

# ADOPTION INTENTION OF PHOTOVOLTAIC SOLAR SYSTEMS

## *INTENÇÃO DE ADOÇÃO DE SISTEMAS SOLARES FOTOVOLTAICOS*

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## ABSTRACT

**Purpose** – The research objective is to analyze the influence of key factors contributing to consumers' purchase intention grid-connected photovoltaic systems among residential energy consumers.

**Design/methodology/approach** – A survey based on Korcaj et al. (2014) was conducted in a major Brazilian city; 209 valid responses were obtained directly. Data was analyzed using structural equation modeling.

**Findings** – Among significant decision influences are environmental, financial, and autarchy benefits onto perceived global benefit and perceived behavioral control construct onto purchase intention; perceived social benefits, however, were not a relevant influence as opposed to previous studies.

**Research limitations/implications** - Weakness of the model's reliability leading to the exclusion of the perceived total cost construct, which in turn could reduce sample bias and increase the reliability of the model and regarding clarity regarding the product "solar photovoltaic energy system", as no text was used; this could have left questions unanswered due to the lack of knowledge of respondents about solar technology.

**Practical implications** - The high purchasing power and high education level, along with favorable weather and geography, may contribute to promising perspectives for the product. Furthermore, to promote adhesion of the technology in the city there is a need to increase benefits, to reduce perceived technology costs, and to value the importance of solar energy generation among reference groups.

**Social implications** - The analysis of factors influencing the city's residents' intentions of to adopt photovoltaic systems favors further promotion of the technology in the city.

**Originality/value** - It contributes to the development of consumer behavior studies regarding the adoption intention of ecologically sustainable technologies, i.e., GCPs, thus, filling a gap in the literature on consumer behavior for this product.

**Keywords** - Consumer behavior, Decision making, Purchase decision, Photovoltaic systems.

## RESUMO

**Objetivo** – É analisar a influência dos principais fatores que contribuem para a intenção de compra dos consumidores de sistemas fotovoltaicos conectados à rede entre os consumidores de energia residencial.

**Projeto/metodologia/abordagem** – Pesquisa realizada com base em Korcaj et al. (2014) foi realizada em uma grande cidade brasileira; 209 respostas válidas foram obtidas diretamente. Os dados foram analisados utilizando-se modelagem de equações estruturais.

**Achados** – Entre as influências significativas das decisões estão os benefícios ambientais, financeiros e atarquias sobre o benefício global percebido e a construção do controle comportamental percebido sobre a intenção de compra; os benefícios sociais percebidos, no entanto, não foram uma influência relevante em oposição a estudos anteriores.

**Limitações/implicações da pesquisa** - Fraqueza da confiabilidade do modelo levando à exclusão do construído de custo total percebido, o que, por sua vez, poderia reduzir o viés amostral e aumentar a confiabilidade do modelo e quanto à clareza em relação ao produto “sistema de energia solar fotovoltaica”, como nenhum texto foi utilizado; isso poderia ter deixado perguntas sem resposta devido à falta de conhecimento dos entrevistados sobre tecnologia solar.

**Implicações práticas** - O alto poder aquisitivo e o alto nível de escolaridade, juntamente com o clima e a geografia favoráveis, podem contribuir para perspectivas promissoras para o produto. Além disso, para promover a adesão da tecnologia na cidade é necessário aumentar benefícios, reduzir custos de tecnologia percebidos e valorizar a importância da geração de energia solar entre os grupos de referência.

**Implicações sociais** - A análise de fatores que influenciam as intenções dos moradores da cidade de adotar sistemas fotovoltaicos favorece uma promoção ainda maior da tecnologia na cidade.

**Originalidade/valor** - Contribui para o desenvolvimento de estudos de comportamento do consumidor sobre a intenção de adoção de tecnologias ecologicamente sustentáveis, ou seja, GCPSs, preenchendo assim uma lacuna na literatura sobre o comportamento do consumidor para este produto.

**Palavras-chave** - Comportamento do consumidor, tomada de decisão, decisão de compra, sistemas fotovoltaicos.

## 1 INTRODUCTION

The adoption of photovoltaic solar systems in households, including photovoltaic (PV) systems, and their usage in various contexts have been increasingly addressed in studies. Over the years, as projected by Oliver and Jackson (1999), the PV industry has shown considerable growth due to economies of scale and government incentives encouraging large PV projects (Sommerfeld, Buys, & Vine, 2017). However, PV technologies still show high potential for energy generation and share in the global energy matrix (Cho, Shaygan, & Daim, 2009; Choudhary & Srivastava, 2019).

Such potential for PV generation is propelled by its acknowledgement as a key source of renewable energy and alternative to fossil fuels – key pollutants and drivers of climate change – that diminishes the ecological effects related to climate change and excessive reliance on fossil fuels (Ferreira, Kunh, Fagnani, De Souza, & Tonezer, 2018; Gastaldo et al., 2019; Karjalainen & Ahvenniemi, 2019). Moreover, as PV systems offer a cost-effective alternative for households and allow convenient on-demand energy storage, such technologies have become an increasingly technically and economically viable alternative of sustainable energy supply (Oliver & Jackson, 1999; Ellaban & Alassi, 2019; Gastaldo, et al., 2019), despite recent worrying discussions regarding decommissioning and recycling PV structures (McDonald & Pearce, 2010; Xu et al., 2018).

Renewable energies also contribute to the sustainable progress of developing economies (i.e., reducing the need for energy imports, shielding natural resources, lowering grid emissions, promoting access to modern energy generation technologies). In the case of distributed solar adoption, specific benefits include lower electricity bills for adopters, community benefits and engagement,



and grid resilience. Altogether, such implications could yield economic development, especially in remote areas (Laumanns, Reiche, & Bechberger, 2004; Lukanov & Krieger, 2019).

Despite all the favorable impacts, PV adoption and projects are contingent on suitable locations for installation (Rediske, Siluk, Gastaldo, Rigo, & Rosa, 2018) and several other variables: solar irradiation, substation distance, slope, distance of roads, distance from urban areas, and land use. Ideal locations exist in various municipalities across Brazil's northeastern states (Ferreira, Kunh, Fagnani, De Souza, & Tonezer, 2018). Thanks to Brazil's favorable geography, production of photovoltaic solar energy has grown in its Southern and Southeastern regions. Nevertheless, despite displaying a higher incidence of solar radiation, the Northern and Northeastern regions have not yet shown significant growth in their use of grid-connected photovoltaic systems (GCPSs), likely due to the following reasons: little consumer awareness; low dissemination of GCPS technology and its economic, social, and environmental benefits; and ineffective economic incentives.

After reviewing previous contributions to the adoption of GCPSs, specifically how consumers perceive them and justify the purchase of a technology with a high upfront cost, the following research question was proposed: How do the main factors contributing to consumers' purchase intentions of GCPSs vary in Northeastern Brazil compared to previous studies? The research objective is to analyze the factors influencing residential energy consumers' intentions to purchase PV systems. The location selected for the field research is the city of Fortaleza due to its current prominent leadership in this segment in Northeastern Brazil.

## 2 LITERATURE REVIEW

### 2.1 Barriers to the adoption of residential PV systems

The adoption of PV systems is influenced by individual and collective benefits and location suitability; however, over the years, barriers have impeded the increased utilization of renewable energies, especially in developing countries lacking financing and political support for renewables (Laumanns, Reiche, & Bechberger, 2004). Recently, Karakaya and Sriwannawit (2015) have argued that, though PV technologies have become more accessible and competitive, the diffusion of these technologies has not grown accordingly vis-à-vis traditional energy sources. The authors indicate four dimensions of barriers in various countries: sociotechnical, management, economic, and policy. Moreover, they found that the involvement of different actors (i.e., firms within the PV industry, buyers/adapters, local communities, governments, NGOs, and financial institutions) is essential for societal adoption of such technologies (Karakaya & Sriwannawit, 2015). As regulation and policy are the most investigated barriers to the adoption of PV systems, the next section presents a detailed account of these factors.

#### 2.1.2. Regulation and policy

Regulation is a central issue in the adoption of PV systems and PV generation. While various studies have described the development and institutionalization of regulatory and incentive mechanisms in European countries, in developing economies (i.e., Brazil), comprehensive policies involving both incentives and regulatory bases are still embryonic, notwithstanding Brazil's large existing solar potential and its share of the country's energy matrix (Ferreira, Kunh, Fagnani, De Souza, & Tonezer, 2018). Broadly, projects promoted by the government emphasize autonomous systems instead of distribution networks. Moreover, the market for solar energy remains underdeveloped, delaying the reduction of production costs along the PV chain, and the absence of appropriate financing for PV



generation impedes further adoption (Ferreira et al., 2018). Furthermore, Moriggi (2017) concludes that institutional regulatory models in the Brazilian electric sector do not consider long term results and are bound to state and economic agents' interests, often being affected by market risks, uncertainty, and opportunistic behavior. This scenario requires innovative institutional and regulatory processes for more efficient contracts and a more socially equitable structure.

In European countries, Marques, Fuinhas, and Pires Manso (2010) show evidence that the lobby of companies and organizations linked to oil, coal, and other traditional energy sources obstruct the expansion of renewable sources. However, the authors find that emphasizing the reduction of energy dependency may increase the adoption of renewable energy.

Under this perspective, Sommerfeld, Buys, and Vine (2017) assert that policy implementation may not align with the policy objectives of energy professionals, and thus, research and analysis of consumers and their interactions with solar PV policy is important in assessing policy outcomes and how they can be better delivered or adapted. The next section discusses individual and collective benefits, derived from consumer studies, that influence the adoption of PV systems.

## **2.2 Individual and collective benefits influencing the adoption of PV systems**

The adoption of photovoltaic systems, as an example of an energy system transition, is marked by complexities (i.e., technological reliability, public acceptance, and environmental awareness). This, in turn, requires innovative policies for continuous adoption, encompassing not only measures to reduce energy costs but also to promote social acceptance, build capacity, and form collaborations to increase its share in the energy matrix (Choudhary & Srivastava, 2019). Correspondingly, energy transitions like the increased adoption of PV systems in society entail multiple dimensions (technical, economic, and social) due to their decentralized nature (i.e., public approval and trust and their economics) (Candas, Siala, & Hamacher, 2019).

According to Gastaldo et al. (2019), decisions around the purchase of green power generation systems are still scarce, and as adherence to energy-efficient systems in households is highly unequal throughout society, a behavioral perspective is justified. Their research in Brazil has revealed that consumers are largely motivated by investment opportunities, low-effort installation, environmental protection, and likely tariff reductions. In addition, regarding the socio-psychological profile, values such as benevolence, altruism, cooperation, universalism, environmentally-conscious behavior, and an "ecocentric" posture were also evidenced.

Müller and Rode (2013), using a geocoded data set of the grid-connected PV systems, found a significant relationship between previously installed systems in adjacent locations and the decision to adopt PV systems. This confirms the hypothesis that households' installation decisions can be explained by peer effects measured by preexisting installations' geography.

In Germany, Kastner and Wittenberg (2019) make the case for greater incorporation of social influence into policy measures to promote "energy-relevant investments". Among investment determinants, they address injunctive and descriptive standards and economic, ecological, and autarkic motives. While descriptive standards were found to be more significant than injunctive standards regarding investment decisions, both were considerably less important than economic, ecological, and autarkic motives. Thus, agents that are more prone to exert social influence are those in similar situations, as opposed to specialists or industry representatives (Kastner & Wittenberg, 2019).

While PV system adoption in Finland is still low, Karjalainen and Ahvenniemi (2019) have conducted a qualitative study on how Finnish consumers have overcome adoption barriers. Overall,



consumers tend to base their choices on user experience, using trustworthy information and advice from both experts and other adopters. Adopters show satisfaction with their systems and citizenship regarding domestic energy issues. They also show optimism and engagement in embracing other green technologies and pleasure in knowing that they are easily producing clean energy and being key influencers of future adopters.

While examining the impact of environmental value, ecological lifestyle, and customer innovativeness on the intention to install PV systems, Chen (2014) collected data from 203 college students in Taiwan and found that environmental value has a positive impact on ecological lifestyle and intention. Although ecological lifestyle is positively related to intention, the effect disappears when environmental value is included in the model. Furthermore, although customers showed a propensity to seek novelty, the impact of independent assessment on intention did not show a significant relationship.

Korcaj, Hahnel, and Spada (2014) analyzed key influencers of PV system purchase intentions in Germany based on social psychology concepts from Ajzen and Fishbein (1977) and Ajzen (1991). Their findings show a high propensity to adopt PV systems within the sample, but upfront costs hinder such motivation. Subjective standards and attitude (both individual and collective aspects) towards PV systems are among the most significant predictors of PV adoption. Social status, autarky, and financial gains were positive influencers, while costs, risks, and efforts were identified as hindering factors. Increased availability of information aimed at reducing risks is recommended to promote adoption among German citizens. Maia (2016) conducted the same survey in Brasilia, Brazil, but unlike Korcaj et al. (2014), Maia found that financial benefits, autarkic benefits, and subjective standards were non-relevant and that total perceived cost was a relevant factor.

In a longitudinal study in Sweden, Palm (2018) shows that although the PV market changed profoundly between the 2000s and 2010s, making it easier for households to sell the electricity produced, financial incentives have become increasingly important, as investment costs remain a setback despite their reduction over time. Installation, once a major barrier, is now commonly performed by PV companies; however, present-day impediments for adoption are bureaucracy, lack of supplier-related information, and energy compensation.

In the Netherlands, Vasseur and Kemp (2015) investigated the perceived relative advantages of the technology, complexity, social influence, and knowledge of grants and costs and their relation to the adoption of PV systems. They found that differences between adopters and non-adopters are intrinsically connected to the value of the benefits of the technology, suggesting that costs alone are not crucial. Furthermore, lack of knowledge related to PV systems hinders further adoption, suggesting that better information about solar energy may stimulate adoption (i.e., costs, quality, and social and environmental issues).

Through a study in Wisconsin, USA, Schelly (2014) found that environmental values are not sufficient nor required for the adoption of PV technologies; on the financial side, meticulous calculation of return is also less important than timing for household economic decisions. An unanticipated result was that communication through social networks is an important source of information for further adoption; also, curiosity toward technical innovation and satisfaction regarding technical aspects of energy systems is a special feature.

Araújo, Boucher, and Aphale (2019) investigated the attributes of early adopters of clean energy (i.e., electric vehicles and PV technology) in New York. The authors analyzed trends with locational, political, and sociodemographic profiles to identify areas of convergence and divergence in adoption patterns. As in the case of Ellaban and Alassi (2019), they confirmed the importance of income and median home value for early-stage electric vehicle and PV technology adoption in a relatively under-studied region. Similarly, in Oregon, USA, Cho, Shaygan, and Daim (2019) show evidence of a significant relationship between education, income, and PV adoption.



While assessing the conscious and subconscious attitudinal, control, and normative beliefs of American homeowners toward the adoption of traditional solar PV system innovations, Abreu, Wingartz, and Hardy (2019) found that initial costs, maintenance, and attractiveness, usual drawbacks to the adoption of PV systems, were less impactful for innovative PV technology (adhesive panels) than for traditional PV systems. This, as verified by Palm (2018), suggests that barriers and motivations for PV adoption should be continuously assessed.

Graziano, Fiaschetti, and Atkinson-Palombo's (2019) study in Connecticut, USA shows that the adoption of PV systems varies substantially as the effectiveness of state policies is mediated by local regulations. It also shows evidence that peer-effects have limited influence on the adoption of new PV systems in inner cities, while spatial spillovers from neighboring block groups exceed municipal barriers more naturally. Results suggest that centralized, non-voluntary support policies may have larger effects if implemented beyond the town level; also, peer-effects change their determination power depending on the underlying built environment (Graziano, Fiaschetti, & Atkinson-Palombo, 2019).

In assessing how energy transition occurs among various demographic and socioeconomic groups in California, USA, Lukanov and Krieger (2019) found that disadvantaged areas have significantly lower levels of PV adoption, thus evidencing that PV policies do not include vulnerable populations. The authors also show a strong correlation between PV adoption and health, environmental, and demographic indicators. Such aspects, however, have not been considered thoroughly in public policies. This aspect relates to previous studies, such as Guidolin and Mortarino (2010), Grösche and Schröder (2011), and Macintosh and Wilkinson (2011), in which PV adoption is a complex decision requiring specific and not freely accessible information. These studies also show that households with higher levels of education and income may access information on PV systems more easily.

Through a qualitative study among Australian consumers, Sommerfeld, Buys, and Vine (2017) demonstrate that awareness and concern of increasing electricity prices is the most significant stimulus for PV information gathering and adoption. They also highlight the importance of aligning policy implementation with the objectives of energy professionals, especially when it involves tariffs.

In examining influencing factors for PV systems in Kyoto City, Kosugi, Shimoda, and Tashiro (2019) analyzed social attributes (i.e., population structure and living environment) within neighborhoods and found an observed peer (or neighbor) effect within a radius of 1,000m and that diffusion is positively influenced by lower population density and a higher number of household members. Diffusion is positively influenced by a higher proportion of young people through various mechanisms. Non-economic initiatives are, thus, fundamental in promoting peer effects in the adoption of PV systems (Kosugi, Shimoda, & Tashiro, 2019).

In Pakistan, Jan, Ullah, and Ashfaq (2020) surveyed 100 households and found that household income, monthly cost of energy consumption, education, information about solar PV systems in the market, and awareness are the key determinants of social acceptability of solar PV systems. Therefore, household-, community-, and market-related variables play a key role in the social acceptability of solar PV systems, and such conclusions have led the authors to endorse the country's incentive-based government policies to escalate the adoption of PV systems. In the same way, while assessing the diffusion rate of green technologies (PV panels and green roofs), Ramshani, Li, Khojandi, and Omitaomu (2020) found the affordability of green technologies and public awareness to be the key drivers for the adoption of such technologies, highlighting the role of the adopters in impacting the diffusion rate.

In Brazil, Uriona-Maldonado, Caliar, de Souza Costa, and Vaz (2021) assessed the processes behind the PV supply chain and its performance regarding diffusion and found that technology diffusion is recent and still faces several tax obstacles to its development – confirming previous comments by Moriggi (2017) and Ferreira et al (2018). Notwithstanding, the industry is clearly expanding by means of numerous PV systems projects.

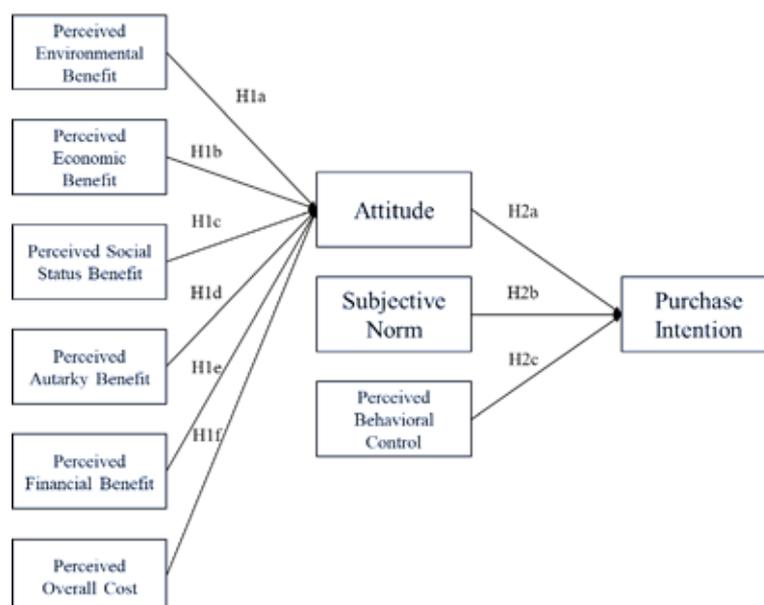


Garlet, Ribeiro, Savian, and Siluk (2019), while addressing key barriers to the adoption of PV systems in residences in Southern Brazil, found the following: poor quality of systems, high initial investment cost, financing dependence, absence of a consumer culture, lack of knowledge, poor service, dependence on imports of solar panels from China, and lack of specific incentives to enhance the adoption of PV systems. Similarly, David, Buccieri, and Rizol (2021), through an applied research approach mainly in Sao Paulo state, found six main obstacles to the implementation of photovoltaic systems in residences: lack of knowledge, lack of priority, cultural issues, lack of informational dissemination, multiple standards across different states, and costs related to the purchase and implementation of the system.

### 2.3 Theoretical model and hypotheses

Though various recent contributions have provided new insights regarding the adoption of PV systems, the work of Korcaj et al. (2014) was selected for two reasons: it is a contribution to the theory of planned behavior (Ajzen & Fishbein, 1977; Ajzen, 1991) and, thus, additional research is desirable to test it. Moreover, the same model has already been employed in a Brazilian municipality. Therefore, comparison of results should provide insights toward a broader understanding of adoption/purchase intention of PV systems in Brazil.

Figure 1 shows the theoretical model used in this research, as also used by Korcaj et al. (2014) in Germany and Maia (2016) in Brazil.



**Figure 1.** PV purchase prediction model as an extension of the theory of planned behavior proposed by Ajzen and Fishbein (1977) and Ajzen (1991). Antecedents of the Attitude construct are incorporated by Korcaj et al (2014).

The hypotheses derived from the model are as follows:

- H1a: Perceived environmental benefit positively influences purchasing attitude;
- H1b: Perceived financial benefit positively influences purchasing attitude;
- H1c: Perceived social benefit positively influences purchasing attitude;
- H1d: Perceived autarky benefit positively influences purchasing attitude;

- H1e: Perceived economic benefit positively influences purchasing attitude;
- H1f: Total perceived cost negatively influences purchasing attitude;
- H2a: Perceived overall benefit positively influences purchase intention;
- H2b: Subjective standard negatively influences purchase intention;
- H2c: Perceived behavioral control positively influences purchase intention.

### 3 METHODOLOGY

The model used by Korcaj et al. (2014) and Maia (2016) shows that a PV system purchase involves both environmental and non-environmental issues (as also shown by other authors in the literature review), and there are individual- (social status and financial), collective- (environmental and economic benefit), and community-related (autarky) benefits. Korcaj et al. (2014) also suggest incorporating perceived overall cost to the theoretical model, as it is an intrinsic aspect of PV systems.

A questionnaire derived from the theoretical model was reviewed with each item translated from English to Portuguese and then back-translated to English to assure reliability. The questionnaire was divided in two parts: the first one covering items related to ten constructs (42 statements; Korcaj et al., 2014) and the second one covering demographic characteristics (gender, age group, marital status, monthly family income, and education level and area). Regarding the constructs, Purchase Intent (PI) was formed by one item, Perceived Global Benefit (PGB) by 3 items, Subjective Norms (SN) by 7 items, Perceived Behavioral Control (PBC) by 5 items, Perceived Environmental Benefit (PEB) by 4 items, Perceived Economic Benefit (PECB) by 4 items, Perceived Social Benefit (PSB) by 6 items, Perceived Financial Benefit (PFB) by 5 items, Perceived Autarky Benefit (PAB) by 4 items, and Perceived Total Cost (PTC) by 3 items.

A non-probabilistic sample was preferred in view of the low rate of response at the beginning of the data collection phase. Following this approach, the researchers intervened and selected the most reachable sample units to increase the number of responses. An electronic link to the survey was directed at WhatsApp groups, and in field data collection in residential neighborhoods was carried. To estimate the size of the minimum applicable sample, the G\*Power 3.1.9.2 software (an acknowledged reference tool to compute statistical power analyses for various statistical tests) was used, yielding a minimum number of 74 cases. However, as model consistency was a valued aspect, a minimum of twice or three times the suggested value was considered. The field research was conducted in 38 days, between May 11 and June 18, 2018, and despite the non-probabilistic sampling, all subprefectures of the city of Fortaleza were included.

Data collection was executed both through the internet and in person. Over the internet, a link was sent to consumers of the city's energy distribution company in the seven subprefectures along with an explanatory e-mail about the survey. The survey targeted consumers who did not own a solar photovoltaic system. As for in person data collection, the survey was conducted in residential neighborhoods with a letter elucidating the research to respondents.

Data treatment was performed via structural equation modeling (SEM), which encompasses a set of multivariate statistical techniques and several methodologies, such as regression, covariance analysis, path analysis, and confirmatory factor analysis. The software chosen for this task was SmartPLS, which uses partial least squares and seeks to address common issues in marketing research, such as the absence of symmetrical distribution of measured variables, theories in their initial phase, formative models, and scarce data still based on variance (Ringle, Silva, & Bido, 2014). That is the case of this research, as it uses exploratory modeling.

As for the sample size, the critical question in SEM involves how large of a sample is needed. Although there is no single criterion to dictate the required size, between 200 and 400 observations are recommended for models with 10 to 15 constructs (Hair, Anderson, Tatham, & Black, 1998).



## 4 RESULTS

In this section, a detailed account of the respondents' profile, data analysis derived from the measurement model, the structural model, and further comparison to similar studies are presented.

### 4.1 Subjects' profile

The sample covers 209 valid responses, a representative number, as it exceeds the minimum sample size 2.8 times ( $n = 2.8 \cdot 74$ ). Profile data were categorized according to marital status (66.2% married respondents), age group (balance of generations, except 6% of the respondents were older than 61 years), sex (balance between male and female respondents), education (60.6% of the sample hold an undergraduate degree), place of residence and monthly income. In terms of residence, the respondents are distributed according to the seven subprefectures (SPs): SP-I (5.3%), SP-II (29%), SP-III (5.3%), SP-IV (9%), SP-V (7%), SP-VI (42%), and SP in the inner city (2.4%).

### 4.2 Data analysis and measurement model adjustment

After excluding all missing data, the database used was formed by 209 valid observations (approximately 93.7% of the original sample), within the sample size suggested in the literature for SEM procedures. Following the recommendations of Ringle et al. (2014), the PLS algorithm was used to treat the data collected. The main SEM was conducted along with bootstrapping procedures, providing a resampling technique, and assessing the significance (p-value) of the correlations (measurement model) and regressions (structural model).

Moreover, in accordance with Ringle et al. (2014), to generate the model under study, the software was run using the path weighting scheme option, considered suitable for the SEM. Thus, the software provided data on the reliability and validity of the constructs shown in Table 1.

Table 1 - Reliability and validity measures of constructs

	Cronbach's Alpha	Rho A	Composite Reliability	Average Variance Extracted (AVE)
Perceived Global Benefit (AT)	0.821	0.835	0.893	0.736
Perceived environmental benefits (PEB)	0.847	0.898	0.896	0.684
Perceived autarchy benefits (PAB)	0.716	0.775	0.820	0.540
Perceived economic benefits (PEB)	0.770	0.791	0.850	0.588
Perceived financial benefits (PFB)	<b>0.697</b>	0.743	0.797	<b>0.449</b>
Perceived social benefits (PSB)	0.757	0.795	0.797	<b>0.409</b>
Perceived behavioral control (PBC)	<b>0.638</b>	0.716	0.762	<b>0.409</b>
Perceived total cost (PTC)	<b>0.560</b>	1.061	<b>0.649</b>	<b>0.430</b>
Purchase intention (PI)	1.000	1.000	1.000	1.000
Subjective norms (SN)	0.851	0.870	0.885	0.526

Note. Table shows reliability and validity measures for each construct (Cronbach's alpha, Rho A, composite reliability, average variance extracted [AVE]).

In accordance with Henseler et al. (2009) and Gotz et al. (2010), model fit analysis was performed using convergent validity, the reliability of the model, and discriminant validity.



#### 4.2.1 Convergent validity

According to Ringle et al. (2014), convergent validity is obtained by observing the average variance extracted (AVE). The Fornell and Larcker (1981) criterion was adopted, according to which AVE values should be greater than 0.50 (Henseler et al., 2009). Average variance extracted is explained by each of the constructs or latent variables (VL), corresponding to their sets of variables or how much, on average, the variables correlate positively with their respective constructs. From examining the model under study, Table 1 identifies the AVE values of the PFB, PSB, PBC, and PTC constructs as being less than 0.50, meaning an inadequate convergent validity. Thus, a further adjustment of the model by eliminating the variables with factor loads (correlations) of lesser value (PEB2, PFB1, PFB4, PSB3, PSB5, PAB4, PTC2, PBC1, PBC5, and SN7) and then reprocessing a new SEM was necessary; this procedure is described in Table 2.

Table 2-Reliability and validity of constructs - subsequent adjustment of the model

	Cronbach's Alpha	Rho A	Composite Reliability	Average Variance Extracted (AVE)
Perceived Global Benefit (AT)	0.821	0.834	0.893	0.736
Perceived environmental benefits (PEB)	0.852	0.874	0.909	0.770
Perceived autarchy benefits (PAB)	0.745	0.775	0.851	0.657
Perceived economic benefits (PEB)	0.770	0.791	0.850	0.588
Perceived financial benefits (PFB)	0.645	0.655	0.808	0.584
Perceived social benefits (PSB)	0.692	0.744	0.803	0.513
Perceived behavioral control (PBC)	0.643	0.677	0.811	0.593
Perceived total cost (PTC)	0.450	0.955	0.735	0.603
Purchase intention (PI)	1.000	1.000	1.000	1.000
Subjective norms (SN)	0.839	0.855	0.882	0.557

Note. Table shows reliability and validity measures for each construct (Cronbach's alpha, Rho A, composite reliability, average variance extracted [AVE]) obtained after adjustment of the model.

#### 4.2.2 Model reliability

Regarding the model's reliability, Cronbach's alpha, a measure based on the intercorrelation of variables, and composite reliability were used. The latter is more suitable for PLS-PM; since it ranks variables according to their reliability, Cronbach's alpha is sensitive to the number of variables in each construct. Both measures are often used to assess whether the sample is free from bias or whether the responses are reliable. Alpha values above 0.60 and 0.70 are considered adequate in exploratory research, and composite reliability values of 0.70 and 0.90 are considered satisfactory (Hair et al., 2014). Despite the partial increase in the model's reliability indicators after subsequent adjustments, there is still a need for robustness for its validation. Thus, alpha values were not appropriate for the PTC construct ( $\alpha = 0.450$ ); therefore, since responses for the items (PTC1, PTC2, and PTC3) were not reliable (not free from bias), they were excluded from the analysis.

#### 4.2.3 Discriminant validity

Discriminant validity is understood as a measure of independence among latent constructs (Hair et al., 2014). This evaluation occurs in two ways: the first one is by observing the cross loads – indicators with higher factor loads in their respective constructs than in others (Chin, 1998), while the other follows the criterion of Fornell and Larcker (1981), according to which the square roots of



the AVE values of each construct are compared with (Pearson) correlations between the constructs. The square roots of the AVEs must be greater than the correlations between those of the constructs. This research verified that the factorial loads of the observed variables in the original constructs are always greater than in others. It was found that the model has discriminant validity according to Chin's (1998) criterion. As for the criterion of Fornell and Larcker (1981), the model meets the discriminant validity thresholds since the square roots of the AVEs are greater than the correlations between all constructs (Table 3).

Table 3 - Correlation values between factor loads of constructs and RMSE values (in gray)

	PGB	PEB	PAB	PECB	PFB	PSB	PBC	PTC	PI	SN
PGB	0.858									
PEB	0.379	0.877								
PAB	0.410	0.367	0.810							
PECB	0.335	0.386	0.376	0.767						
PFB	0.420	0.285	0.549	0.406	0.764					
PSB	0.376	0.533	0.460	0.615	0.400	0.716				
PBC	0.019	-0.143	0.171	0.057	0.121	-0.024	0.770			
PTC	-0.189	-0.129	-0.155	0.012	-0.174	-0.047	-0.085	0.777		
PI	0.531	0.080	0.173	0.309	0.276	0.240	0.313	-0.093	1.000	
SN	0.372	0.083	0.185	0.403	0.345	0.485	0.255	0.135	0.504	0.746

Note. RMSE values are in gray. Perceived global benefits (PGB), perceived environmental benefits (PEB), perceived autarchy benefits (PAB), perceived economic benefits (PECB), perceived financial benefits (PFB), perceived social benefits (PSB), perceived behavioral control (PBC), perceived total cost (PTC), purchase intention (PI), subjective norms (SN).

### 4.3 Structural model analysis

While the measurement model connects factors to measures, the structural model defines the causal or dependency relationships between the constructs, connecting one factor to another (Jarvis, Mackenzie, & Podsakoffo, 2003; Marôco, 2014).

The analysis of the structural model aims to test the hypotheses in the conceptual model, considering the adequacy of the conceptual model to the collected data (Garver & Mentzer 1999). In this stage of the analysis, the focus is on the significance of the hypothesized paths to confirm or refute the hypotheses. For this purpose, the parameters, which are equivalent to regression coefficients, are estimated in the path diagram reflecting the relationships between the constructs.

#### 4.3.1 Hypotheses analysis

To analyze the hypotheses and test the significance of the relationships between constructs and observed variables, the bootstrapping module (resampling technique) was used on SmartPLS to calculate Student's t tests for each correlation relationship between observed variables and constructs and for each relationship between constructs. In cases where there is a high degree of freedom, values above 1.96 correspond to p-values  $\leq 0.05$  (between -1.96 and +1.96 p-values correspond to a 95% probability and, outside this range, to a 5% probability, considering a normal distribution) (Ringle et al., 2014).

##### 4.3.1.1 Results of hypotheses tests

After running the bootstrapping module, the values of Student's t test were obtained and show that all values of the relationships between observed variables and between constructs are



within the range of reference values suggested in the literature, except for the following relationships: PSB-PGB, PECB-PGB, and PTC-PGB. In general, it may be stated that the correlations and regression coefficients are significant (Table 4).

Table 4 - Level of significance of correlations and regressions

	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	t statistics (O/STDEV)	p-values
Perceived global benefits (PGB) à Purchase intention (PI)	0.420	0.413	0.061	6.928	0.000
Perceived environmental benefits (PEB) à Perceived global benefits (PGB)	0.181	0.177	0.083	2.178	0.030
Perceived autarchy benefits (PAB) à Perceived global benefits (PGB)	0.150	0.150	0.071	2.119	0.035
Perceived economic benefits (PECB) à Perceived global benefits (PGB)	0.082	0.089	0.079	1.037	0.300
Perceived financial benefits (PFB) à Perceived global benefits (PGB)	0.205	0.207	0.079	2.610	0.009
Perceived social benefits (PSB) à Perceived global benefits (PGB)	0.073	0.078	0.104	0.700	0.484
Perceived behavioral control (PBC) à Purchase intention (PI)	0.232	0.240	0.073	3.169	0.002
Perceived total control (PTC) à Perceived global benefits (PGB)	-0.104	-0.111	0.063	1.660	0.098
Subjective norms (SN) à Purchase intention (PI)	0.289	0.292	0.061	4.753	0.000

#### 4.3.1.2 Discussion

The analyses of the proposed model confirm that of the nine formulated hypotheses, six were supported. Therefore, any hypothesis with statistical significance equal to or less than 10% ( $p \leq 0.10$ ) is considered supported, according to conventional standards in the social sciences. Thus, the results are distributed as follows: six hypotheses were supported with statistical significance equal to or less than 5% ( $p < 0.05$ ), one hypothesis was excluded for having a Cronbach's alpha value inferior to 0.60, and two were not supported because they are not statistically significant ( $p \geq 0.1$ ; Table 5).

Table 5 - Summary of hypotheses' tests results

Hypothesis	Description	t student	p value	Result
H1a	PEB à PGB	2.178	0.030	Accepted*
H1b	PFB à PGB	2.610	0.009	Accepted*
H1c	PSB à PGB	0.700	0.484	Rejected
H1d	PAB à PGB	2.119	0.035	Accepted*
H1e	PECB à PGB	1.037	0.300	Rejected
H1f	PTC à PGB	1.660	0.098	Rejected
H2a	PGB à PI	6.928	0.000	Accepted*
H2b	SN à PI	4.753	0.000	Accepted*
H2c	PBC à PI	3.169	0.002	Accepted*

Note. \*t Student  $\geq 1,96$  and p-values  $\leq 0.01$ .

As proposed in H1a, the perceived environmental benefit construct had a positive and sig-



nificant effect on the intention to purchase a solar photovoltaic system ( $t = 2.178$ ;  $p = 0.030$ ). Therefore, it is evident that the respondents intend to buy the photovoltaic solar system because they believe that they will contribute to the environment in some way.

H1b (perceived financial benefit construct) was also verified as a determining factor in the intention to purchase a solar photovoltaic system ( $t = 2.610$ ;  $p = 0.009$ ). Respondents may believe that the photovoltaic solar system will effectively meet their energy consumption and that it is a safe financial investment, as it will yield returns.

H1c, regarding the perceived social benefit construct, was rejected. The positive and significant effect of the purchase intention of the photovoltaic solar system was not confirmed ( $t = 0.700$ ;  $p = 0.484$ ). This result shows that respondents are not concerned with social status when deciding on the acquisition of a photovoltaic solar system; hence, they do not believe that owning this system will earn them appreciation in their milieu.

H1d (perceived autarchy benefit construct), alternatively, showed a positive and significant effect ( $t = 2,119$ ;  $p = 0.035$ ). Thus, respondents believe that the photovoltaic solar system will compensate for the increased costs in the energy bills, generate greater control, and ensure part of the energy supply.

H1e (perceived economic benefit construct) was rejected ( $t = 1.037$ ;  $p = 0.300$ ), confirming that respondents are not concerned with the economic benefits that the photovoltaic solar system may provide, such as promoting local or national companies in the sector or jobs in Brazil.

H1f, related to the perceived total cost (PTC) construct, despite meeting the  $p$ -value  $\leq 0.01$  ( $p = 0.098$ ) threshold, was rejected, as the construct was either biased or responses were non-reliable ( $\alpha < 0.60$ ). The result of this hypothesis does not allow a conclusion as to whether respondents believe that the high monetary cost and other risks related to purchasing the product affect or do not affect the intention to purchase a photovoltaic solar system.

H2a (perceived global benefit construct or attitude) was verified as a determining factor of the intention to purchase a photovoltaic solar system ( $t = 6,928$ ;  $p = 0.00$ ). Hence, for the subjects, a photovoltaic solar system is a sensible decision, it is a valuable product, and it generates a positive feeling among them.

As predicted in hypothesis H2b, the standard construct presented has a negative and significant effect, acting as an unfavorable factor in the intention to purchase the photovoltaic solar system ( $t = 4,753$ ;  $p = 0.00$ ). Thus, respondents either do not consider reference groups of their familiarity to be important in this decision or these groups do not consider the adoption of photovoltaic systems to be important.

Finally, regarding H2c, referring to the perceived behavioral control construct, a positive effect was verified ( $t = 3,169$ ;  $p = 0.002$ ). The confirmation of this hypothesis shows that subjects believe they can pay for and install a photovoltaic solar system in their homes, thus contributing to their purchase intention toward the system.

#### 4.4 Comparison to other studies and literature

As the hypotheses were analyzed, a comparison was made with previous studies using the same research instruments, Korcaj et al. (2014) and Maia (2016) in Freiburg, Germany and Brasília, Brazil, respectively (Table 6).



Table 6 - Comparative summary with previous studies

Variables	This research	Maia (2016)	Korcaj et al. (2014)
Perceived environmental benefits (PEB)	Relevant	Irrelevant	Irrelevant
Perceived financial benefits (PFB)	Relevant	Irrelevant	Relevant
Perceived social benefits (PSB)	Irrelevant	Relevant	Irrelevant
Perceived autarchy benefits (PAB)	Relevant	Irrelevant	Relevant
Perceived economic benefits (PEB)	Irrelevant	Relevant	Relevant
Perceived total cost (PTC)	Excluded	Relevant	Irrelevant
Perceived Global Benefit (AT)	Relevant	Relevant	Relevant
Subjective norms (SN)	Irrelevant	Irrelevant	Relevant
Perceived behavioral control (PBC)	Relevant	Relevant	Not compared

Comparing research results with the literature, beyond pure economic factors, revealed that cultural, social, personal, and psychological factors may also influence consumers' purchase intentions, as detailed below:

- Cultural factors (culture, subculture, and social classes): in opposition to the literature, this research shows a negative effect from cultural factors, especially the social factor, as subjects signaled that having a photovoltaic system will not contribute to their status in society (as evidenced by H1c);
- Social factors (reference group, family, roles, and social positions): like the cultural factor, findings related to social factors in this study also contradict the literature, particularly regarding reference groups. Respondents signaled that they do not consider the reference group of their coexistence in society as important (as supported by H2b);
- Personal factors (age and stage of the life cycle, occupation, economic conditions, lifestyle, and personality): the survey identified the profile of the respondents who will contribute to the adoption of photovoltaic systems, which have a high initial acquisition cost, which corroborates the view of personal factors in the literature. This may allow marketers to direct business strategies;
- Psychological factors (motivation, perception, learning, beliefs, and attitudes): while Korcaj et al. (2014) and others have observed that people tend to believe in and adopt technological and complex products (i.e., photovoltaic solar systems) when stimulated or encouraged to learn particularities about the product, the findings in this research differ from those presented by Korcaj et al. (2014), as no detailed explanation about the benefits of the product were provided to the subjects;
- Political, economic, technological, environmental, and market factors: most studies do not address these factors. In this research, the environmental factor had its hypothesis (H1a) supported, as respondents believed they would contribute to the environment with the product acquisition. For the economic factor, H1e was rejected because respondents did not believe in the contribution of technology to the generation of jobs at a local or national level. Regarding the financial aspect, H1b was accepted, as evidence indicated respondents' belief in the safe financial return provided by the adoption of this product. Political and market factors were not addressed in this research.



## 5 CONCLUSION

This study aimed to investigate residential energy consumers' intention to purchase solar photovoltaic systems, focusing on environmental, financial, social, autarchy, economic, and other factors of a personal and social nature.

The factors and relationships that most influenced the purchase intention toward this technology were environmental, financial benefits, autarchy with the perceived global benefit, perceived global benefit, and perceived behavioral control.

The results of the Fortaleza survey were influenced by the contributions of environmental, financial, and autarchy factors, among others. However, the high purchasing power (69.3%) and high education level (60.6%) of respondents, along with climatic conditions and the favorable geographical position for the implementation of this technology, may contribute to a promising growth scenario for this product

To increase the purchase intention and subsequent consumption of this product in the neighborhoods of Fortaleza, a greater marketing emphasis by companies in the industry is recommended for the following weaknesses: perceived social benefit, perceived economic benefit, and subjective standards, which if effectively addressed, may increase the purchase intention.

The variable perceived total cost (TCO) was excluded from the analysis when the sample collected did not show adequate reliability ( $AC = 0.450$ ). The quality adjustment of the model signaled that data are not free from bias, so this variable was eliminated. However, it should be noted that a reduction in TCO (which includes risks and perceived efforts) may cause an increase in the consumption of the product, particularly price reduction of the main accessories of photovoltaic solar systems, such as panels (modules) and inverters, which are imported and subject to high taxes and a high initial cost (with tax exemptions and greater incentives for investment in renewable energy for residential owners). Another alternative action would be the creation of a consumer consortia for this product and financing options with low interest rates. In general, strategies aimed at reducing costs and investment payback period contribute in providing key information for consumers, making the product more appealing.

In summary, to promote adhesion of the technology in the city, there is a need to increase benefits, reduce perceived costs of technology, and promote the importance of solar energy generation in society, especially among reference groups. The results of this work bring relevant contributions to both knowledge in the marketing area and the renewable energy market, specifically photovoltaic energy. This study, however, presents certain limitations, which if overcome, may contribute to future research:

- Weakness of the model's reliability leading to the exclusion of the perceived total cost construct (PTC), with Cronbach's alpha value around 0.450 since it was not possible to adjust it to a value greater than 0.60, which in turn could reduce sample bias and increase the reliability of the model.
- Weakness regarding product clarity of the "solar photovoltaic energy system", as no text was used; this could have left questions unanswered due to respondents' lack of knowledge about solar technology.
- Consumer behavior and marketing literature show few studies on the factors that influence consumer behavior regarding photovoltaic solar systems. Future studies in this thematic area should adopt larger samples and include other Brazilian regions to yield more data and diversify the scenario being analyzed. They should also include other



consumer behavior variables, such as culture, politics, government, and taxation, all of which may be linked to the results. Thus, knowledge about consumers of renewable energy solutions may be further broadened, expanding knowledge and bringing improvements to society.

## 6 CONTRIBUTIONS

In theoretical terms, this research contributes to the development of consumer behavior studies regarding the adoption of ecologically sustainable technologies (i.e., GCPSS) and, thus, fills a gap in the literature on consumer behavior for this product. As for practical contributions, the study verifies how potential residential customers in Fortaleza assess the perceived costs and benefits related to the product. From the data, managers at companies supplying photovoltaic systems may be able to identify which aspects of the technology are still flawed and thereby create and direct more effective marketing strategies aimed at expanding the perceived value among the population not yet correlated with the intention of purchase.

The analysis of factors influencing residents of Fortaleza regarding the photovoltaic systems and purchase intentions generated by the research favors a further promotion of the technology in the city. Through this research, it will be possible to increase the perceived benefits or remove the noted barriers and, hence, contribute to an increase in product adoption.

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## APPENDIX A

### Questionnaire

#### Profile data

1. Marital status: ( ) Single ( ) Married ( ) Divorced ( ) Widowed
2. Age: \_\_\_\_\_
3. Gender: ( ) Female ( ) Male
4. School grade? ( ) Elementary School ( ) Middle School ( ) Higher Education ( ) Master ( ) Doctorate
5. Neighborhood you live in: \_\_\_\_\_
6. Considering the sum of individual monthly income(s) of the residents of the house, in which family income range do you fit? ( ) Up to R\$600.00; ( ) Between R\$600.00 and R\$1,350.00; ( ) Between R\$1,350.00 and R\$2,500.00; ( ) Between R\$2,500.00 and R\$4,000.00; ( ) Between R\$4,000.00 and R\$18,800.00
7. Already have the photovoltaic solar system installed? ( ) Yes; ( ) No.
8. Please carefully read the following items and assign a grade of 1 to 5 regarding your degree of agreement, 1 = I totally disagree; 2 = I disagree; 3 = I do not agree/disagree; 4 = I agree; 5 = I totally agree.

#### Items for purchase intention, attitude, subjective standards, and perceived behavioral control

1 2 3 4 5

#### Purchase Intent

I intend to install a photovoltaic system in my residence in the next three years.

#### Attitude

A photovoltaic system brings me a good feeling.

Installing a photovoltaic system is a sensible decision for me.

Installing a photovoltaic system is very useful to me.



### **Subjective Standard**

People important to me would like me to install a photovoltaic system in my residence.  
People in my community would like me to install a photovoltaic system in my residence.  
People expect me to install a photovoltaic system in my residence.  
I feel obliged to install a photovoltaic system in my residence.  
Several people I consider important have photovoltaic system in their homes.  
For people in my position, it is common to install a photovoltaic system.  
Several people in my community have photovoltaic systems.

### **Perceived Behavioral Control**

It is possible to install a photovoltaic system in my residence (there are no shadings on the roof).  
I can afford a photovoltaic system.  
I could install a photovoltaic system if I wanted to.  
It is possible to get approval to install a photovoltaic system in my residence.  
I decide what happens on the roof of my residence.

### **Items for attitude predictions**

**1 2 3 4 5**

#### **Environmental**

I believe that with a photovoltaic system, I am protecting the environment.  
I believe that a photovoltaic system improves air quality.  
I believe that the operation of a photovoltaic system is environmentally friendly.  
I believe I save natural resources with a photovoltaic system.

#### **Economical**

I believe that with a photovoltaic system, I promote companies from Brazil.  
I believe that photovoltaic systems are important products exported to the Brazilian economy.  
I believe that with a photovoltaic system, I help create and maintain jobs in Brazil.  
I believe that with a photovoltaic system, I support the research and development of technology in Brazil.

#### **Social**

I believe that with a photovoltaic system, I show myself to be socially responsible.  
My friends and family like photovoltaic systems.  
I believe that homeowners with photovoltaic systems have superior social status.  
I believe that by having a photovoltaic system installed on my roof, I will be appreciated in my community.  
I believe that a photovoltaic system will improve my position in my community.  
I believe that a photovoltaic system shows that I am concerned about the environment.

#### **Financial**

I believe that a photovoltaic system serves as a financial provision for the older generation.  
I believe that a photovoltaic system is a secure financial investment.  
I believe that with a photovoltaic system, I can generate energy to supply my consumption.  
I believe a photovoltaic system is profitable.  
I believe that the initial cost of a photovoltaic system will be returned.



### Autarky

- I believe I can offset the rise in electrical costs with a photovoltaic system.
- I believe that a photovoltaic system allows me to secure part of my energy provision.
- I believe that a photovoltaic system generates greater control over my energy provision.
- I believe that a photovoltaic system allows me to be independent of electricity distributors.

### Total cost perceived

- I believe that having a photovoltaic system has many risks.
- I believe that the costs linked to owning a photovoltaic system are very high.
- I believe that owning a photovoltaic system takes a lot of effort.

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Contribution	[Author 1]	[Author 2]	[Author 3]
1. Definition of research problem	√	√	
2. Development of hypotheses or research questions (empirical studies)	√	√	
3. Development of theoretical propositions (theoretical work)		√	√
4. Theoretical foundation / Literature review	√	√	√
5. Definition of methodological procedures	√	√	√
6. Data collection	√		
7. Statistical analysis		√	√
8. Analysis and interpretation of data	√	√	√
9. Critical revision of the manuscript		√	
10. Manuscript writing	√	√	
11. Other (please specify)			

### Conflict of Interest

The authors have stated that there is no conflict of interest.

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