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Rooftop solar in the United States: Exploring trust, utility perceptions, and adoption among California homeowners

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ABSTRACT

The transition to a more sustainable grid is likely to involve residential customers who make decisions about whether or not to install solar panels on their property. It will require that utilities engage customers in order to effectively manage the demand and supply of electricity. This means that relationships between customers and utilities are key to the future electric grid. Although industry consultants are increasingly drawing attention to the importance of customer trust in their utility, little research examines the issue. Using an exploratory sequential mixed methods design, we draw on semi-structured interviews conducted with 61 California residents and analyzed with line-by-line coding to identify the main themes related to people's perceptions of their utility company and their interest in solar energy. The interview results helped to inform the development of a survey conducted with California homeowners (N = 3402) and analyzed using a series of logistic regressions to quantitively assess the role of distrust. The findings from the two sets of data are complementary. Together they show that people who distrust their utility are more likely to be interested in and to have rooftop solar panels. Our findings have implications for the successful transition to a more sustainable grid.

1. Introduction

The US electricity delivery system is undergoing a transition, increasingly incorporating renewable energy sources. Because supply and demand must be balanced at all times, and renewable sources of energy are inconsistent (the sun does not always shine and the wind does not always blow), renewable energy creates challenges for grid management. These challenges are exacerbated when the electricity supply is distributed, with customers not only consuming electricity, but also producing their own electricity and sending it to the grid. Most notably, households can install photovoltaic (solar) panels on their roofs or elsewhere on their property. Household production of electricity affects how much electricity households purchase from and send to the grid, and when they do so.

Historically, relations between a utility company and its customers were simple; utilities provided electricity and customers paid their bills. As households install solar panels and become not only consumers but also producers, this relationship is becoming more complicated. A key strategy for utility companies to maintain grid functioning in the face of unpredictability created by household renewable energy production is to coordinate with customers to shift demand and supply. Recognizing this, industry consultants have begun to argue that utility companies must pay more attention to their relationships with customers, and in particular, to increase customer trust (e.g., [1,2]). Yet, little research examines the role of customer trust in their utility in their energy related behavior.

Here, we begin to address this gap in the literature – looking at customer distrust in their utility company in the context of installing rooftop solar panels. We used an exploratory sequential mixed methods design (QUAL → QUAN → QUAL) [3], collecting data in California, one of the largest states in the US and a leader in social energy production [4]. To explore people's sentiments and beliefs about their utility companies, we conducted 61 semi-structured interviews with a purposive sample of homeowners in southern (San Diego area) and northern (Sacramento area) California. Interview participants spoke at length about how they felt about their utility companies – explaining their high levels of distrust and desire to distance themselves from their utility company – and linking their distrust with interest in solar energy. They also identified two other factors that they saw as important in the adoption decision – financial and environmental concerns. The interview results informed the development of a survey (N = 3402) to quantitatively assess levels of household distrust in their utility company

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across the state and to test whether distrust predicted interest in and having solar panels. These survey data allow us to quantitatively test the associations between distrust and interest in/having rooftop solar panels.

Based on our interview data and on existing literature on trust and customer engagement, we hypothesize that higher levels of distrust will be associated with more interest in rooftop photovoltaic (PV) and a higher likelihood of having it. We also expect that customer beliefs that solar energy is financially and environmentally beneficial, along with caring about the environment, will have a positive effect on these outcomes. The survey results show that distrust in utility companies, pro-environmental personal norms, as well as positive evaluations of the benefits of solar are associated with interest in and having rooftop solar panels. The less people trust their utility, the more interested they are in installing solar and the more likely they are to have it.

Empirically our paper contributes to the literature on the relationship between California utility companies and their customers, in a context in which this relationship is increasingly important for management of the electricity deliver system. Theoretically, our findings provide evidence of the importance of trust even for expensive investments such as solar panels. As a practical matter, given that one of the ways of addressing challenges with incorporating unpredictable renewable energy sources is coordination between utility companies and customers, the association between distrust and interest in/having solar is potentially problematic. Customers who are the least interested in working with utilities may be the most likely to be interested in and to have solar, with potentially negative consequences for grid management. Our findings highlight the need for future research on customer distrust in their utility companies and the implications of distrust for management of the electric grid and the energy transition.

2. Literature and hypotheses

Social science research on solar adoption that moves beyond cost-benefit analyses tends to approach understanding of solar adoption as a variant of proenvironmental behavior. It relies on a variety of social psychological theories (e.g., value-belief-norm theory, the theory of planned behavior, diffusion of innovations theory, peer effects, etc.; e.g., [5]) and identifies a multitude of factors (over 200) that predict household adoption of solar panels (e.g., [6–12]). Much of this work focuses on characteristics of individuals, with some extending beyond the household to look at peer and community effects. Here, we view solar adoption as a component in the transition of the electricity delivery system to a smarter, more sustainable grid, a transition that involves a relationship between customers and industry actors and requires their coordination. However, researchers have relatively little understanding of the relationship between customers and their utility companies. We seek to understand this relationship and its implications for household adoption of rooftop PV. We focus in particular on customer trust in their utility company.

Trust refers to an individual's belief that another party will respond to their advance [13–15]. It is relevant in exchanges in which an actor makes an advance toward the other party that puts them at risk of loss depending on that other party's behavior – for example, an individual may send money to a company trusting that the company will send a quality product back to them. The person who trusts expects that the other will act in consideration of their interests [16]. A substantial literature finds evidence for the importance of customer trust in company success. This research tends to focus on decisions involving relatively low-cost purchases such as airline and theatre tickets (e.g., [17]). It shows that people who trust a company are more likely to engage with that company whereas people who distrust a company are more likely to distance themselves from it [18–20].

In the context of the electricity delivery system, however, very little work examines customer trust in electricity providers (for an exception see [21]). There is some work on trust in the energy context, but it tends to focus on consumer acceptance of energy policy (e.g., [22–24]), energy projects (such as the building of windfarms, hydrogen fuel stations, or energy transmission lines in their area) that are managed and controlled by others (e.g., [25,26]), and green technology (e.g., [27–29]). Similarly, research on diffusion of innovations, to the extent that it includes trust, focuses on trust in clean energy providers and installers, or informal network ties (e.g., [5]). In general, research on trust in the energy context finds that trust in providers leads to increased acceptance of energy policies, projects, and technologies.

That research, however, says little about the role of trust in the relationship between customers and utility companies and in customers' decisions about their personal energy investments. Industry consultants and academic researchers are beginning to suggest that trust may be important for consumer engagement with their utility company, just as it is for consumer engagement with companies generally (e.g., [1,2,21,30–32]). For example, research suggests that trust in the protection of one's data is strongly associated with willingness to pay for smart meters [32,33]. The implication of this literature is that people who trust their utility company are more likely to engage with it (just as consumers who trust other kinds of companies are more likely to engage with those companies) and those who distrust their utility will seek to disengage from it by taking a more active role in their own energy production, storage, and management [34].

We extend existing research to examine the role of trust in a relatively high-cost household energy investment – installation of rooftop solar panels. Because rooftop PV provides households with an alternative source of energy that does not need to be purchased from their utility company, installation of solar panels is one step households can take to disengage from their utility. Indeed, research shows that autarky is a motivator for purchasing a solar system [9,10] and for adopting energy storage systems [35]. Currently, given the erratic nature of electricity produced by the sun and the high cost of energy storage, complete disconnection from the grid is not feasible for most households [34]. Nonetheless, installation of rooftop solar means that customers are producing some of their own electricity rather than relying solely on their utility company. Accordingly, we expect that low levels of customer trust in utility companies will be associated with greater interest in disengaging from those companies through identifying alternative sources of electricity [36]. In particular:

H1: Distrust in utility companies will be positively associated with interest in and having rooftop PV.

Historically, utility companies have assumed the primacy of financial motivations in customer decision-making (e.g., [37,38]). Researchers also emphasize financial factors in predicting consumer energy-related decisions (e.g., [8]). Even work that highlights the importance of social psychological factors acknowledges the potential importance of cost-benefit assessments. For example, Value-Belief-Norm theory points to the role of self-interest in environmental decision-making [5,39]. Similarly, diffusion of innovations theory describes persuasion about the relative advantages of a technology as a component of the decision-making process [5]. In general, research suggests that people are more interested in adopting solar systems if they see doing so as personally beneficial [5]. In thinking about financial factors, households may consider the size of the energy bill, their home value, and the availability of government incentives. Research shows that savings on electricity bills in conjunction with the cost of the system are the most important drivers of adoption [31]. People view solar as a protection against future electricity price increases [36,40–44] and some appear to be motivated by the belief that solar increases the value of their homes [45].

Utility companies have also begun to recognize that customers are interested not only in financial factors, but also in environmental issues [46–49]. Perceived environmental attributes of new technologies are a key driver of adopting sustainable innovations [50]. Many people see solar electricity as good for the environment (e.g., [4]) and research shows that, across countries, people consider environmental benefits a major factor in their decision to adopt rooftop solar [40,51–53].

However, expectations about environmental benefits alone are likely not sufficient to drive adoption (e.g., [11]). Instead, recent work suggests that expectations about environmental and financial benefits are intertwined (e.g., [5,29]). We expect that when people believe rooftop PV has financial and environmental benefits, they will be more interested in it and more likely to have it.

H2: Beliefs that solar has financial and environmental benefits will be positively associated with interest in and having solar panels.

Social science researchers have also emphasized the importance of people's values and attitudes (e.g., [39]). For example, applications of Value-Belief-Norm Theory to the study of environmental behaviors highlights the importance of personal norms as antecedents to those behaviors; values affect beliefs, which affect personal norms [54,55]. In the context of interest in solar panels, there is some evidence that personal norms regarding an individual's perceived obligation to protect the environment predict interest in solar energy [5]. Further, research shows that households with interest in and concern about environmental issues are more likely to invest in energy-saving technologies [56–60]. And those with a "green political orientation" are more likely to install solar PV [61]. Accordingly, we assess whether:

H3: Proenvironmental personal norms will be positively associated with interest in and having rooftop PV.

3. Interview data

To understand customers' relationships with their utility companies, we began inductively, exploring people's sentiments and beliefs about their utility company and about solar energy. We conducted 61 semi-structured interviews with people in southern (San Diego area) and northern California (Sacramento area). Interviews were conducted in the summers of 2018 and 2020. Our first round of interviews was conducted face-to-face. Due to Covid-19 and the need to maintain physical distancing, our second round was conducted via Zoom. The first round of interviews informed the development of the survey (which was conducted in 2019). We planned for a second round of interviews to follow-up on any unexpected findings in the survey. The survey results were generally as expected and the results from the interviews were consistent across the two rounds. Therefore, we present the results of the two rounds together.

3.1. Sampling and procedures

In each location, we began by talking with personal contacts of the researchers who had either adopted solar energy or not. We then relied on snowball sampling to broaden our sample. Sixty-four percent of our sample was female. Mean age was 55 (s.d. = 11). Participants were relatively well-educated, with a mean of 16.22 years of schooling (sd = 2.79). Our sample was also quite well-off, with half making $100,000 or more.[1] Thirty-three percent of our participants were Democrats and 43 percent were Republican. Three percent identified as supporting the Green party, two percent reported being Libertarian, five percent were independent, and 15 percent chose "other" or did not respond. A few participants identified themselves in terms of political ideology (conservative, moderate, liberal) rather than party. Forty of our 61 participants had solar panels. Of the 21 who did not have solar, 15 were interested in getting it; six were not. Our sample was not designed to be representative of homeowners in California, but rather to facilitate an in-depth understanding of household experiences with their utility company and their perceptions of solar energy. We relied on snowball sampling to seek a diversity of viewpoints, by asking participants to recommend friends and neighbors with different perspectives and experiences with solar energy.

We asked people questions designed to elicit their perceptions of their utility company, views on solar energy, and self-reported rationales for adopting or being interested in solar. Interviews lasted 60 min, on average. Participants were compensated for their time with a gift card. We also asked participants to complete a short sociodemographic survey following the interview.

3.2. Analysis

All interviews were professionally transcribed and cleaned by the research team. We analyzed the data in two broad phases. First, following each interview, the interviewer completed an analytic memo in which they addressed questions about the participant's motivations for adopting solar and their evaluation of their utility provider. Next, we analyzed transcripts using a line-by-line coding method [62]. This entailed reading each transcript and analytic memo to identify the main themes of the interview as they pertained to the broad categories of motivations for getting solar panels and perceptions of the utility. This process generated seven broad categories with 13 sub-categories. We then conducted a second round of analysis in which we coded excerpts of texts to these categories. In describing our results, we identify participants using pseudonyms.

4. Interview results

The qualitative analyses reveal participants' distrust in their utility companies and desires to be independent from their utility as a motivation for getting solar. Consistent with existing research conducted in other locations (e.g., [29,53]), participants also cited financial and environmental rationales for adopting rooftop PV.

4.1. Distrust: Wanting to disengage from utility companies

Participants across the political spectrum expressed significant distrust in their utility companies and said that they wanted more power to alter or exit from their relationship. When we asked Drew, a higher-income Republican, why he wanted to install solar in his home, he told us: "At this point, it's to get PG&E [Pacific Gas and Electric] out of our lives." Pam, a Republican who also wanted to install a solar system, expressed the same sentiment more vehemently. She told us she aspires to have a standalone solar system because, "SDG&E [San Diego Gas and Electric], who I've hated, despised, loathed, and just outright venomously…I can't even think of the word, for about at least 40 years, would be out of the loop." More succinctly, when asked about her interest in solar, Gail a middle-income Republican, said, "Independence from SDG&E. That is a big, big thing."

This distrust was reflected in participants' concerns about market power and the values and priorities of their utility provider. They saw utilities as unfair monopolies that did not care about their customers. Our participants voiced a sense that it is unfair for utilities to have so little competition. They wanted to do something to act on their frustration, but felt relatively powerless to do so. For example, when we asked Jerry, a higher-income owner of rooftop solar and battery storage, for his thoughts about his electric utility, he said, "They're extremely crooked, but what do you do? You're kind of stuck with them. You can't do anything else." In a context where most people have quite a bit of choice with respect to consumer purchases, the lack of choice for electricity bothered our participants. As Karen, a higher-income Democrat, noted, not having that choice makes "you feel powerless" and yet because, "you have to use electricity to survive," households are left with very little sense of control over their consumption of electricity.

[1] In our presentation of the interview results, we try to contextualize the participant by including information about their wealth. We describe as higher-income those who make $100,000 or more, middle income those who make $60,000-$99,999, and lower-income those who make less than $60,000. The people who we report as higher income in our sample may or may not be considered relatively wealthy in their community, depending on the local cost of living.

Solar energy offers a possibility. For example, Connie, a higher-income Republican with solar panels on her home, explained her decision to get solar panels as a way to avoid supporting the monopolistic market power of her utility company: there is, "free power out there, why should I be paying …a huge monopoly."

It is not only the market power of utility providers that cultivates distrust, it is also a sense that utilities abuse that power. Part of participants' dissatisfaction was rooted in a sense that the costs they paid for electricity were not the true costs of that service, but instead reflected their utility provider's greed for profit. Adam, an Independent, told us that he installed solar because his goal was, "to get off the grid." More specifically, he explained that he was frustrated by the poor service he received at the same time as he was faced with rising costs: "Services keep going down and rates keep going up. I'm just not into that… They're allowed to make a profit, so they just keep raising their rates to keep making their profits, keep their shareholders happy. My goal is to not be part of that system." Barbara, a higher-income Democrat, made similar comments, suggesting that running a utility company to maximize profit benefits shareholders and creates risks for households. She told us, "They have CEOs whose job it is to make sure that they're profitable as much as possible." She felt that as a result, the company, "takes major risks and endangers the people around it." Overall, people sensed that shareholders and wealthy utility executives benefit from the relationship between utility providers and their customers—and that customers are left paying the price. Solar PV is a way to disrupt this arrangement. As Ethan, a higher-income Democrat, concluded, "If everybody [had solar panels] they would make no money…How are they going to buy their Porsches?"

4.2. Saving a buck: Financial motivations for solar adoption

Although there is little recognition in existing literature of the role of customer trust in their utility company in motivating interest in or having solar, there is widespread awareness that perceived financial and environmental benefits of solar panels strengthen people's interest in the technology. Our participants were no exception. The people we interviewed saw solar as a prudent financial choice and as a solution to environmental problems. They discussed these two benefits as inextricably tied together.

Participants highlighted the current cost-savings and protection from future rate increases that they saw as associated with producing their own power. For instance, Adam (quoted above) explained the research he conducted before getting solar panels: "I basically just watched the pricing and the technology get better…Once it reached the point where the technology and the pricing was good enough, it boiled down to what my average electric bill per month was. That's when I went with the solar." When we asked Edward, a higher-income Republican, what led him to install solar, he told us he adopted solar panels to "save money" and then commented on the likelihood of future rate increases: "Electric bills gonna do nothing but go up as far as usage. It's already started." Ricky, a higher-income Democrat, similarly emphasized the importance of saving money: "If you can afford it, I mean, down the long run, you're going to save money." In addition to talking about their monthly electric bills, people focused on solar energy as an investment. For example, Mitch, a higher-income Democrat, emphasized the value of solar relative to other possible investments: "We invested 45 grand and I can tell you that it would not pay me back that every month if I had invested that somewhere else."

4.3. Greening the grid: Environmental motivations for solar adoption

Interview participants also associated solar energy with environmental protection. Across the political spectrum, participants viewed solar energy as a way to have a positive impact on the environment. For instance, Marilynne (a lower-income Democrat) said that she liked "the idea of grabbing something out of the sky" and further that solar was "more environmentally friendly." Similarly, Karen, a higher-income Democrat, when asked about her reasons for being interested in solar said, "Mostly environmental. We've tried to decrease our footprint." She said that when she sees someone with solar panels she thinks, "They care about the environment." Fred, a Republican, said, "I imagine that those giant solar fields are taking a huge chunk out of having to burn fossil fuels. I think if you could have a large enough area like that, yeah, I think it [rooftop PV] would make a huge impact on the environment."

This perception of solar panels as environmentally beneficial spanned political ideology, although conservatives were particularly likely to contrast solar to sources they saw as dirtier or more dangerous. For example, Sandra, a higher-income Republican, explained that she saw solar panels as benefitting air quality. In her words, "Well, I think we're not burning as much fuel… and I think that makes the air nicer to breathe as far as killing the ozone." When we asked Gail, quoted above, what kind of impact she saw her solar panels having on the environment, she said that by having solar panels, she was helping to make the energy grid safer. She argued, "The more people that have panels, the less of these dangerous places become necessary." Gail specified, "Places like Santa Onofre [a nuclear generating station near her home] now, it's closed, and it's dangerous…So, I think having the solar panels is a good thing."

Participants also expressed a sense of being personally responsible for reducing their environmental impact (what Value-Belief-Norm theorists term a "personal norm"). For example, Gail, quoted above, said that, "environmentally friendly is what I would like to be." Edward, a higher-income Republican, expressed a sense of responsibility for preserving the environment for future generations saying, "I think as you get older you get more … concerned about what you're going to leave behind."

Although we describe participants' environmental and financial motivations separately, our participants saw them as intertwined. Those who cited environmental motivations for adopting solar also commented on the financial benefits, and vice versa. For instance, Jim, a highly-educated Democrat, articulating the relative importance of these two motivations, explained, "Mainly the environment and then the money" but then recanted, "Well, the money might be also just as much [a motivator]." Similarly, Tim, an older liberal who recently installed solar, initially voiced this sense of responsibility to personally contribute to environmental protection: "I feel like we need to do as much for the environment as possible." He immediately added: "but also to save on the electric bills." Lisa, a middle-income Democrat who would like to have solar at some point, mentioned cost-savings, but also emphasized the appeal of feeling that she would be doing something to reduce her environmental impact: "I mean, obviously the cost savings, but I think more just like the idea that you would be doing something that's less detrimental to the environment."

4.4. Summary of interview results

In sum, our participants expressed high levels of distrust in their utility companies. They saw utility companies as focused on profits at the expense of customers and as being unfair monopolies, and they expressed strong desires to be independent from their utility companies. Participants also highlighted the importance of financial and environmental considerations and their personal environmental commitments in motivating their interest in and adoption of solar PV.

5. Survey data

Building on these themes from the first round of interviews, we developed a survey to quantitatively assess participants' trust in their utility company and the associations between distrust, financial and environmental benefits, and personal environmental norms, and interest in/having solar. We conducted the survey in fall 2019.

5.1. Sampling and procedures

To identify households with solar panels, we extracted records from online county building permit records (in California, permits are required for solar installations [63]). Our sample thus excludes counties (typically smaller) that did not post this information online (for a table of included counties see the online Appendix A1). The adopter sample was randomly selected from these records. To identify California households that did not have solar, we relied on general public address-based samples to match the counties for which we had information on solar installation permits. A sample was randomly drawn from this list. Entries that duplicated the adopter sample were removed. Two hundred cases were ineligible because the address was either a rental residence or a non-residential location. The response rate is based on the eligible addresses ($N = 26{,}023$).

We administered the survey using the Tailored Design Method [64]. We mailed an invitation letter with a one-dollar pre-incentive, asking participants to go to an online survey link. This was followed by another mailing again directing people to the survey link. We then sent a follow-up letter that included both the survey link and a paper copy of the survey and followed that with a reminder postcard. From these mailings we obtained 3402 completed or partially completed surveys for a 13.1 percent response rate. We received more responses from adopters ($N = 2234$; response rate = 18.1 percent) than non-adopters ($N = 1168$; response rate = 8.5%). Our experience recruiting participants for qualitative interviews suggested that California residents felt inundated with sales pitches for solar, which seemed to lower their willingness to participate in solar-related research. In addition, although our recruiting materials specified that we were interested in the opinions of those who had solar and those who did not, people who did not have solar may still have felt that they had little to say. Finally, the disruptions in fall 2019 due to wildfires, outages, and evacuations may also have reduced the response rate.

For these reasons, and because we focus on homeowners and exclude renters, our sample was not representative of California residents generally. Our sample was 42% female. Mean age was 59 (s.d. = 14.15) with 39 percent of our sample age 65 or older, compared to 34 percent of homeowners in the American Community Survey (ACS) [65]. Education levels were high, with a mean of 17 years of schooling. Seventy-four percent of our survey participants had a bachelor's degree or higher, whereas only 45 percent of the ACS sample had a college degree [65]. Median income was $125,000 in our sample compared to only $103,870 in the ACS [66]. Sixty-nine percent of our sample was white, compared to 54 percent of the ACS sample [65]. Our sample was somewhat liberal, with 22 percent identifying as Republican and 40 percent as Democrat. These rates are quite similar to the 2019 California voting records which show 24 percent Republican and 43 percent Democrat [67]. Our sample is thus more educated, whiter, and higher income than the general California population – more similar to homeowners who research suggests are likely to get solar [68]. The characteristics of our sample may be due, in part, to the topic of the survey. See Appendix Table A3 for sociodemographic characteristics of the adopter and nonadopter samples reported separately.

4.2. 5.2 Measures

Dependent measures: We were interested in understanding interest in solar energy as well as whether or not people had rooftop PV. Accordingly, we asked participants whether their residence had solar panels (yes or no). For those who did not already have solar, we asked how interested they were in getting solar panels installed (1 = not at all; 5 = very). From this question we created a binary variable with 0 = 1, 2, or 3 and 1 = 4 or 5. This recoding allowed us to run parallel analyses for interest in solar and having solar. Theoretically, we were interested in the distinction between those who were affirmatively interested in solar and those who were not, rather than the distinction between those who were disinterested and those who were not. As we report in the results section below, we ran the analyses coding interest both ways, with the substantially similar results for distrust, our primary variable of interest. Here we report the results for the coding that captures what we see as the theoretically relevant distinction. For exact wording of all items see Appendix Table A1.

Independent measures: We measured participants' distrust of their utility by asking them how much they trusted their electric utility company to act in their best interests (1 = strongly distrust; 5 = strongly trust). We recoded responses so that 1 = strongly trust and 5 = strongly distrust. This measure is consistent with our conceptualization of trust as an individual's expectation regarding whether the other will take one's interest into account. Our use of a single item measure is consistent with existing approaches to studying trust in institutions and findings that trust in institutions is one dimensional [69–71].

We also asked questions designed to evaluate respondents' perceptions of the benefits of solar panels and their personal proenvironmental norms. Based on comments from our interview participants, we included four items aimed at assessing perceived benefits (see Appendix Table A2). These items are highly correlated and have high internal reliability (Cronbach's alpha = 0.80). We also asked seven questions (again, derived from the interview data) to capture variation in respondents' sense of responsibility to protect the environment (see Appendix Table 2A). All items were measured on a five-point scale from strongly disagree to strongly agree. They also are highly correlated and have high internal reliability (Cronbach's alpha = 0.93). We entered the 11 items into a principal components analysis with varimax rotation. This yielded a two-factor solution with Eigenvalues of 2.570 and 5.045, respectively; the model explained roughly 69% of the cumulative variance. This suggests that the items tap two distinct latent constructs – one characterized in the environmental psychology literature as personal pro-environmental norms and the other estimating the respondents' views on the benefits of solar (both financial and environmental loaded onto a single factor). For details on the items used in the factor analysis and the item loadings, see Appendix Table A2.

Finally, we included questions on the sociodemographic characteristics described above. For exact wording and coding of all survey measures see Appendix Table A1. Mean responses for the independent measures, and correlations between them are summarized in the Appendix Tables A4 and A5.

6. Survey results

Results of logistic regression analyses are reported in Table 1. These analyses examine the associations between distrust in the utility company and interest in getting (Models 1 and 2) and having (Models 3–6) solar. They also show the associations between expectations regarding the benefits of solar, personal proenvironmental norms, respondent characteristics, and the dependent variables. Models 1, 3, and 5 report results without sociodemographic controls. Models 2, 4, and 6 include sociodemographic controls. Nonresponse rates for sociodemographic variables ranged from seven to 16 percent, thus the N is smaller for models that include those variables. We examined the means of our theoretically relevant variables for the full samples and for samples dropping missing variables and found no statistically significant difference. Further, the results for the theoretically relevant variables are substantially similar whether or not sociodemographic variables are included, suggesting that missing data do not account for our results.

Hypothesis 1 predicts that people with higher levels of distrust will be more interested in and more likely to have solar. Models 1 and 2 explain varying levels of interest in solar. The statistically significant positive *Distrust Utility* coefficient indicates that people who distrust their utility company are more likely to be interested in solar panels. Models 3 and 4 explain having or not having solar. Here the *Distrust Utility* coefficient indicates that the more people distrust their utility company, the more likely they are to have rooftop PV. We also examine

Table 1
Logistic regressions predicting interest in solar and having solar.

	Model 1		Model 2		Model 3		Model 4		Model 5		Model 6	
	Predicting Interest vs No Interest				Predicting Solar vs No Solar				Predicting Solar vs Interest			
	Odds Ratio (s.e.)	*p*	*Odds Ratio* (s.e.)	*p*	*Odds Ratio* (s.e.)	*p*	*Odds Ratio* (s.e.)	*p*	*Odds Ratio* (s.e.)	*p*	*Odds Ratio* (s.e.)	*p*
Distrust Utility	1.32 (0.13)	0.003	1.28 (0.13)	0.018	1.21 (0.06)	0.000	1.25 (0.07)	0.000	1.02 (0.07)	0.790	1.08 (0.08)	0.287
Benefit Solar	3.79 (0.62)	0.000	3.90 (0.73)	0.000	2.52 (0.18)	0.000	2.25 (0.17)	0.000	1.37 (0.13)	0.001	1.24 (0.14)	0.047
Personal Env Norm	1.69 (0.24)	0.000	1.63 (0.30)	0.008	.79 (0.05)	0.001	.92 (0.08)	0.374	.62 (0.06)	0.000	.73 (0.10)	0.021
Age	——	——	.98 (0.01)	0.002	——	——	1.01 (0.00)	0.069	——	——	1.02 (0.01)	0.000
Female (=1)	——	——	.73 (0.16)	0.142	——	——	1.05 (0.12)	0.682	——	——	1.26 (0.20)	0.138
Educ	——	——	1.07 (0.05)	0.150	——	——	.98 (0.02)	0.398	——	——	.97 (0.03)	0.360
White (=1)	——	——	1.14 (0.26)	0.551	——	——	1.15 (0.13)	0.215	——	——	1.16 (0.19)	0.376
Income ($10 K)	——	——	1.01 (0.02)	0.633	——	——	1.03 (0.01)	0.009	——	——	1.02 (0.01)	0.124
Liberal	——	——	1.02 (0.08)	0.810	——	——	.92 (0.04)	0.046	——	——	.91 (0.05)	0.103
Constant	.00 (0.00)	0.000	.00 (0.00)	0.000	.09 (0.03)	0.000	.06 (0.03)	0.000	14.77 (8.41)	0.000	4.54 (3.72)	0.065
LR chi2	153.89		145.37		211.06		171.93		25.91		40.12	
Pseudo R-sq	0.18		0.20		0.07		0.07		0.02		0.03	
N	647		538		2549		2185		2149		1858	

Note. * p < .05; ** p < .01; ***p < .001. Models 1 & 2 dependent var 0 = disinterest; 1 = interest. Models 3 & 4 dependent var 0 = do not have solar; 1 = have solar. Models 5 & 6 dependent var 0 = interest; 1 = have solar. Model 3 adopter N = 1899, nonadopter N = 650; Model 4 adopter N = 1645; nonadopter N = 540; Model 5 interested N = 250, adopter N = 1899; Model 6 interested N = 213, adopter N = 1645.

whether distrust explains the difference between having solar versus just being interested in it. Models 5 and 6 report the results for this comparison. The nonsignificant distrust coefficients in these models show that distrust does not distinguish between being interested in solar and having it.

Hypothesis 2 predicts that beliefs about the financial and environmental benefits of solar drive interest in and adoption of solar panels. We find that perceptions of benefits are positively associated with interest in and having solar panels (see the *Benefit Solar* coefficient across models; Table 1).[2]

Hypothesis 3 predicts that personal proenvironmental norms will be associated with interest in and having solar. Consistent with existing research, the results show that people who say they care about the environment are also more likely to be interested in rooftop PV (Models 1–2). Personal proenvironmental norms also distinguish between those who do not have solar and those who do (Model 3), but this effect is in the opposite direction than predicted. Those who care about the environment are less likely (rather than more likely) to have solar. But the coefficient becomes statistically insignificant when sociodemographic controls are included (Model 4). This drop in significance may be due to missing data associated with nonresponses to sociodemographic questions. Finally, personal norms distinguish between those who are interested in solar and those who have it (Models 5 and 6). Again, the effect is in the opposite direction than predicted.

Finally, our analyses include participant sociodemographic characteristics as controls (Models 2, 4, and 6, Table 1). Research on the associations between age and adoption has produced inconsistent results (e.g., [72,73]). We find that younger people are more likely to express interest in solar energy (Model 2) and that older people are more likely to have solar (rather than just be interested in it (Model 6). Although existing research finds that women have more environmental concern than men (e.g., [74,75]), we find that respondent gender is not associated with either interest in or having solar panels, perhaps because the decision to adopt solar is not seen solely in environmental terms and because respondents are not necessarily responsible for energy decisions in their households. Respondent education also has no effect. Existing research is divided on the effects of education [6]. Our result is consistent with work finding that education is not a significant predictor. Although existing research shows that solar adoption is more common in majority white areas (e.g., [76,77]), we find no association between race and interest in or having solar. Consistent with existing work, we find that respondent income is not associated with interest but is positively associated with having solar as compared to not having it (Model 4) (e.g., [6,68,78]). However, income does not explain having solar versus simply being interested in it (Model 6). Finally, we find that liberals and conservatives express similar interest (Model 2), but liberals are less likely to have solar (see the Liberal coefficient in Model 4) (see [79] for insights into political ideology and activity, and solar installations).

7. Discussion

Our survey results show that people's distrust of their utility company and desire to be independent from it are associated with increased interest in and having versus not having solar energy, but do not distinguish between those who are interested in solar and those who have it. Our qualitative interviews suggest that feelings of distrust are deeply held and capture perceptions of utility malfeasance. Participants expressed a desire to be less dependent on their utility and to pay less money to an institution they saw as unreliable and untrustworthy. Consistent with existing research, our results also show that financial and environmental considerations matter. When people believe that solar panels have positive environmental and financial consequences, they are more likely to be interested in and to have solar panels. Personal

[2] The questions that make up the *Benefit Solar* variable also included a "don't know" answer choice. In the analyses reported here, "don't know" is recoded as missing. We conducted additional analyses in which we recoded "don't know" as 3 (on the 1–5 response scale). These analyses produced qualitatively similar results except that *Benefit Solar* is statistically insignificant when predicting solar vs interest in a model that includes sociodemographic controls (Model 6).

proenvironmental norms are also associated with interest in and having solar panels [5]. Together, our results suggest that distrust, perceived benefits, and personal environmental norms predict interest in solar; moving people from being interested to having solar requires that people view solar as beneficial and that they care about the environment.

7.1. Implications

Research on trust in the energy context tends to focus on trust in companies building grid-scale generation facilities such as nuclear power plants or wind farms (e.g., [26,80,81]). That work shows that people who have more trust in a company will be more accepting of its generation facilities. It highlights strategies companies use for developing trust among community members, including good communication and engagement with residents (e.g., [80]) and an emphasis on procedural fairness [81]. It also shows that increased trust is associated with perceptions of lower risk. Instead of focusing on consumer trust and acceptance of grid-scale generation facilities, here we examine customer distrust and interest in self-generation of power. We show that distrust matters. The lessons from the earlier research regarding factors relevant for trust may be useful for utility companies interested in increasing customer trust and engagement in utility programs.

Such insights matter because customer distrust of their utility providers has potential implications for management of the electric grid. Utility companies currently engage in demand response efforts – incentives provided to customers to shift their electricity consumption. Integrating more renewable energy into the grid will require even more of this coordination and cooperation between utilities and consumers in order to ensure that supply and demand are balanced. Solar owners have a particular role to play because of their impacts on the grid. Grid-tied solar owners (which constitute the majority of residential solar installations) produce electricity that flows into the grid; this supply must be managed so that the grid does not receive too much power during sunny periods. In addition, people tend to increase their electricity use after installing solar, but that increased use is not necessarily at the same time that solar panels are producing electricity (for example, one of our participants said that after they got solar panels they began putting up exterior Christmas lights) (e.g., [82–86]). The implication is that residential solar energy producers may exacerbate peaks and valleys in supply and demand [78]. We find that people with low levels of trust are most likely to be interested in and have solar. Existing research also suggests that customers who do not trust their energy company are less interested in utility programs [87]. The implication is that utility companies may run into difficulties if they do not address consumers' concerns. Future research should further investigate the grounds for consumer distrust and steps that utilities might take to increase customer trust. More generally, it should also examine trust and its potential role in decarbonization efforts and the energy transition.

Another potential implication of our findings is that the financial frustrations identified in previous research (e.g., [88,89]) may be about more than just money. They may also reflect people's resentment that utilities have a monopoly, that costs seem to increase even as service quality does not, and that utilities are not held responsible for their actions. Thus, the impacts existing research has attributed to money may be capturing, at least in part, people's distrust in their utility.

Our findings regarding environmental and financial benefits are consistent with existing research on the social psychology of adoption of solar panels (e.g., [5,90]). Diffusion of innovations theory, for example, highlights the importance of people's beliefs about a technology being advantageous. Similarly, value-belief-norm theory points to self-interest as a motivator. Consistent with these arguments, we find that people who believe that solar is financially and environmentally beneficial are more likely to be interested in and to have a solar system. Value-belief-norm theory suggests that altruism is relevant for decisions. Similarly, we find that people who care about the environment have more interest in solar.

7.2. Limitations

Our research was conducted in California, a state with a particular set of characteristics. Given California's unique history of outages, high costs, and wildfires, it is unclear whether the results found here would be replicated elsewhere (although there is evidence of customer frustration in other states with severe weather and of distrust in utility companies across the country) (e.g., [91,92]). Similarly, wildfires and outages may have been particularly salient when the survey was administered. Even if there are differences in levels of distrust across states (or over time within states), our theory would still predict that higher distrust will lead to increased interest in alternative energy sources. This effect is likely to vary depending on factors such as the viability of solar in the area (e.g., number of sunny days). In addition, the structure of the energy market may have implications for trust – for example, in most of the US, people are unable to choose their utility, but in deregulated markets, customers have choice. The ability to choose one's utility may produce increased trust. Future research should assess the effects of customer distrust in their utility company on household energy decisions across states.

In addition, because California has a large proportion of investor-owned utility companies, our research does not speak to relationships between customers and municipal or cooperative utilities. Future research could examine whether such utility ownership arrangements matter, examining levels of trust in areas where utilities are investor-owned, run by a municipality, or managed as a cooperative. It is possible that the complaints our participants voiced are specific to utilities that are motivated to generate profits and that motivations to install solar may vary depending on the ownership structure of utility providers.

Further, our interviews and survey were limited to homeowners. Because interview participants were identified using snowball sampling, they are not representative of California homeowners generally. It is also possible that people who responded to the survey differ from non-respondents. For example, people who were more frustrated with their utility company may have been more or less likely to respond. In addition, there may be differences in who opted into the survey in the adopter and non-adopter samples. If so, then our results may report higher or lower levels of distrust than actually exist or there may be differences across the samples not revealed here. Missing data may also have affected our results, though given the consistency of our findings we think it unlikely that they are due to bias associated with the missing data.

Our survey uses a single item trust measure that focuses on respondents' beliefs about whether their utility company would act in their best interest. The trust literature uses a range of strategies for capturing trust – single items questions such as in the General Social Survey (e.g., [21,93]), multiple item scales, questions about past trusting behavior (e.g., how often do you lend money to friends), and behavioral measures captured in laboratory experiments (e.g., the trust game) (e.g., [94]). Single item measures of trust in institutions are common (e.g., [69–71]). Nonetheless, future research could assess the role of distrust that is specific to particular domains that are relevant in the utility context. It could also assess whether the effects of trust are consistent across different measures.

Our survey was cross-sectional and therefore allows us to assess associations but not causality. It is possible, for example, that having solar panels affected beliefs about the benefits of solar, rather than the other way around. Future research could test causal relationships.

Finally, our study does not examine all possible causes of household adoption of rooftop PV. For example, existing research finds evidence of peer effects, showing that when others in a geographic area have installed rooftop PV, an individual household is more likely to do so as well [12,95,96] and that social influences can help to overcome barriers in adoption (e.g., [10,97]). Psychological theories incorporate an array of individual internal states including attitudes, beliefs, preferences, and

personality traits (e.g., [6,7]). It is possible that if one of these factors caused both trust and interest in solar, then the association between trust and solar found here might be due to that factor. However, scholars know little about causes of customer distrust in their utility company. More research is needed to identify these factors. Whatever the reason for the association (whether the association is causal or due to a third factor), the fact that people with higher levels of distrust are more likely to be interested in and have solar, along with research showing that customer distrust in companies is associated with less engagement, means that utility companies seeking to increase engagement with solar owners will also need to consider distrust.

7.3. Conclusion

We find that people who distrust their utility company express more interest in solar energy and are more likely to have rooftop PV than those with low levels of distrust. Incorporating renewable energy into the grid, particularly when those renewable sources are distributed across residential producers, as is the case for solar panels on household rooftops, increases the need for cooperation and coordination between utilities and consumers in order to maintain reliability of supply. Our results suggest that people who distrust their utility are most likely to be interested in and have solar. Along with research showing that people who distrust a company are least likely to engage with it, the implication is that consumer concerns about their utility companies should be taken into account as the US transitions to a more sustainable grid.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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