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Explaining interest in adopting residential solar photovoltaic systems in the United States: Toward an integration of behavioral theories

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ABSTRACT

Increased household adoption of solar photovoltaic systems has the potential to reduce greenhouse gas emissions associated with providing electricity. Although residential solar has recently become more affordable, market penetration in the U.S. remains relatively low. This study proposes a theoretical framework for investigating the psychological and social determinants of interest in residential solar drawn from three theories that may explain the decision to pursue it: diffusion of innovations theory, theory of planned behavior, and value-belief-norm theory. We test this framework using survey data from 904 non- adopter homeowners, with the aim of identifying potential levers for intervention. Overall, we find that consumers see solar electricity in multiple ways: as an environmental benefit, a consumer good, and an innovative technology. Notably, individuals who trust installers and believe solar will be personally beneficial are more likely to consider contacting an installer, as are individuals drawn to novel products. Proenvironmental personal norms indirectly increase interest through perceived personal benefits, suggesting that marketing efforts aimed at environmentally-concerned individuals may need to emphasize non-environmental benefits. The results also support leveraging trusted social networks to convey the benefits of solar. We conclude by discussing the value of the integrated framework along with implications for policymakers and marketers.

1. Introduction

In many parts of the world, including substantial portions of the U.S.A., solar photovoltaics have great potential to reduce greenhouse gas emissions and other adverse impacts from current methods of generating electricity [1–3]. Achieving this potential will require behavioral changes on the part of producers, suppliers, and potential adopters of this technology. This study considers the factors that may lead potential adopters of residential photovoltaics (RPV) to take a key first step toward adoption: showing interest in contacting an RPV installer.

Although RPV have been available for household use in the U.S. since the late 1970s, their deployment proceeded at a slow rate until recently [4]. Since 2010, the cumulative installed capacity of RPV in the U.S. has grown from 380 megawatts (MW) to 5644 MW in 2015 [5]. Several technological, economic, and policy factors have made possible the recent increase in adoption rates. These include more reliable and efficient technologies, lower production costs, and more favorable laws and financial incentives. Notably, the federal solar investment tax credit (ITC), state and utility rebates, and net metering policies have significantly lowered the installed cost of RPV in many states [6]. In addition, new third-party ownership models have made RPV affordable to a larger portion of U.S. households [7,8]. Under such arrangements, RPV systems are installed on a homeowner's property but owned and maintained by a third party company – often with no upfront costs. Homeowners can lease the system, paying a subsidized upfront cost or a monthly fee, or enter into a power purchase agreement (PPA) to buy the electricity generated from the system at a set per-kilowatt-hour rate. Both lease fees and PPAs are designed to be competitive with electricity rates charged by the utility.

Despite these advances in the U.S. RPV market, there remain opportunities for improvement. The U.S. Department of Energy

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projects that if the price of solar technologies were to fall by 75% of 2010 prices by 2020, solar could meet 27% of U.S. electricity needs by 2050 [2]. In the context of residential solar, this means reducing the installed cost of RPV to $1.50 per peak watt. Currently 11.6% of the installed cost of RPV (or $0.36 of $3.09 per watt) is attributed to the "soft costs" of acquiring new customers [9]. For policymakers and PV companies looking to spur further adoption of RPV, understanding potential leverage points for increasing interest in RPV – and reducing soft costs – is critical.

To date, research on U.S. RPV adoption has primarily involved statistically modeling adoption trends and future penetration rates [7,10–14]. Only recently has attention turned toward understanding the characteristics of consumers who install RPV and the psychological and social factors that affect their decision-making. Most work in this area has relied on retrospective surveys of RPV adopters. Researchers have examined, for example, self- reported motivations for "going solar," the role of expected financial returns, the effects of seeing neighbors with RPV installations, and the influence of learning about RPV through different information sources such as installers or existing owners [8,15–18].

While this body of work sheds light on different aspects of RPV decision making, it lacks theoretical coherence [19]. Some studies reference Rogers' [20] diffusion of innovations theory to explain the influence of information channels and peer effects on RPV adoption [15,17], others evaluate the extent to which adopters engaged in rational economic evaluations of RPV [8] , while still others examine determinants of adoption in the absence of any theoretical framework [16]. To our knowledge, only one study, based on qualitative interviews, attempts to look across multiple behavioral theories to explain RPV adoption [18]. This failure to build on known behavioral theories and concepts from the noneconomic social sciences that might have predictive value is characteristic generally of the literature on household energy investments [21], and does not bode well for the accumulation of knowledge. Furthermore, the existing literature, with its emphasis on examining the decisions of adopters post hoc, may overlook crucial information about the motivations or barriers affecting non- adopters.

In this study, we take a step toward building a theoretically grounded account of RPV adoption by examining interest in RPV – among non-adopters – as a function of numerous potential influences, including not only aspects of the diffusion of innovations theory but also elements of two other well-known behavioral theories that can reasonably be expected to have predictive value. As RPV is the purchase of a consumer good, albeit an unusual one, theories that have proven helpful in understanding consumer decision making could be useful. In particular, the theory of planned behavior (TPB) [22] has been deployed in analyzing a wide variety of consumer behaviors. Because RPV has substantial benefits in reducing greenhouse gas emissions, homeowners may also be motivated in part by environmental concerns. Thus we consider measures drawn from a well-developed theory of individual environmental decision making, the value-belief-norm theory (VBN) [23]. Extensive literatures have used either TPB or VBN to understand proenvironmental consumer behavior [21,24–26]. However, as adoption of RPV involves a larger financial commitment and a more visible change in household technology than perhaps any other consumer behavior, it is not clear the extent to which results from studies of less expensive and less visible behaviors will generalize. Indeed, one contribution of this analysis is to examine whether aspects of existing theories of proenvironmental consumer behavior are valuable in explaining such a substantial step.

We view these theories – DOI, TPB, and VBN – as complementary rather than competitive; each considers unique aspects of decision making. Accordingly, we propose and test an integrated model of interest in RPV that includes and combines aspects of all three theories to identify factors that are particularly influential and that may be possible levers for enhancing adoption, as well as to consider whether a full understanding must go beyond these individual theories. The parable of the blind men and the elephant reflects our view of the adoption phenomenon. The parable is attributed to the Buddha as an admonition against sectarian division. Several blind observers offer their assessment of an elephant. The observer who touches the leg declares the elephant to be rather like a tree trunk. The observer who touches the tail declares the elephant to be rather like a broom, the trunk leads to the conclusion of a snake and so on. Of course, the methods of science urge us to share observations, and after some conversation it is likely that the observers would come to an accurate description of the elephant. So, too, with the multiple theories that describe aspects of the decision to go solar: each describes an aspect of reality. As Klöckner [27] noted, integrating variables from the most successful theories of behavior change may yield both theoretical and practical benefits: we may better understand which variables are key determinants of behavior, which should be targeted for intervention, and which of the more distal variables may be useful for influencing more proximal ones.

In this case, we are looking at three aspects of the "elephant" of RPV. Since it is an innovative technology, we have drawn on elements of DOI theory. Since it is a consumer behavior, we have drawn on elements of TPB. And since it is a proenvironmental behavior, we have drawn on elements of VBN theory. We emphasize that given the practical limits of survey length, we have not conducted a comprehensive test of any of these theories. To continue the analogy, there are likely aspects of the elephant we have not considered. Those could be added to an integrated model in future research, as could other aspects of our three theories that we have not included in this study. At some point, it would be useful to have an overarching comprehensive theory, a full picture of the elephant, that integrates across existing partial theories. We are taking a first step in that direction but certainly do not offer such a full integration.

Rather than an integrative theory or a comprehensive comparative test of the theories, the aim of this paper is to offer a better understanding of what factors influence interest in contacting an RPV installer, a key precursor to actual adoption. We examine this question using survey data collected from non-adopter homeowners in four U.S. states that have relatively high rates of RPV adoption (AZ, CA, NJ and NY). Measures on the survey were informed by each of the three theories as well as conversations with leaders in the RPV industry who suggested measures that, in their experience, influenced the decision to move toward solar.

In the remainder of this section, we discuss how each of the three theories – DOI, TPB, and VBN – may help explain interest in RPV and provide evidence from relevant past literature. Section 2 describes our survey measures and methodology for testing the framework. Section 3 presents results, and Section 4 discusses their implications.

1.1. Three theoretical perspectives on interest in RPV

1.1.1. Diffusion of innovations: RPV as an innovation

In most of the United States, RPV will be seen by homeowners as an innovative and relatively unknown, new technology. Even in states such as California where climatic and policy conditions for RPV are favorable, only 5.7% of homeowners have adopted them [28,29]. Diffusion of innovations (DOI) theory describes the process by which an innovation diffuses through a social system as a result of information being communicated through media and person-to-person communication channels (see Fig. 1a) [20]. The theory proposes that the process for adopting an innovation occurs in five stages: individuals become aware of an innovation (knowledge), form attitudes about it (persuasion), decide whether to adopt it (decision), implement the innovation (implementation), and then