (0.429)

(Note: Coefficients that are significant on 0.05 level are marked out with *.)

The color Black was, on average, considered to be the most preferred color, with a coefficient mean of 1.694. Blue was, on average, the second most preferred color. Red and Green panels were much less preferred, with near zero coefficients. Solar cells with big and small rounded corners were in general more preferred than the squared ones (which had the baseline coefficient 0). Solar cells with even surfaces were more preferred than uneven surfaces. A Black frame was slightly more preferred over a Silver frame or No frame, but this difference was statistically insignificant.

Note that coefficients with significant means also had significant standard deviations, indicating heterogeneous preferences among the population that could not be neglected. Preliminary latent class analysis identified sub-groups of respondents who preferred square solar cells more than the rounded-cornered ones, or preferred blue panels over other colors.

The importance values of each attribute were calculated according to Equation (3) and are reported in Table 5. The importance of each attribute was first estimated on individual levels and then aggregated. A larger importance indicated more weight was put on the attribute when respondents made their choices.

Table 5 Importance Comparison of Solar Panel Visual Appeal Attribute

Attribute Importance	Mean	St Dev
Color	0.257	0.185
Shape	0.104	0.113
Pattern	0.113	0.113
Frame	0.0017	0.0008

The importance of Color was the largest, indicating that color of a solar panel was generally the most critical factor in respondents' judgment of visual appearance. The importance of Shape and Pattern had similar values, suggesting that the shape and surface pattern of solar cells played similar roles in influencing respondents' judgment. The importance of the Frame was close to zero, suggesting that the style of solar panel frame had little influence on its visual appeal.

4.1.2 The Influence of Context on Preference for Solar Appearance

Based on the model generated for solar panel appearance, the utility of all possible combinations of visual attributes was calculated. Six panels with distinct appearance utilities were chosen: two with low utilities, two with medium, and two with high, as shown in Appendix I. The ranking of non-contextualized panels based on Survey I modeling utilities and the ranking based on Survey II respondents' ratings (also see Appendix I) correlated highly with each other, with a Spearman correlation coefficient $\rho = 0.9429$. This consistency lent confidence that the proposed utility model for appearance was valid, and justified the use of the selected solar panel images to test the tradeoffs between solar appearance and non-appearance attributes.

Twelve contextualized versions of these panels were created, with four different roof images in black, blue, red and green. Each roof was matched with a panel of the same color so that the panel would appear to blend into the background; and two other panels of different colors (Appendix II). Visual preferences for the panel appearance appeared to be significantly influenced by the inclusion of context. A comparison of the panel image ratings with and without context is summarized in Table 6.

Table 6: Rating Comparison of Panel Images with/without Context

Average rating (St Dev)	Without Context	Context Roof Color			
		Black	Blue	Red	Green
Black Panel	5.19 (1.20)	**5.30 (1.46)**	4.05 (1.56)	4.42 (1.56)	5.19 (1.37)
Blue Panel	4.52 (1.58)	3.88 (1.57)	**5.01 (1.42)**	3.79 (1.59)	3.57 (1.62)
Red Panel	4.26 (1.64)	--	3.17 (1.64)	**5.25 (1.36)**	--
Green Panel	4.02 (1.48)	2.98 (1.51)	--	--	**4.82 (1.49)**

(Note: The highest ratings for each panel are highlighted.)

It can be seen that color was a major factor in visual preference. All panels were rated higher if they were seen on a roof with the same color. Most of them (except black panels on green roof) were rated lower if on a roof with different color. ANOVA (analysis of variance) showed the differences in ratings were statistically significant.

4.2 Tradeoffs between Solar Appearance and Non-appearance Attributes

4.2.1 Models for Solar Panel Non-appearance and Appearance Attributes

In Survey II, each participant completed a pairwise choice questionnaire without images, then completed another pairwise choice questionnaire with images. In order to examine the preference structure before and after presenting the solar panel images, as well as to compare the preferences between Group N (no context) and Group C (with context), mixed logit models were constructed from each questionnaire for each group. The preference utility models constructed for questions without images were not statistically different between Group N and Group C, thus the data were combined to generate one single preference model. The coefficients of the models and their standard errors of estimations are summarized in Table 7. The 10-year warranty, 10% efficiency, $1/W price and no grid-tying service were held out as baselines. The appearance of both non-contextualized and contextualized images were input into the models as attributes, where the image ratings (ranging from 1 to 7) were used as the levels. Appearance was treated as a continuous variable and the models assumed linear effect.

Table 7: Mixed Logit Model of Solar Panel Non-appearance Attributes and Appearance Trade-off

	No Image (Group N & C)		**Non-contextualized Image (Group N)**		**Contextualized Image (Group C)**	
Coefficients Estimation	**Mean (se)**	**St Dev (se)**	**Mean (se)**	**St Dev (se)**	**Mean (se)**	**St Dev (se)**
Constant	0.014*(0.269)	2.691*(0.215)	-3.548*(0.407)	2.697*(0.272)	-2.248*(0.329)	2.302*(0.216)
Reliability: 20-year warranty	1.669*(0.134)	0.723*(0.147)	1.504*(0.151)	0.152 (0.228)	1.028*(0.130)	0.309 (0.221)
Reliability: 30-year warranty	2.463*(0.171)	0.894*(0.211)	2.194*(0.199)	0.544 (0.314)	1.835*(0.172)	0.215 (0.237)
Efficiency: 20%	2.332*(0.144)	0.119 (0.115)	1.822*(0.165)	0.136 (0.199)	1.265*(0.152)	0.081 (0.185)
Efficiency: 30%	4.088*(0.172)	0.764*(0.132)	3.49*(0.212)	1.043*(0.188)	2.497*(0.175)	1.268*(0.154)
Price: $2/W	-1.035*(0.137)	0.082 (0.106)	-1.059*(0.169)	0.563*(0.193)	-0.799*(0.153)	0.028 (0.206)
Price: $3/W	-2.451*(0.167)	0.859*(0.171)	-1.674*(0.192)	1.107*(0.221)	-1.871*(0.183)	0.967*(0.184)
Grid-tying service: On	1.411*(0.133)	1.414*(0.132)	1.336*(0.149)	1.053*(0.171)	1.153*(0.126)	0.753*(0.152)
Appearance	-	-	0.609*(0.053)	0.100*(0.061)	0.631*(0.050)	0.273*(0.049)

(Note: Coefficients with significance level 0.05 are marked with *.)

In all cases, longer warranty, higher efficiency, lower price, and grid-service "on" had higher average coefficients. This was not surprising since these levels represented better quality and better pricing of solar panels. *Appearance* had positive mean coefficients for both non-contextualized images and contextualized images, validating that better-looking solar panels (which had higher ratings on their visual appeal) were more preferred.

The importance values of the attributes are presented in Table 8. *Efficiency* had the largest average importance value in all three conditions, followed by *Price*. *Reliability* and *Grid-tying services* had similar importance.

Table 8: Importance Comparison of Solar Panel Non-appearance Attributes and Appearance

Attributes Importance	No Image		Non-contextualized Image (Group N)		Contextualized Image (Group C)	
	Mean	**StDev**	**Mean**	**StDev**	**Mean**	**StDev**
Reliability	0.198	0.089	0.162	0.035	0.145	0.021
Efficiency	0.390	0.079	0.360	0.116	0.275	0.150
Price	0.296	0.011	0.284	0.007	0.262	0.007
Grid-tying Services	0.180	0.123	0.177	0.100	0.137	0.076
Appearance	-	-	0.161	0.017	0.169	0.069

After introducing solar panel images to the pairwise choice questions, the importance of non-appearance attributes decreased, whether the images were contextualized or not. This confirmed our expectation that people took visual appeal into consideration when making solar panel decisions. Another interesting result was that the importance values of all non-appearance attributes were lower in Group C than in Group N, while the importance of appearance was higher in Group C than in group N. This indicated that the importance of solar panel appearance was higher for the contextualized groups. In other words, when survey respondents saw solar panels within context, they perceived the visual appeal of solar panel to be more important, and put more weight on panel appearance when making their choices. Also, the importance of appearance to importance of price ratio was higher in Group C, suggesting people were willing to pay more money for better-looking solar panels.

4.2.2 Directly Stated Attribute Importance

Among the attributes that participants listed to be important at the beginning of Survey II, before the pairwise choice questions, price was stated most frequently, by 23% respondents in group N and 21% in group C, followed by efficiency, appearance and reliability. Appearance was mentioned more frequently by Group N participants (17%) than Group C participants (14%). However, Chi-square test results (Chi-square = 3.758, p-value = 0.709) showed no significant difference between the two groups.

At the end of Survey II, after the pairwise choice questions, participants were asked to rank the attributes according to their own perceptions of their importance. The results are summarized in **Table 9**. Consistent with the Importance value revealed by the mixed logit model, *Efficiency* was considered to be the most important attribute, followed by *Price*.

Table 9: Ranking of Attributes Importance

Frequency / Attributes	Non-Contextualized					Contextualized				
	1st	**2nd**	**3rd**	**4th**	**5th**	**1st**	**2nd**	**3rd**	**4th**	**5th**
Reliability	32	44	56	39	13	31	47	46	33	16
Efficiency	78	62	29	14	1	63	56	32	18	4
Price	51	51	46	28	8	46	45	43	29	10
Grid-tying Services	13	9	20	58	84	9	9	22	50	83
Appearance	10	18	33	45	78	24	16	30	43	60

Chi-square analysis was conducted to detect any difference in ranking between the two groups. Group C ranked *Appearance* to be more important than group N did, with Chi-square = 8.261, p-value = 0.0825, which was statistically significant assuming $\alpha = 0.1$. This was consistent with the result in section 4.2.1, that seeing contextualized images of solar made people perceive solar panel appearance to be more important. The other attributes were not found to differ significantly between groups.

5. Discussion

In this study, two preference models for solar panels were constructed: one for solar panel appearance, and one to capture the tradeoffs among appearance, price, efficiency and other attributes. These models, together with analysis of stated preference information, answer the three questions that were posed at the beginning of the paper.

> Q1: *What design elements are most important to consumers regarding the visual appearance of a solar panel?*

Four attributes with a total of twelve combinations of solar panel appearance were investigated in Survey I. Color was found to be the most important attribute, with Black to be the most preferred color in general. From the survey participants' comments it was found that black was usually assumed to absorb more sunlight and thus be more efficient. Also it was considered to be less visible thus visually less intrusive. Shape and surface pattern were also found to be important to the visual appeal of solar panels. The majority of respondents found solar cells with rounded corners and without surface patterns to be more appealing.

> Q2: *How do preferences change when a consumer is shown a solar system with and without context?*

After being shown solar panels in the context of a colored roof, panels that were more preferred in the non-contextualized scenario were sometimes considered less appealing and vice versa. In general solar panels with colors that matched the color of a roof were more preferred. This suggested that people tended to prefer solar panels that blended into the background.

Q3: *Does the visual appeal of solar panels influence consumer preference for functional attributes and price of the product?*

In Survey II, participants were tested on their preferences for the *Reliability, Efficiency, Price* and *Grid-tying services* of the solar panels. Later they were tested on the same attributes with the addition of images of solar panels. Solar panels with higher appearance ratings were more preferred, as expected. In addition, this preference for better-looking solar panels sometimes impacted the choices the participants made. For example, if panel A cost the same as a slightly-better-performing panel B, or panel A had the same performance as panel B but was less expensive, a respondent would be expected to make the rational choice and select panel A. However, if the respondent was also shown images of the solar panels and panel B had better appearance than panel A, the participant might instead choose panel B. Whether a respondent changed his/her choices or not depended on how he/she made tradeoffs between the functional attributes, price and the visual appeal of solar panels.

The *Importance* value quantified these tradeoffs. The relatively high *Importance* of *Appearance* confirmed that it was a key attribute that people referred to when making choices on solar panels. The *Importance* of *Price* decreased after introducing solar panel images, indicating that survey respondents were willing to pay more money for the better-looking products. Also the contextualized images, which created more realistic choosing scenarios, made the perceived importance of visual appearance even higher compared to non-contextualized images.

These findings provide important lessons to both renewable energy researchers and practitioners. First, this study suggests that visual appeal is such an important feature of the solar panels that presenting solar panel images significantly decreases users' perceived importance of the price of the product. Thus the visual appearance of renewable energy systems must be considered when these products are designed.

Consequently, effort should be put into developing better-looking renewable products. Our finding suggests that users in general prefer dark solar panels (black or blue) along with an even surface pattern that are visually less intrusive. Understanding these preferences and making solar products with more preferred appearance should be taken seriously as strategies to increase the product adoption. Solar shingles, and transparent and flexible solar panels are good examples of exploring options to make solar more visually appealing.

Finally, the context in which the products are presented is linked to significant differences in user preferences. Simulating real use scenarios of renewable products will help capturing more realistic preferences from users. This also suggests that solar installers should carefully take the color and style of a roof into consideration when designing rooftop solar systems for potential customers. Rendering images of solar panels on the roof will help homeowners clearly visualize how the panels will make their houses look. This can reduce the uncertainty of installing solar for customers, which could lead to more adoption.

There exist limitations to this study. The majority of the survey respondents were not solar users yet, thus didn't have much firsthand experience installing or using solar systems. However, most respondents said they were familiar with residential solar panels and a majority of them said it is likely that they would adopt solar in the future. In addition, there was detailed information about all attributes that were tested in the survey. Thus we assumed the participants had sufficient understanding to make rational choices. Also, the design space explored in this study was not entirely realistic considering current technology. In particular, today a red solar panel cannot have the same efficiency as a black one. This factor was simplified and a hypothetical marketplace with all possible combinations of appearance and functions of a solar panel was explored, in order to capture participants' perceived importance of these attributes.

Last but not the least, the selection of attributes for the conjoint analysis has strong impact on the results. For example, the unit price of a solar panel ($/watt) was used to characterize the cost of the product in this study, which allowed price to be separated from other variables such as the capacity of the system. However, in the real world, consumers would also consider the total price of a system. In addition, the focus of the product context was on the color of the roofs. Other aspects of the context may also influence people's preference for solar panels, such as shingle type and the style of the house.

6. Conclusions and Future Work

The larger goal of this work was to explore the influence of visual appearance on consumer evaluations of renewable energy systems. Using residential solar panels as a case study, two surveys were conducted to test potential solar adopters' preferences for a variety of attributes of the product.

This work validates our hypothesis that the visual appearance of solar panel plays an important role in the preferences of potential consumers. Survey results suggest that people may be willing to pay a higher price for better-looking solar panels, which supports a strategy of improving the aesthetics of residential solar panels to help increase adoption. Among all visual attributes considered, the shape and pattern of solar cells, and especially panel color, strongly influence consumers' evaluation of solar panels' visual appeal. Black panels are in general the most preferred. However, when considered within the context of use, panels with colors that match the color of roof are more preferred. These findings could work as guidelines for designers and manufacturers to improve solar panel appearance.

This work suggests several avenues for future research in sustainable systems. A key assumption of this work is that there is value in approaching sustainable systems from the perspective of consumer product development rather than solely from an engineering one. While the focus of the work is on residential solar panels, it will be valuable to investigate consumer preferences for other types of sustainable systems, such as clean water and transportation. This will be of particular interest for those systems with a consumer-facing element.

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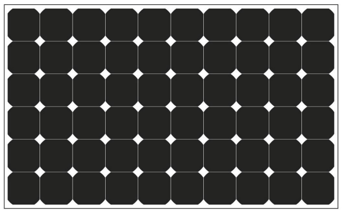
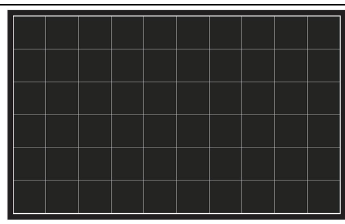
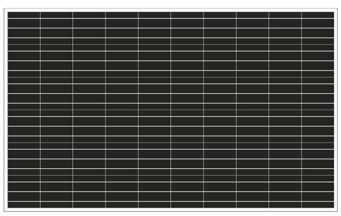
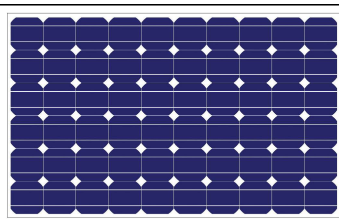
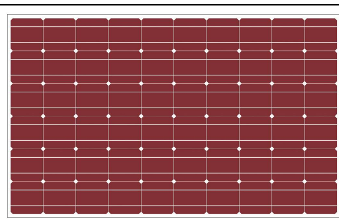
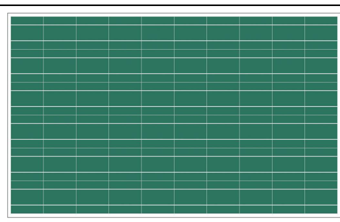
Appendix I – Estimated Utility and Average Rating (SD) of Non-Contextualized Images

Panel	Image	Average Utility $\widehat{U}$ (St Dev)	Utility Ranking	Average Rating (St Dev)	Rating Ranking
Black Panel 1*		7.16 (3.02)	1	5.19 (1.20)	1
Black Panel 2		6.88 (3.00)	2	4.82 (1.26)	2
Black Panel 3		6.22 (2.87)	3	4.32 (1.36)	4
Blue Panel		5.65 (3.04)	4	4.52 (1.58)	3
Red Panel		4.49 (3.31)	5	4.26 (1.64)	5
Green Panel		4.26 (2.86)	6	4.02 (1.48)	6

Note*: Black Panel 1 was used as the representation of black panels to generate the contextualized images.

Appendix II – Average Rating (SD) of Contextualized Images

Black roof			
Rating Average (Standard error)	2.98 (1.51)	3.88 (1.57)	5.30 (1.46)
Blue roof			
Rating Average (Standard error)	3.17 (1.64)	5.01 (1.42)	4.051 (1.56)
Red roof			
Rating Average (Standard error)	5.25 (1.36)	3.79 (1.59)	4.42 (1.56)
Green roof			
Rating Average (Standard error)	4.82 (1.49)	3.57 (1.62)	5.19 (1.37)