Residential Solar Power Adoption in Brazil

Abstract: This study proposes a model integrating three different behavioral theories to verify the factors influencing the intention to use residential solar panels. Data were collected in an online survey with 216 respondents and analyzed via structural equation modeling. The results suggest that the system's ability to generate financial savings, the support of individuals close to the potential user and the feeling of moral obligation to adopt the technology to avoid harmful impacts on the environment are essential factors in adopting residential solar panels. These findings may represent an initial step in formulating policies that encourage the diffusion of solar technology.

Keywords: renewable energy, intention to use, technology adoption, innovation, solar panels

INTRODUCTION

Electricity consumption directly impacts people's lives and the environment through the effects accumulated by the generation, transmission, and use of energy. The conversion of carbon-rich natural resources, such as oil, natural gas and coal, currently represent 80% of global energy demand and significantly contribute to the increase in the planet's temperature and the generation of waste that contaminate the air, water and soil (Lacchini & Rüther, 2015). Therefore, the growing demand for greener products and services enhances the challenge of simultaneously seeking the development of society and sustainability in using natural resources for governments, business managers and scholars (Lacchini & Rüther, 2015).

The recent focus on developing a more sustainable energy matrix brings greater utilization of renewable sources, such as solar energy, to the center of the discussion. The ability to transform the sun's rays into electricity and thus produce renewable energy for future generations makes solar energy one of the “cleanest” sources available (Lacchini & Rüther, 2015), as it replaces conventional resources, like coal and oil, and does not cause climate change (Solangi et al., 2011). These advantages become even more evident when considering that individuals can produce their own energy through the installation of solar panels in their homes, which is the focus of this work. In addition to the production of clean energy, there are relevant benefits for users of photovoltaic panels, such as the partial or total reduction of the electricity bill, independence from the supplier company, and protection against tariff increases and power cuts (Silveira, Tuna, & De Queiroz Lamas, 2013; Schelly, 2014). In Brazil, for example, excess energy not consumed during the month becomes a credit to be used within a period of up to 60 months. Meanwhile, in many countries, this reserve is “sold” back to the distributor at the current tariff price or even above this, further reducing the owner's expenses.

There are, however, numerous barriers that prevent the spread of solar panels more rapidly, such as the lack of political will, ignorance of the technology and its benefits (Farhar & Coburn, 2000), cultural barriers (Sovacool, 2009) and, mainly, the high cost of installation and maintenance. Despite attractive credit lines, subsidies to producers and discounts to users, photovoltaic solar energy still requires a high investment for most people (Zhai & Williams, 2012). Although the advantages of photovoltaic solar energy innovation seem evident, its development in many countries is still shy, particularly in the case of Brazil, despite the efforts of the Brazilian government to change this scenario (De Souza & Cavalcante, 2016). This fact reaffirms the importance of studying, in the Brazilian context, how personal motivations and perceptions about photovoltaic solar energy can be translated into the intention to adopt it. Even though there were other studies conducted in other emerging countries, such as China (Irfan et al., 2021), Pakistan (Jabeen et al., 2019), India (Aggarwal, Syed, & Garg, 2019), the current study focuses specifically on determinants that influence the intention to use residential solar panels in Brazil.

Diffusion of Innovations (DOI)

The theory of diffusion of innovations, by Rogers (2010), is a classic model describing how innovations are diffused. For Rogers (2010), the diffusion of a new idea, practice, or technology results from the communication process through channels over time between members of a social system (Rogers, 2010). According to the author, forming a favorable or unfavorable attitude towards innovation affects its adoption rate. In addition, the perception of the suitability of an innovation for an individual occurs through the assessment of five attributes: relative advantage, compatibility, complexity, experimentability, and observability.

Relative Advantage is “the degree to which an innovation is perceived as better than the idea it replaces” (Rogers, 2010, p. 229). The perceived advantages can be economic, social, environmental, among others. Compatibility refers to how compatible the innovation is with potential adopters' sociocultural values, beliefs, needs, and practices. Complexity is the perception of the difficulty of understanding and using an innovation. Some innovations can be easy to use and spread faster, while others are more complicated and adopted at a slower pace. Experimentability is “the degree to which an innovation can be experienced for a limited time" (Rogers, 2010, p. 258), that is, the possibility of testing a new technology without requiring commitment or risk, reducing uncertainties regarding its performance and increasing the likelihood that it will be adopted. Observability refers to how visible the innovation is to others. Easily observable innovations tend to be more easily diffused, as the results and effects arising from their use become clear to potential adopters through the observation of others using them. Therefore, four of Rogers’ innovation attributes (relative advantage, compatibility,

experimentability and observability) are positively related to the innovation adoption rate, while one (complexity) is negatively related.

Theory of Planned Behavior (TPB)

The theory of planned behavior (Ajzen, 1991) extends the theory of rational action (Fishbein & Ajzen, 1977) and is one of the most utilized social psychology models to analyze human behavior. The theory has already been used to explain intentions and behaviors in different contexts and areas, such as condom use (Reinecke, Schmidt, & Ajzen, 1996), healthy initiatives (Hu & Lanese, 1998) and sustainable behaviors (Han, Hsu, & Sheu, 2010), to name a few.

According to Ajzen (1991), behavior is determined by the individual's intention to perform it, which is a central concept of the theory, summarizing motivational aspects that indicate the willingness to perform a given action, that is, the greater the individual's intention, the greater the probability that the intended behavior will be performed. Also, according to Ajzen (1991), intention results from a rational decision process that involves three spheres: attitude towards behavior, subjective norms and perception of control over behavior.

Thus, attitude refers to "the degree to which a person assesses a behavior as favorable or unfavorable" (Ajzen, 1991, p. 188). This is formed by beliefs about the consequences of a certain action. If the consequences are assessed as desirable, the individual presents a positive attitude towards the behavior, whereas, if evaluated as undesirable, a negative attitude towards the behavior in question is formed.

Subjective norms, in turn, refer to the perception that important people or reference groups for the individual approve or disapprove of the behavior in question. Social pressure can inhibit or reinforce an individual's intention regardless of their attitude about the behavior. Finally, the perception of control over behavior refers to the degree of difficulty or perceived ease in performing it. Perceived control is important, as a favorable attitude towards a specific behavior and the approval of close people can be minimized if the individual does not have the resources (money, time, etc.) or skills necessary to carry it out (Ajzen, 1991).

Value-Belief-Norm Theory (VBN)

The value-belief-norm theory (Stern et al., 1999) results from the link between extensive literature on the social psychology of environmentalism and studies on social movements. From the combination of concepts from three other theories, the norm activation model (Schwartz, 1977), the theory of basic values (Schwartz & Bilsky, 1990; Schwartz, 1992, 1994) and the new ecological paradigm (Dunlap & Van Liere, 2008), VBN proposes a new approach that investigates engagement

in environmental initiatives through a chain that brings together personal values, beliefs and norms. The model is widely used in different applications, such as using transport with low pollutant emissions (Liu et al., 2017), choosing hotels with sustainable practices (Choi, Jang, & Kandampully, 2015) and conscious use of energy (Wilson & Dowlatabadi, 2007). According to the authors, engaging in environmental causes depends on feelings of moral obligation to act, which are more significant when there is awareness of environmental problems and concern for the environment, factors, in turn, influenced by personal values (Stern et al., 1999). Thus, personal norms form the basis for sustainable behaviors.

CONCEPTUAL MODEL AND HYPOTHESES

Intention of use

Intention is a fundamental part of theories that study human behavior (Ajzen & Fishbein, 1977). It is a construct that "gathers motivational factors that influence behavior, being an indicator of how much a person is willing to strive to perform a given action" (Ajzen, 1991, p. 181), in which, by definition, it is stipulated that the greater the individual's intention, the greater the probability that the intended behavior will be carried out (Ajzen, 1991). In general, the difficulty of measuring the actual behavior itself during data collection favors the definition of intention as the central element to be analyzed in research, being recognized as an efficient and approximate measure of behavior (Ajzen & Fishbein, 1977; Sheppard, Hartwick, & Warshaw, 1988). Furthermore, from a managerial point of view, the importance lies in understanding the antecedents that affect the individual's propensity to adopt an innovation and not necessarily its actual adoption. Thus, in accordance with several studies that investigate technology adoption (Sang & Bekhet, 2015), intention to use photovoltaic solar panels is defined here as the study's dependent variable, also used in the study by Kim et al. (2014) on solar panels. It is believed that the extensive applicability of this variable, established as a standard in field research, can facilitate analyzes and allow a basis for comparison with other studies, as opposed to that used in the model by Wolske, Stern and Dietz (2017) – "interest in contacting an installer of solar panels."

Relative Advantage

Innovations that have advantages compared to what they replace tend to be more easily adopted by the public (Rogers, 2010). In this model, relative advantage represents the perception that investment in solar panels can provide benefits, especially financial ones, such as a reduction in the electricity bill, protection against increases in the electricity tariff and property appreciation. In several studies in the field of green technologies, the positive relationship between these advantages and the

intention to use variable is supported (Farhar & Coburn, 2000; Korcaj, Hahnel, & Spada, 2015). Finally, results from Labay and Kinnear (1981) and Jansson (2011) also reveal a positive relationship between “relative advantage” and “intention to use” green technologies. The following hypothesis is then proposed:

H1: Relative advantage has a direct and positive effect on intention to use.

Perceived Risk

Wolske, Stern and Dietz (2017) adapted Rogers' (2010) compatibility construct to perceived risk. In theory, the more compatible solar energy technology is with potential adopters' practices, values , and needs, the more easily it is diffused. In this case, the authors use the “perceived risk” variable to measure whether potential users perceive an innovation as incompatible with their practices and values, that is, whether there is a perception of risk in investing in solar panels. Ram and Sheth (1989) define four types of risk: physical, economic, functional and social. Physical risk is what can cause harm to a person or property. Economic risk is associated with the financial cost of the innovation, and thus, if it is too high, potential adopters may give up on adopting it or decide to wait for cheaper versions of the product. Functional risk refers to the uncertainty regarding the performance of an innovation. On the other hand, social risk refers to the negative opinions other people might form if they can see the user of a novelty. If the perceived risks of an innovation are barriers that generate resistance and inhibit the desire to adopt it (Ram & Sheth, 1989), it is naturally expected that they have a negative effect on the intention to use. Other studies have already experimented with the attributes of the theory of diffusion of innovations together with perceived risk, pointing out this relationship (Jansson, 2011; Labay & Kinnear, 1981). The following hypothesis is then proposed:

H2: Perceived risk has a direct and negative effect on intention to use.

Experimentability

All innovations have some degree of uncertainty linked to their adoption (Ram & Sheth, 1989). Rogers (2010) establishes that the possibility of experiencing a novelty for a short period without requiring a high commitment reduces uncertainties and increases the probability that it is adopted. For this reason, it is inferred that experimentability has a positive effect on the intention to use, a hypothesis confirmed, for example, by Varabyova et al. (2017). In terms of sustainable initiatives, researchers perceive the difficulty of testing solar panel technology without compromise as a barrier to the expansion of its use (Faiers & Neame, 2006). Still, Wolske, Stern and Dietz (2017) add to experimentability aspects that reflect the willingness to interact with technology users, inserting the concept of peer influence (Rogers, 2010), which is essential to overcome the difficulty of testing

innovations (Farhar & Coburn, 2000; Karakaya, Hidalgo, & Nuur, 2015; Rai & Robinson, 2013; Palm, 2017). Therefore, it is inferred that the more an individual is willing to test and interact with solar panel users, the greater their intention to adopt the technology. Thus, the following hypothesis is proposed:

H3: Experimentability has a direct and positive effect on the intention to use.

Environmental Benefits

Photovoltaic solar energy is often referred to as a "green technology" whose adoption is predominantly motivated by environmental issues (Yadav & Pathak, 2016). In this study, the variable expresses the notion that solar panels are clean technologies that produce electricity without environmental impact, and that their use contributes to containing climate change. It is assumed that the variable has a positive effect on the "intention to use," that is, the more the individual realizes that solar panels are beneficial to the environment, the more willing they are to use them. This link can be observed from examining other sustainable behaviors (Han, Hsu, & Sheu, 2010; Sang & Bekhet, 2015; Yadav & Pathak, 2016).

In the case of solar panels, the positive output provided to the environment can also be seen as a relative advantage compared to conventional forms of electricity production. Improving air pollution, conserving natural resources, reducing global warming, and protecting future generations are examples of the technology's environmental advantages (Farhar & Coburn, 2000). Jager (2006) surveyed users of photovoltaic systems and found that "contributing to a better environment" was the most determining aspect of the purchase. Other similar results reaffirm the reasons associated with climate protection as drivers with the greatest impact on the decision to purchase solar panels (Zhai & Williams, 2012; Karakaya, Hidalgo, & Nuur, 2015). Thus, the following hypothesis is proposed:

H4: The perception of environmental benefits has a direct and positive effect on the intention to use.

Personal norms

Personal norms refer to an individual's sense of moral obligation to act in a certain way for the well-being of many. If a person acts according to the norm, he feels satisfied and proud, and his self-esteem is high. However, if the action is inconsistent with the norm, feelings of shame and guilt can reduce self-esteem (Schwartz, 1977). This topic is essential for the value-belief-norm theory (Stern et al., 1999), as values and beliefs have an indirect effect on behavior through personal norms, that is, environmentally responsible behaviors require people to feel the duty to act in favor of the collective to avoid or minimize damage to the environment (Stern et al., 1999).

For example, in the context of behaviors associated with energy saving, psychological aspects, such as personal norms, have shown their importance for some decades (Jansson, Nordlund, & Westin, 2017). In addition, Van Der Werff and Steg (2016) and Jansson (2011) suggest that the consumption of ecological innovations is highly induced by psychological motivators of moral order (Jansson, Nordlund, & Westin, 2017; Liu et al.; 2017). Thus, the following hypothesis is proposed:

H5: Personal norms have a direct and positive effect on intention to use.

Subjective norms

Subjective norms represent one of the determinants of intentional behavior initially present in the theories of reasoned action by Fishbein and Ajzen (1975) and planned behavior (Ajzen, 1991). This element deals with the social pressure perceived by the individual on the decision to engage or not in given conduct. As social beings, people often make choices based on an expected mode of behavior to value their own image in desired social circles (Bearden, Netemeyer, & Teel, 1989). The approval or disapproval of family members, friends, and reference groups can inhibit or reinforce the individual's intention with greater or lesser intensity regardless of their attitude towards the behavior (Ajzen, 1991).

In many studies, “subjective norms” refer only to the social pressure an individual may suffer to act in a certain way. However, solar panel technology is an innovation with a still restricted portion of users in the world. Thus, as Wolske, Stern and Dietz (2017) propose, this study treats subjective norms not as a social pressure to adopt the technology but as the individual's perception that close people would support him in this decision. Thus, it is proposed that:

H6: Subjective norms have a direct and positive effect on intention to use.

Novelty Seeking

Innovativeness is a construct studied for decades by theorists with different views on its conception (e.g., Hirschman, 1980; Rogers, 2010). Rogers (2010) establishes that time is the element that defines how innovative an individual is. In his perspective, innovativeness is the degree to which an individual adopts new ideas in a faster timeframe than other members of a group (Rogers, 2010, p. 267). Although Rogers' (2010) interpretation is used in numerous studies that seek to evaluate categories of innovativeness of users of some innovation, it differs from the innovativeness construct, which indicates a predisposition to innovative behavior and innovation adoption. In this sense, Hirschman (1980) contributes by associating innovativeness with the concept of searching for novelties. Expanding on that idea, Manning, Bearden and Madden (1995) adapted the essentially generic definition by Hirschman (1980) to the level of consumer behavior as “the desire to search for

new information about products" (Manning, Bearden, & Madden, 1995, p. 330). The authors then developed scales for a construct called "novelty seeking." In general, innovators assess technologies more positively and are willing to test and adopt them more easily (Bashiri & Alizadeh, 2017; Hirschman, 1980). Based on this discussion, the following hypotheses are proposed:

H7: Novelty seeking has a direct and positive effect on relative advantage.

H8: Novelty seeking has direct and negative effect on perceived risk.

H9: Novelty seeking has a direct and positive effect on experimentability.

H10: Novelty seeking has a direct and positive effect on intent to use.

Figure 1 presents the proposed conceptual model:

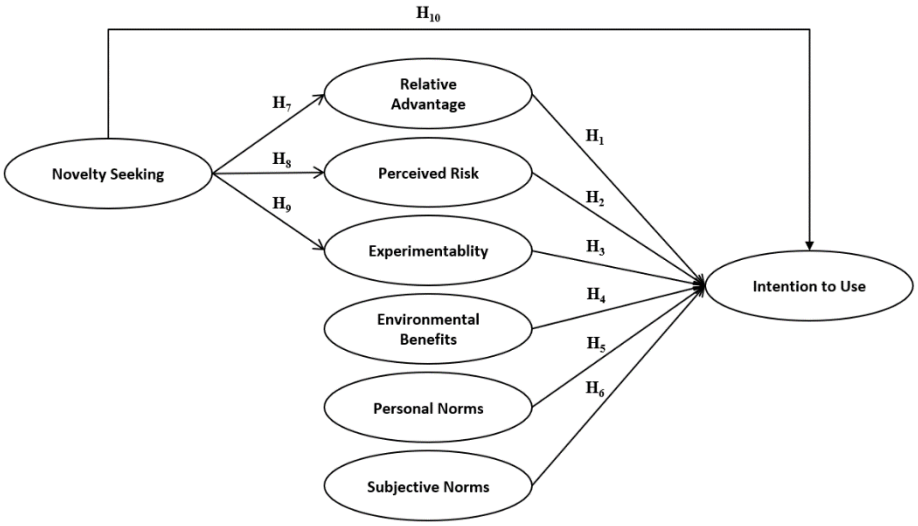

Figure 1. Proposed Model and Hypotheses.

METHODOLOGY

To test the hypotheses formulated for the study, a cross-sectional survey was carried out (Parasuraman, Grewal, & Krishnan, 2006) with a non-probabilistic sample of the population of interest, a procedure in line with other studies on technology adoption and sustainable behavior (Girod, Mayer, & Nägele, 2017; Palm, 2017). Data collection was performed through self-administered questionnaires distributed via the internet.

Operationalization of variables

First, the present study used already developed and tested scales to measure all the constructs involved in the proposed model, namely (i) three-item scales developed by Wolske, Stern and Dietz (2017), all composed of three items, to measure subjective norms, personal standards, environmental benefits and perceived risk; (ii) a five-item scale to measure relative advantage and a four-item scale

to measure experimentability, also developed by Wolske, Stern and Dietz (2017); (iii) a three-item scale developed by Manning, Bearden and Madden (1995) for novelty seeking and (iv) a three-item scale developed by Davis (1989) and adapted by Kim et al. (2014) for intention of use.

Two pre-test stages of the questionnaire were carried out. The first pre-test aimed to assess the respondents' understanding and difficulties about the questions presented. Questionnaires were applied to a small sample of 15 people. Based on the suggestions received at this stage, improvements were made, and a new version of the questionnaire was developed and sent in digital format to additional ten respondents. With the results of this last pre-test, the final version of the questionnaire was elaborated, consisting of 27 items measured with five-point Likert scales, ranging from “totally disagree” (1) and “totally agree” (5), in addition to another nine items related to the categorization and demographics of respondents.

Sample and Data Collection Procedures

The study encompassed residents of Rio de Janeiro, Brazil, holding a higher education degree or ongoing, all who do not own solar panel systems. All questionnaires were self-administered and completed voluntarily by the respondents themselves. The link to the questionnaire was distributed via e-mail and posted on social networks. An initial sample of 277 respondents was obtained, of which 39 were eliminated due to missing data and another 22 for not fitting the defined minimum educational profile. Thus, the final sample consisted of 216 valid questionnaires.

In the final sample, 51.2% were female and 48.8% male. Regarding their average family income, 56.5% of the respondents declared having a family monthly income above R$12,000 (around US$2,200), 17.2% declared a family income between R$8,501 and R$12,000 and only 1.6% declared having an income below R$2,500. In addition, 36.1% of the sample hold a graduate degree and 38.3% were bachelors. As for the age group, the sample has an average age of 38 years (with a standard deviation of 15.51), with 52.4% declaring ages between 21 and 30 years, 13.4% between 31 and 40 years and 14.7% between 51 and 60.

RESULTS

Measurement Model

A confirmatory factor analysis (CFA) was performed to test the validity, unidimensionality and reliability of the scales used. The measurement model's fit indices had a $\chi 2$/d.f ratio of 1.439, lower than the value of 3.0 suggested by Byrne (2010). In addition, the incremental fit indexes were greater than 0.90, with a CFI (comparative fit index) of 0.945, a TLI (Tucker-Lewis index) of 0.932, and an IFI (incremental fit index) of 0.947. In turn, the absolute fit indices presented values below the limit

of 0.08 established in the literature (Byrne, 2010; Hair et al., 2009), also indicating a good fit, with an RMSEA of 0.044 (CI from 0.033 to 0.055) and an SRMR of 0.058. Face validity was guaranteed during the development of the research instrument (choice of scales already used in the literature, careful translation and pre-tests). Nomological validity was analyzed using the correlation matrix between constructs, with all correlations being in the expected direction. With regard to convergent validity, the average extracted variance for each construct (AVE) was calculated. All calculated AVE values were between 0.51 and 0.63, showing the convergent validity of the employed scales (Hair et al., 2009). Regarding the internal consistency and reliability, all scales met the minimum levels of reliability considered adequate in the literature (Hair et al., 2009), with values between 0.70 and 0.81 for the alpha coefficient and between 0.71 and 0.83 for composite reliability. Finally, the shared variances were lower than the variance extracted (AVE) by the items that measure the constructs, indicating adequate discriminant validity.

Structural Model

Structural equation modeling (SEM), via the AMOS software, was used to test the proposed model and the research hypotheses. All fit indices ($\chi 2$/d.f. of 2.245, CFI of 0.913, TLI of 0.901, IFI of 0.914, RMSEA of 0.038, SRMR of 0.080) indicated a good fit of the structural model to the data (Byrne, 2010; Hair et al., 2009). To test the research hypotheses, an analysis of the magnitude, direction and significance of the estimated standardized coefficients for each relationship between constructs was performed (Byrne, 2010; Hair et al., 2009). The results are shown in Table 1.

Table 1. Coefficients, Hypotheses and Significance

Proposed Hypotheses	**Coefficient Standardized**	**p-value**	**Hypothesis Verified**
H1: Relative Advantage → Intention to Use	0.250	0.018	Yes
H2: Perceived Risk → Intention to Use	-0.240	< 0.001	Yes
H3: Experimentability → Intention to Use	-0.076	0.080	No
H4: Environmental Benefits → Intention to Use	0.180	0.002	Yes
H5: Personal Norms → Intention to Use	0.270	< 0.001	Yes
H6: Subjective Norms → Intention to Use	0.153	0.005	Yes
H7: Novelty Seeking → Relative Advantage	0.035	0.220	No
H8: Novelty Seeking → Perceived Risk	-0.080	0.160	No
H9: Novelty Seeking → Experimentability	-0.040	0.610	No
H10: Novelty Seeking → Intention to Use	0.095	0.016	Yes

As seen in the results illustrated in Table 1, out of the ten research hypotheses, the proposed model verified six, two at a significance level of 0.001 and four at a level of 0.05. The coefficient of determination (R^2) of 0.50 indicates that the independent variables could explain half of the variation in the intention to use photovoltaic solar panels.

Relative advantage variable had a significant influence on intention, being the second-highest coefficient found (0.250). It appears that the diffusion of solar panels in Brazil is dependent on their ability to provide cost savings, which suggests that the adoption of the technology is perceived as an investment that should generate financial return, a result in accordance with previous research (Korcaj, Hahnel, & Spada, 2015). This finding also emphasizes the relevance of the economic aspect of this innovation in the Brazilian context since energy tariffs in Brazil are high compared to others countries and are susceptible to political maneuvers (De Souza & Cavalcante, 2016). For these reasons, the Brazilian consumer may recognize the possibility of producing their own energy as a solution to this situation.

On the other hand, perceived risk had a negative and significant impact on the respondents' intention to use. The concept of "risk" encompasses different dimensions (Ram & Sheth, 1989), raising different interpretations by the Brazilian consumer. They may associate the risk to the reputation of the system manufacturer and seller, the lack of support and maintenance (Farhar & Coburn, 2000), or uncertainties regarding the system's power generation capacity and financial return to the owner.

Surprisingly, experimentability had no impact on the dependent variable. Thus, the result contradicts the hypothesis that the individual's willingness to try the technology and exchange information with other owners before the decision to adopt it increases the intention of potential consumers to use it. Although the reason for the result is not apparent, the fact that the vast majority of respondents live in apartment buildings (72.8%), while solar panels are more often associated with installation on house roofs, may have contributed to this result, given that testing or experimenting solar panels in apartment buildings is a rather complicated proposition, a decision that must involve all the inhabitants of the building. Specifically, about the exchange of information with owners and the possibility of getting to know solar panels in person, it is possible that the Brazilian consumer, a priori, trusts information from companies in the sector. Thus, Brazilians would not find it helpful to exchange information with previous adopters. This result contradicts the evidence presented in other studies (Farhar & Coburn, 2000; Rai & Robinson, 2013) that attest to the importance of contact between users and potential adopters during the decision process. However, this result does not disqualify the importance of peer influence (Rogers, 2010) in other stages of the innovation diffusion process. Many studies indicate the relevance of exchanging information with acquaintances to foster

initial interest in the technology (Schelly, 2014; Palm, 2017) and as a facilitating mechanism for the adoption process (Rai, Reeves, & Margolis, 2016).

In turn, the research results verify the significant effect of environmental benefits on intention to use, with a coefficient of 0.18, which agrees with previous studies (Jager, 2006; Korcaj, Hahnel, & Spada, 2015). This result indicates that Brazilians are concerned about the environment and alternative forms of energy generation when they decide on adopting sustainable technologies, not only with the financial gains associated with the use of solar panels.

Furthermore, personal norms significantly impacted the dependent variable, confirming the proposed hypothesis. The result is in line with other studies in the field of sustainable practices and adoption of green technologies (Jansson, 2011; Van Der Werff & Steg, 2016; Wolske, Stern, & Dietz, 2017) and reinforces the argument of Stern et al. (1999) on the importance of personal standards in the analysis of environmentally responsible behavior. The data also verified the effect of subjective norms on intention to use solar panels, indicating that perception that the approval of relevant others to the adoption decision may play a key role. The result is in line with previous research (Chen, Xu, & Frey, 2016; Farrow, Grolleau, & Ibanez, 2017; Wolske, Stern, & Dietz, 2017) regarding the importance of subjective norms even in contexts where the sample has limited knowledge about technology. This result reveals the perception that acquiring solar panels involves risks, uncertainties, and investments that require the approval of important people for the decision-maker. Potential users would not feel safe in adopting the innovation without the support of others (Rai & Beck, 2015).

Out of the four proposed hypotheses involving the novelty-seeking construct, three were not significant. The hypotheses proposed that individuals who actively sought information about new products and experiences would perceive more advantages in the innovation, fewer risks, and be more willing to experiment with it. However, novelty-seeking significantly affected the intention to use, indicating that while consumers' cognitive evaluations about solar panels are not being impacted by their innate innovativeness (as measured by novelty-seeking), the direct effects of novelty-seeking are relevant in the construction of an individual's intention to adopt solar panels. These results posit that the intention of installing solar panels in residences is directly influenced by the innate desires of consumers to try and seek information about new technologies, even though this innovative predisposition does not change their evaluations about more specific product attributes, such as advantages, risks or the possibility to try it out beforehand (Girod, Mayer, & Nägele, 2017).

CONCLUSIONS

First, this work suggests that integrating different theoretical currents is convenient in an attempt to explain complex or poorly studied phenomena, such as the use of solar panels in Brazil. The

results indicate that each of the theories contributed to the analysis, confirming the importance of evaluating consumption behaviors from a perspective that contemplates the various facets of a phenomenon. Thus, it is concluded that the three theoretical lines and the respective variables added to the proposed model were able to explain, at least in part, the intention of use of residential solar panels, attesting to the validity of these concepts for the analysis of the adoption of technologies related to sustainability issues.

The intention of proposing a more straightforward and more replicable conceptual model was also successfully carried out. The seven antecedent variables could explain 50% of the variability of intention to use. By way of comparison, the research model by Wolske, Stern and Dietz (2017), composed of 22 variables from the same three theories and, therefore, much less parsimonious than the model proposed in this study, was able to explain 51% of the variation in the dependent variable.

In line with the literature (Girod et al., 2017), this research indicates the validity of the constructs of relative advantage, perceived risk, environmental benefits, personal norms and subjective norms in studies that assess the adoption of green innovations by the final consumer. However, it was found that the experimentability was not significant; that is, it is possible to admit that, at least in some contexts, the impossibility of testing the technology and exchanging information with other owners does not influence the diffusion of solar panels. Finally, novelty-seeking predispositions did not present the expected relevance. Perhaps this dimension could be more influential if it contemplated more specific aspects about technologies and sustainable behavior.

The research presents results that can be useful both for private companies that invest in the photovoltaic market, as well as for public agencies that seek to promote the technology. Suppose the effectiveness of its dissemination depends on a wide range of factors (private investment, political will, business profitability, etc.). In that case, consumer knowledge of the technology is an essential element without which it is impossible to aspire to a more sustainable future. Research indicates that individuals with greater knowledge about renewable energy and solar panels are more likely to use sustainable innovations (Chen, Xu, & Frey, 2016; Bashiri & Alizadeh, 2017), making important initiatives that familiarize the target audience about how this technology works. In the long term, this investment is fundamental for forming individuals who are more aware of the benefits of solar panels and have less uncertainty about the performance of this innovation.

The relevance of the financial return reinforces the need to communicate technology acquisition as an investment. Companies that deal directly with the end consumer must be skilled in presenting commercial plans transparently that simplify the calculation of return on investment and bring more confidence in the technology's ability to generate savings and reduce the impact of energy tariff volatility. Presenting contractual guarantees about system performance can also be a good

alternative. At the same time, all efforts to reduce costs to the end-user and provide faster returns are valid. Photovoltaic module importers, component manufacturers, installation companies and others involved in this industry should seek to cut costs and reduce their margins, transferring such deductions to the potential user. This initiative is fundamental in the initial stage of market development when the financial returns tend to be more critical for the user, and the industry demands more stimulus. As in all places where there is a growth in solar panel technology, government initiatives through tax exemption and articulation with financial institutions to grant loans at attractive rates to companies in the sector are also indispensable.

The communication strategy of companies that sell solar panels must reach not only the investment decision maker but also those close to them, such as their family. This communication, whether through meetings, media advertisements or fairs, in addition to the financial aspect, should seek to present the climate issue as a problem for all and the acquisition of solar panels as an opportunity for each one to contribute with their share.

One of the limitations of this research refers to the criterion for delimiting the sample. As noted, the data reflect the view of individuals residing in the city of Rio de Janeiro, with a high level of education and family income. It is natural to assume that they have more contact with new technologies and information about products and experiences than the general population, a fact that prevents the generalization of the results. As the installation of solar panels is more commonly associated with houses, while the sample is mainly composed of people living in apartment buildings, it is possible that this circumstance has impacted the respondents' assessment of the technology's viability.

A suggestion to future research would be the addition of an intermediate variable between the determinants and the dependent variable, such as the dimension of attitude towards residential solar panels. Because most participants have never even considered the option of acquiring the technology, this construct could contribute towards explaining precisely how the consumer's assessment of the technology is formed, and then verifying whether this assessment is reflected on the intention to use it. The investigation of possible moderating effects of variables such as income, region of the country, forms of financing or knowledge of technology could also enrich the discussion of the topic. As seen, although significant, the explanatory power of the model indicates that there are factors not covered in this study that can be important influencers of the Brazilian consumers' intention to use in relation to solar panels. Exploring these suggestions, in addition to other aspects, is essential to enrich academic knowledge on the subject, develop more effective models, and, ultimately, provide interested audiences with useful information to assist in the development of assertive management strategies for the diffusion of residential photovoltaic energy generation.

References

Aggarwal, A. K., Syed, A. A., & Garg, S. (2019). Factors driving Indian consumer's purchase intention of roof top solar. *International Journal of Energy Sector Management,* 13 (3), 539- 555.

Ajzen, I. (1991). The theory of planned behavior. *Organizational Behavior and Human Decision Processes*, 50, 179−211.

Ajzen, I., & Fishbein, M. (1977). Attitude-behavior relations: A theoretical analysis and review of empirical research. *Psychological bulletin*, *84*(5), 888-918.

Bashiri, A., & Alizadeh, S. H. (2018). The analysis of demographics, environmental and knowledge factors affecting prospective residential PV system adoption: A study in Tehran. *Renewable and Sustainable Energy Reviews*, *81*, 3131-3139.

Bearden, W. O., Netemeyer, R. G., & Teel, J. E. (1989). Measurement of consumer susceptibility to interpersonal influence. *Journal of consumer research*, *15*(4), 473-481.

Byrne, B. M. (2013). *Structural equation modeling with Mplus: Basic concepts, applications, and programming*. Routledge.

Chen, C. F., Xu, X., & Frey, S. (2016). Who wants solar water heaters and alternative fuel vehicles? Assessing social–psychological predictors of adoption intention and policy support in China. *Energy Research & Social Science*, *15*, 1-11.

Choi, H., Jang, J., & Kandampully, J. (2015). Application of the extended VBN theory to understand consumers' decisions about green hotels. *International Journal of Hospitality Management*, *51*, 87-95.

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS quarterly*, 319-340.

De Souza, L. E. V., & Cavalcante, A. M. G. (2016). Towards a sociology of energy and globalization: Interconnectedness, capital, and knowledge in the Brazilian solar photovoltaic industry. *Energy Research & Social Science*, *21*, 145-154.

Dunlap, R. E., & Van Liere, K. D. (2008). The" new environmental paradigm". *The journal of environmental education*, *40*(1), 19-28.

Faiers, A., & Neame, C. (2006). Consumer attitudes towards domestic solar power systems. *Energy policy*, *34*(14), 1797-1806.

Farhar, B., & Coburn, T. (2000). *Market Assessment of Residential Grid-Tied PV Systems in Colorado* (No. NREL/TP-550-25283). National Renewable Energy Lab., Lab., Golden, CO (US).

Farrow, K., Grolleau, G., & Ibanez, L. (2017). Social norms and pro-environmental behavior: A review of the evidence. *Ecological Economics*, *140*, 1-13.

Fishbein, M., & Ajzen, I. (1977). Belief, attitude, intention, and behavior: An introduction to theory and research. *Philosophy and Rhetoric*, *10*(2).

Girod, B., Mayer, S., & Nägele, F. (2017). Economic versus belief-based models: Shedding light on the adoption of novel green technologies. *Energy Policy*, *101*, 415-426.

Hair, J., Black, B., Babin, B., Anderson, R. E., & Tatham, R. L. (2009). Multivariate Data Analysis 7th E‖ Prentice Hall.

Han, H., Hsu, L. T. J., & Sheu, C. (2010). Application of the theory of planned behavior to green hotel choice: Testing the effect of environmental friendly activities. *Tourism management*, *31*(3), 325-334.

Hirschman, E. C. (1980). Innovativeness, novelty seeking, and consumer creativity. *Journal of consumer research*, *7*(3), 283-295.

Hu, S. C., & Lanese, R. R. (1998). The applicability of the theory of planned behavior to the intention to quit smoking across workplaces in southern Taiwan. *Addictive Behaviors*, *23*(2), 225-237.

Irfan, M., Elavarasan, R. M., Hao, Y., Feng, M., & Sailan, D. (2021). An assessment of consumers' willingness to utilize solar energy in China: End-users' *perspective. Journal of Cleaner Production*, 292, 126008, 1-14.

Jabeen, G., Yan, Q., Ahmad, M., Fatima, N., & Qamar, S. (2019). Consumers' intention-based influence factors of renewable power generation technology utilization: a structural equation modeling approach. *Journal of Cleaner Production*, 237, 117737, 1-12.

Jager, W. (2006). Stimulating the diffusion of photovoltaic systems: A behavioural perspective. *Energy Policy*, *34*(14), 1935-1943. https://doi.org/10.1016/j.enpol.2004.12.022.

Jansson, J. (2011). Consumer eco-innovation adoption: assessing attitudinal factors and perceived product characteristics. *Business Strategy and the Environment*, *20*(3), 192-210.

Jansson, J., Nordlund, A., & Westin, K. (2017). Examining drivers of sustainable consumption: The influence of norms and opinion leadership on electric vehicle adoption in Sweden. *Journal of Cleaner Production*, *154*, 176-187.

Karakaya, E., Hidalgo, A., & Nuur, C. (2015). Motivators for adoption of photovoltaic systems at grid parity: A case study from Southern Germany. *Renewable and Sustainable Energy Reviews*, *43*, 1090-1098.

Kim, H., Park, E., Kwon, S. J., Ohm, J. Y., & Chang, H. J. (2014). An integrated adoption model of solar energy technologies in South Korea. *Renewable energy*, *66*, 523-531.

Korcaj, L., Hahnel, U. J., & Spada, H. (2015). Intentions to adopt photovoltaic systems depend on homeowners' expected personal gains and behavior of peers. *Renewable Energy*, *75*, 407-415.

Labay, D. G., & Kinnear, T. C. (1981). Exploring the consumer decision process in the adoption of solar energy systems. *Journal of consumer research*, *8*(3), 271-278.

Lacchini, C., & Rüther, R. (2015). The influence of government strategies on the financial return of capital invested in PV systems located in different climatic zones in Brazil. *Renewable Energy*, *83*, 786-798.

Liu, D., Du, H., Southworth, F., & Ma, S. (2017). The influence of social-psychological factors on the intention to choose low-carbon travel modes in Tianjin, China. *Transportation Research Part A: Policy and Practice*, *105*, 42-53.

Manning, K. C., Bearden, W. O., & Madden, T. J. (1995). Consumer innovativeness and the adoption process. *Journal of consumer psychology*, *4*(4), 329-345.

Palm, A. (2017). Peer effects in residential solar photovoltaics adoption—A mixed methods study of Swedish users. *Energy Research & Social Science*, *26*, 1-10.

Parasuraman, A., Grewal, D., & Krishnan, R. (2006). *Marketing research*. Cengage Learning.

Rai, V., & Beck, A. L. (2015). Public perceptions and information gaps in solar energy in Texas. *Environmental Research Letters*, *10*(7), 074011.

Rai, V., & Robinson, S. A. (2013). Effective information channels for reducing costs of environmentally-friendly technologies: evidence from residential PV markets. *Environmental Research Letters*, *8*(1), 014044.

Rai, V., Reeves, D. C., & Margolis, R. (2016). Overcoming barriers and uncertainties in the adoption of residential solar PV. *Renewable Energy*, *89*, 498-505.

Ram, S., & Sheth, J. N. (1989). Consumer resistance to innovations: the marketing problem and its solutions. *Journal of consumer marketing*, 6(2), 5-14.

Reinecke, J., Schmidt, P., & Ajzen, I. (1996). Application of the Theory of Planned Behavior to Adolescents' Condom Use: A Panel Study 1. *Journal of applied social psychology*, *26*(9), 749-772.

Rogers, E. M. (2010). *Diffusion of innovations*. Simon and Schuster.

Sang, Y. N., & Bekhet, H. A. (2015). Modelling electric vehicle usage intentions: an empirical study in Malaysia. *Journal of Cleaner Production*, *92*, 75-83.

Schelly, C. (2014). Residential solar electricity adoption: What motivates, and what matters? A case study of early adopters. *Energy Research & Social Science*, *2*, 183-191.

Schwartz, S. H. (1977). Normative influences on altruism. In *Advances in experimental social psychology* (Vol. 10, pp. 221-279). Academic Press. https://doi.org/10.1016/S0065-2601(08)60358-5.

Schwartz, S. H. (1992). Universals in the content and structure of values: Theoretical advances and empirical tests in 20 countries. In *Advances in experimental social psychology* (Vol. 25, pp. 1-65). Academic Press.

Schwartz, S. H. (1994). Are there universal aspects in the structure and contents of human values?. *Journal of social issues*, *50*(4), 19-45.

Schwartz, S. H., & Bilsky, W. (1990). Toward a theory of the universal content and structure of values: Extensions and cross-cultural replications. *Journal of personality and social psychology*, *58*(5), 878.

Sheppard, B. H., Hartwick, J., & Warshaw, P. R. (1988). The theory of reasoned action: A meta-analysis of past research with recommendations for modifications and future research. *Journal of consumer research*, *15*(3), 325-343.

Silveira, J. L., Tuna, C. E., & de Queiroz Lamas, W. (2013). The need of subsidy for the implementation of photovoltaic solar energy as supporting of decentralized electrical power generation in Brazil. *Renewable and Sustainable Energy Reviews*, *20*, 133-141.

Solangi, K. H., Islam, M. R., Saidur, R., Rahim, N. A., & Fayaz, H. (2011). A review on global solar energy policy. *Renewable and sustainable energy reviews*, *15*(4), 2149-2163.

Sovacool, B. K. (2009). Rejecting renewables: The socio-technical impediments to renewable electricity in the United States. *Energy Policy*, *37*(11), 4500-4513.

Stern, P. C., Dietz, T., Abel, T., Guagnano, G. A., & Kalof, L. (1999). A Value-Belief-Norm Theory of Support for Social Movements: The Case of Environmentalism. *Human Ecology Review*, 6(2), 81–97.

Van der Werff, E., & Steg, L. (2016). The psychology of participation and interest in smart energy systems: Comparing the value-belief-norm theory and the value-identity-personal norm model. *Energy research & social science*, *22*, 107-114.

Varabyova, Y., Blankart, C. R., Greer, A. L., & Schreyögg, J. (2017). The determinants of medical technology adoption in different decisional systems: A systematic literature review. *Health Policy*, *121*(3), 230-242.

Wilson, C., & Dowlatabadi, H. (2007). Models of decision making and residential energy use. *Annu. Rev. Environ. Resour.*, *32*, 169-203.

Wolske, K. S., Stern, P. C., & Dietz, T. (2017). Explaining interest in adopting residential solar photovoltaic systems in the United States: Toward an integration of behavioral theories. *Energy research & social science*, *25*, 134-151.

Yadav, R., & Pathak, G. S. (2016). Young consumers' intention towards buying green products in a developing nation: Extending the theory of planned behavior. *Journal of Cleaner Production*, *135*, 732-739.

Zhai, P., & Williams, E. D. (2012). Analyzing consumer acceptance of photovoltaics (PV) using fuzzy logic model. *Renewable Energy*, 41, 350-357.