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Photovoltaic systems in residences: A concept of efficiency energy consumption and sustainability in brazilian culture

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A B S T R A C T

The production of energy can generate environmental impacts due to related factors such as the use of fossil fuels for a mechanical generation or even by flooding to reservoirs. The relevance of the subject refers to the strong urgency of better methods for optimization in the Brazilian energy sector, such as distributed generation, which is the focus of the research. Considering the concern with efficient energy consumption and sustainability, this work identifies potential aspects for the implementation of photovoltaic systems in residences. The applied method approach: a comprehensive literature review; institutional government sources and information provided by energy companies; two questionnaires involving specialists and decision makers limited to the residential sector; the Analytical Hierarchical Process as a tool to assist in the decision making of the identified aspects and a case study. As a result, six most relevant aspects were obtained, “lack of knowledge about the topic”; “lack of priority”; “cultural”; “standardization of standards”; “lack of influencers” and “costs”, divided into two classification groups, internal and external factors, and energy savings of 50% monthly in the case study compared to the tariff paid for the conventional concessionaire. Through the identification of the most important aspects of solar photovoltaic systems in residences, it was possible to propose guidelines: the dissemination of the solar source in schools; the standardization of standards between states and a national standard for photovoltaic solar energy with a scope similar to ISO 50001 (energy management systems - requirements with guidelines for use); correct dimensioning of the system and management of energy consumption demand.

1. Introduction

Over the years, the share of renewable energies in the energy matrices of developed and developing countries grows significantly through governance, public acceptance, markets, prices, and political determinants (Sequeira and Santos, 2018). Highlighting solar energy, considered a clean source, free of noise and which in recent years has been the main source of new energy capacity in several important markets such as China, India, Japan, and the United States (REN21, 2018), its growth exceeded expectations despite its investment costs still being considered high. The expansion of the solar market worldwide is due in large part to the growing competitiveness of solar photovoltaic energy, combined with the growing demand for electricity and the growing awareness of the technology’s potential to mitigate pollution, reduce carbon dioxide emissions and provide access to energy to those who do not have it through conventional energy concessionaires (REN21, 2018).

In recent years, much research has been carried out in the pursuit of sustainable development. The global transformation into low-carbon energy systems generates a cleaner energy system that integrates a greater share of renewable energy (Destek and Sinha, 2020; Deng and Lv, 2020; Bocken, 2014; David et al., 2020). The relevance of the subject points to the urgent need for better methods for optimization in the energy sector, the latter being the focus of the article. In Brazil, whose growth in electricity consumption was more than 20% from 2009 to 2019, more than 60% of

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generation is obtained through hydroelectric plants. With the sustainable development that is sought, this energy is not supported by environmentalists (as it generates environmental impacts such as socioeconomic, cultural, and environmental) and has been lowering its percentage levels of participation in the Brazilian energy matrix. Solar energy has been growing its share, but it still does not represent 2% of the total (ANEEL, 2020; Queiroz et al., 2013).

In the world historical context, from 2000 to 2003 the focus was on research on the development of photovoltaic technology, generation risk assessments, and the photovoltaic effect. From 2004, photovoltaic cells; equipment design; project management; energy policies; the dissemination of electric vehicles and cost reduction were the highlights. In 2009, studies began to implement photovoltaic energy as distributed generation; environmental concerns; investment analysis, incentive policies, and energy storage systems. In 2014, the number of publications increased significantly and continued in the following years. This year, environmental concerns have grown and research on greenhouse gases, climate change, and sustainable development has been increasingly approached. In 2015, with several studies and research on photovoltaic systems carried out, it was the time of energy efficiency. Quality energy, conversion efficiency, energy power, and efficient transmission network were sought. As of 2016, there have been many studies on the implementation of photovoltaic generation, case studies, and also the widespread construction of solar photovoltaic plants.

As a way of relating the objectives of the article to the state of the art on photovoltaic solar energy, there are highly recognized works. Kellogg et al. (1998) developed an application for the generation of wind, solar and wind hybrid energy for use as standalone generation systems at the residential customer level, the hybrid generation characteristic is seen as a major impact evolution for the decade. In the following years, solar photovoltaic technology is expected to provide electricity on a large scale, internally safe and environmentally friendly, and the price will be competitive with traditional electricity sources within 10 years (Zahedi, 2006; Koutroulis et al., 2006). Recent studies corroborate these estimates by the mandatory inclusion of photovoltaic solar energy in certain types of buildings and by the fact that the costs incurred by the systems are increasingly lower compared to other energy sources (Comodi et al., 2015; Tsalikis, Martinopoulos, 2015).

In New Zealand, a study similar to the one proposed in this article was developed for an electrical system that has high levels of renewable generation. A strong point of the research program is GREEN Grid is the focus on technical and social aspects such as issues of protection and automation in the distribution network, analysis of the impacts of bidirectional energy flows and protection of network assets. The challenges for a greener and smarter grid identified in the research include managing the increasing variability in supply (especially the increasing use of wind and solar generation) the potential for congestion problems and high quality power levels of small scale distributed generation; the need for greater frequency maintenance and instantaneous reservations as variability increases; and the relatively low level of consumer involvement in responding to demand, which could ideally help with variability (Stephenson et al., 2018).

According to Papageorgiou et al. (2020), in Brazil, the adoption of solar photovoltaic energy has been motivated not only by the diversification of the energy matrix, but also by the needs, problems and barriers that the Brazilian energy sector has faced in recent times. The development of the solar source is affected by several factors with high uncertainty, such as political, social, economic and environmental, which include critical issues of operational sustainability. It should be noted that an elaborate modeling of energy management and a well-structured decision support process are necessary.

When identifying the scientific gaps, there is a lack of analysis regarding solar energy management that addresses a way of understanding and exploring the determinant aspects for the significant development of the solar source in Brazil. As a relevance of the study, the objective is to help societies to become more sustainable and to obtain increased energy efficiency through environmental and sustainability issues, government agencies, institutions and societies. The fluctuation in the data that are addressed by this management corroborates an analysis in which reducing the degree of subjectivity and uncertainty becomes relevant. Therefore, and taking as a research gap, this work identifies potential aspects for the implementation of photovoltaic systems in residences, to identify which aspects are considered most important in decision making. The applied method addresses: a comprehensive literature review; institutional government sources and information provided by energy companies; two questionnaires involving specialists and decision makers limited to the residential sector; the Analytical Hierarchical Process (AHP) as a tool to assist in the decision making of the identified aspects and a case study.

This study consists of five sections, among which the first presents the introduction and objectives. In the second section, the theoretical framework used in the work is evidenced by explaining elements essential to this research. The third section presents the method used. In the fourth section, the results and discussion of the article are observed. Finally, in the last section, the final considerations and future research.

2. Energy resolutions

2.1. Distributed generation

Solar energy was encouraged for the first time in Brazil through regulation by Normative Resolution No. 482/2012 of ANEEL, (Establishes the general conditions for the access of microgeneration and mini-generation distributed to the electricity distribution systems, the energy compensation system, and other measures). With it, the consumer can generate his energy through different energy sources and supply the surplus to the local concessionaire's network (ANEEL, 2012). In the years following the published standard, the government took as its objective the growth of this electric energy compensation system and revised the resolution in 2015, with Normative Resolution No. 687/2015 (ANEEL, 2015).

The potential market for photovoltaic energy production in the Brazilian panorama is considered through the Distributed Generation (DG) (Rigo et al., 2019). GD is an effective way to compensate for the electricity demanded during the night, as a solar system does not produce energy in this period. The so-called energy compensation system occurs, in which the consumer uses the energy produced during the day and at night uses the energy from the local utility network. This process is regulated by laws in Brazil and is still in constant improvement, currently it has some disadvantages such as changes in network procedures, reverse power flow (occurs when the energy that should be unidirectional is changed to the bidirectional type, being injected in opposite directions) and the islanding phenomenon (supply of energy from the photovoltaic system to the local grid even with the grid disconnected).

In São Paulo, one of the main states in Brazil, the energy distribution is divided between five energy concessionaires. In quantitative terms, more than 18 thousand consumer units with distributed generation (UCGD) have been installed (ANEEL, 2019). Among the incentives for solar generation, there is the aspect of the tariff being high in Brazil and encouraging the adhesion of some consumers to the Distributed Generation (Luna et al., 2019) and

Decree 61.439/2015 (Brazil, 2014), which obtained a relevant impact (with the measure, the energy produced by SFCR is tax free). Before the Decree, 30% of the Tax on Circulation of Goods and Services (ICMS) was levied on the surplus energy produced in the residence, which was offered on the network itself (Brasil, 2015). For example, when energy is generated in the residential system and that energy is not fully consumed at that time, the surplus is transferred to the grid of the local distributor and is stored as an energy credit, but when the energy is returned to the residence to be consumed (when energy credits are used), excise taxes were levied.

2.2. Tariff flags

In certain periods of the year, tariff flags are included in the electricity bill. This inclusion is justified by the seasonal problems encountered in the electricity sector. The predominance of energy sources in Brazil is hydroelectric plants, which demand that the dams have their reservoirs at the appropriate levels. When this does not happen, due to lack of rain, for example, the reservoirs are below the necessary limit, impairing their generation. As a result, thermoelectric plants are used, which require more resources than the hydroelectric source, requiring additional charges on the electric bill through tariff flags (ANEEL, 2019). The flags are classified into three types (Table 1).

When the total generation of the plants of the Energy Reallocation Mechanism is less than the sum of their physical guarantees, the GSF is less than 1, and points out that the conditions of hydroelectric generation are not favorable (ANEEL, 2019). The inclusion of tariff flags at certain times of the year makes Brazil's electricity tariff one of the most expensive in the world.

Analyzing institutional changes in the Brazilian energy sector, highlighting the regulatory process and verifying the degree of market efficiency according to the structural changes in the four segments of the sector (generation, transmission, distribution, and commercialization), the regulatory models of the electricity sector Brazilian emerged in an embryonic way, without long-term planning, subordinated to the interests of the State and economic agents, and to the present risks of the institutional market environment and uncertainty (Moriggi, 2017).

2.3. Technology

Brazil has a strong dependence on other countries for the components needed in the manufacture of photovoltaic modules, which can jeopardize its future growth. Currently, 90% of the modules are composed of a silicon semiconductor element. After extraction, silicon is purified by chemical or metallurgical procedures before being ready for photovoltaic applications. The production of this equipment in Brazil would be a great advance for the photovoltaic sector, however, this requires political measures to compete with other countries under the same conditions. Tax breaks and reduced loans are incentives that must be adjusted at the federal and state levels to promote the adoption of the source and incorporate the entire production cycle in its market (Garlet et al., 2019; Uriona Maldonado et al., 2021).

Table 1
Tariff flags.

Flag	Addition
Green	Unchanged
yellow	U$ 0,28 for each 100 kWh
red (baseline 1)	U$ 0,74 for each 100 kWh
red (baseline 2)	U$ 1,11 for each 100 kWh

Source: ANEEL (2019).

The manufacturing activities showed that the country is well consolidated with its traditional companies in the transformation of metallurgical silicon, but with no presence in the subsequent phases of manufacture to transform it into a solar grade, silicon with a high level of purity. Brazil has raw materials (large silicon reserves) and industries that can be adapted for the production of components for photovoltaic systems (Garlet et al., 2019; Uriona Maldonado et al., 2021).

In the assembly of the modules, there has been a significant growth in recent years, after the positive results of the energy auctions and the flexibility of the financing mechanisms. In the provision of services, there is an adequate presence throughout the country, with companies working in the design, maintenance and installation. It is noteworthy that the support industries for composite modules lack companies that produce glass, encapsulant, backsheet and junction boxes (Garlet et al., 2019; Uriona Maldonado et al., 2021).

Although the international market for photovoltaic components is extremely competitive, Brazil has the potential to develop the entire production chain through government policies, technical-economic initiatives, opening and competitive market performance, development of national industry with technological adaptation to meet the conditions national and international research and development of solar panels (Garlet et al., 2019; Uriona Maldonado et al., 2021).

Regarding the contribution of PV technologies installed in Brazil, there are some characteristics in relation to monocrystalline, polycrystalline and thin film technologies. The technology of monocrystalline silicon has the highest levels of real efficiency, due to its high nominal efficiency and the lower impact of temperature on cell performance when compared to polycrystalline silicon. In relation to performance in real conditions, thin film technology has the smallest reductions in electrical efficiency and, therefore, corresponds to the best technology from the point of view of temperature (Simioni and Schaeffer, 2019).

It is also worth mentioning that thin-film photovoltaic technologies with a low power and temperature coefficient present superior output performance. Monocrystallines and polycrystallines showed intense degradation of coastal areas with high temperature and relative humidity. Technologies based on crystalline silicon (monocrystalline and polycrystalline silicon) are the most affected by high temperatures. Meanwhile, fixed-grade photovoltaic technologies least affected by extreme temperatures are thin-film technologies (Nascimento et al., 2018, 2020).

3. Methodology

The study to identify potential aspects for the implementation of a photovoltaic system in residences has gone through several points, ranging from a thorough bibliographic survey, to seeking the opinion of specialists in the energy sector.

Following the flowchart (Fig. 1) proposed for the method of this research, some important factors for the management of solar energy were proposed through the researched theory. To better illustrate the research stages, the flowchart presents the research stages from the completion of the bibliographic research to the evaluation of the results.

The flowchart used to support the research method is divided into three parts: (I) Data collection; (II) Specific planning for verification and (III) Informations collection. Following is a brief summary of the activities developed in each part.

The first part consists of theoretical activities such as bibliographic, bibliometric research, and identification of legislation and incentives. In the bibliometric study, searches were made in the

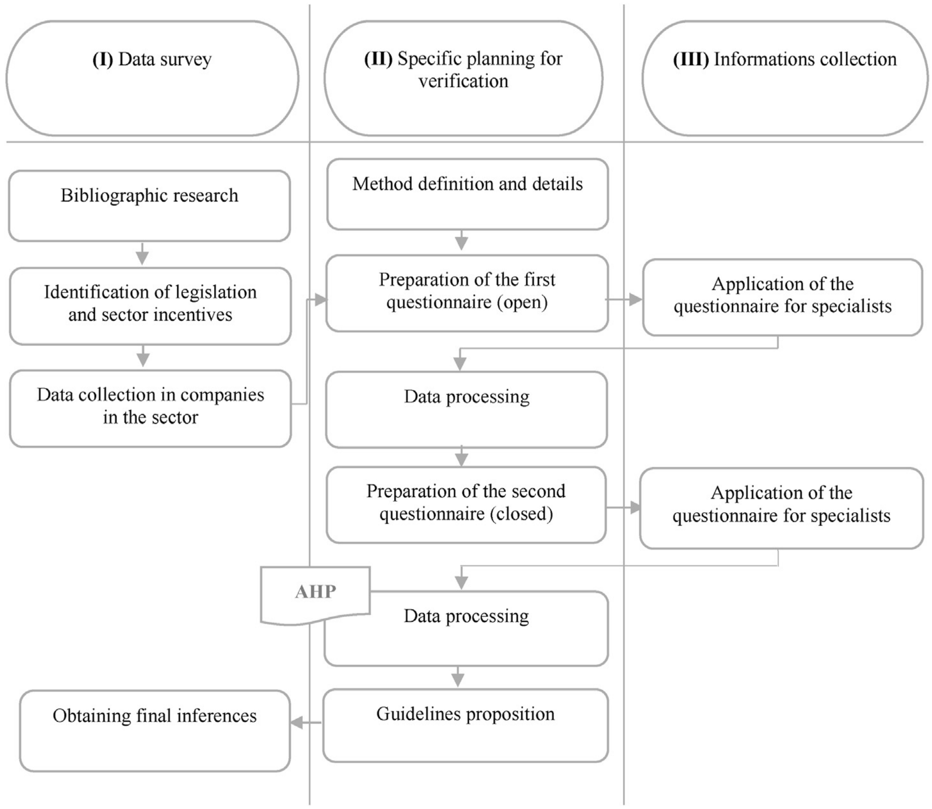

Fig. 1. Flowchart research method.

Scopus database to obtain a set of data for all published studies related to photovoltaic solar energy management. The analysis interval was between the years 2000 and 2020. The keywords used for data collection include solar, energy, management, and photovoltaic. We use a combination of these keywords with Boolean operators to combine the search terms as follows: “solar” and “energy” and “management” and “photovoltaic”. Then, after filtering the jobs, a qualitative analysis was done and the works that contributed to the theme of the study were selected. In the second part, the verification of the obtained data is made as the elaboration and treatment of the answers of the questionnaires. And finally, in the third part, it is composed of the data collections characterized by the application of the two questionnaires prepared for the specialists.

3.1. Specialists

The characteristics of the specialists needed to answer the questionnaire are based on the work of Buccieri (2014) and the article by Addy et al. (2017). In this sense, based on these two studies, the characteristics of the five selected specialists were elaborated for this work. In order to obtain in-depth and generalized information about the aspects, the choice of this group was considered crucial for the development of this work. Some characteristics for the selected profile were specified as the positions held by specialists who were in SFCR installation companies, members of associations that represent and promote the Brazilian photovoltaic sector in the country, such as the Brazilian Solar Photovoltaic Energy Association (ABSOLAR), or by people who have a proven experience in the researched area, but with a focus on management. Secondary characteristics include: experience in the field for more than five years; have availability to respond to the survey in a timely manner, understanding and passing on the required information.

Economic activities are based on knowledge and learning (Smith et al., 2005). With regard to the knowledge sought by specialists, three types were explored. Asheim and Vang, 2017 distinguish three main categories of knowledge base: “analytical”, “synthetic” and “symbolic”, which contain different combinations of tacit and coded knowledge.

The deployment of photovoltaic systems includes processes such as technology selection, acquisition, commissioning, design, installation, and use, as well as the necessary administrative procedures. Particularly in the initial markets, the development of these processes is likely to depend on knowledge that can be tacit in nature and on a knowledge base that is likely to be synthetic rather than analytical (). Thus, the knowledge sought by specialists encompasses the three types mentioned, with greater predominance in synthetic and symbolic knowledge. Table 2 shows the characteristics of the specialists and the types of knowledge sought in a summarized form.

The questionnaire explored the three types of knowledge in order to obtain the individual comparison matrices determined by the AHP method. It is worth mentioning that prior to the application of the questionnaires, interviews were conducted with specialists to confirm whether the participation would meet the specified characteristics or not.

3.2. Method for identifying aspects

After specifying the profile of the specialists who would participate in the research, a first (open) questionnaire was applied that addressed a question intending to obtain opinions about the market, legislative, environmental, social, and economic aspects of

Table 2
Experts characteristics.

Primary characteristics	Secondary characteristics	Knowledge sought
Position in photovoltaic system installation companies.	Experience in the area for more than five years.	Analytical basis: Creation of new knowledge, importance of scientific knowledge.
Members of associations that represent and promote the sector.	Availability to respond to the survey in a timely manner.	Synthetic basis: Importance of applied knowledge, practical knowledge.
Proven experience in the area (focus on management).		Symbolic basis: tacit knowledge, practical skills and search and research skills.

solar photovoltaic systems in residences. The questionnaire was applied using the Survey Monkey, tool.

The results obtained with the first survey served as a basis for the preparation of the second questionnaire that was applied. The second questionnaire contained 6 questions that aimed to compare the aspects identified with the first questionnaire. In this second questionnaire, the six aspects identified were classified into two groups, defined as follows: “Internal factors” and “External factors”. The factors called internal refer to the characteristics imposed on the consumer and the factors called external refer to the characteristics of the photovoltaic system itself and its aspects.

The second questionnaire proposed to the experts contained a relatively low number of questions, given that with a high number of questions to be answered, the experts could be fatigued and not respond with a certainty of judgments. Thus, some aspects raised in the first questionnaire were unified in order to reduce the number to be used in the second questionnaire.

3.3. Method - Analytical Hierarchical Process (AHP)

In the decision-making process, in most cases, the choice of the best decision takes into account multiple criteria, factors, and objectives. The AHP method, which was created by Saaty in the 1970s in the United States, is structured starting with the definition of a desired global objective. After defining the objective, the criteria are described in a tree structure, the global objective being the root (Shimizu, 2006).

A characteristic about the decision tree is that as it moves away from the root, more specific factors are found and the extremes represent the criteria for the evaluation. The basic principle of AHP is the development of the priority vector by calculating the largest auto vector of each parity comparison matrix. In this process, one of the approximate forms specified by Saaty is used (Shimizu, 2006). Depending on the number of criteria that are compared, it can generate a relatively large number of comparison matrices, being considered one of the difficulties in applying the AHP method.

3.4. Research tool

At the stage where the expert opinions are collected, it was necessary to submit questionnaires through the Survey Monkey cloud-based online survey development platform founded in 1999 by Ryan Finley. It is an internet research tool, flexible, robust, and reliable, which makes it possible to collect data in real time, impartially and concerning the necessary privacy of the respondents.

In the present study, two stages of research were developed through a questionnaire survey and applied separately to each specialist by a specific link sent via e-mails via the internet, with simple questions aiming to gather information on the key factors of system management residential photovoltaic, of which each expert expresses his opinion according to his professional and academic experience.

The feedback was collected directly by the Survey Monkey, online platform, tabulated, and then analyzed to infer about the survey results. Fig. 2 presents a macroscopic view of the research questionnaire application process.

After defining the profile of the specialists, the questionnaires that would be applied were prepared. The first questionnaire has a qualitative aspect and the second questionnaire has a quantitative aspect. After defining the format of the first questionnaire, its structure in Survey Monkey began. The next steps were to forward the questionnaire to the experts, send a reminder to those who had not responded and with all the responses collected, the data was compiled. With the data obtained with the first questionnaire, the preparation of the second questionnaire began and the sequence in Fig. 2 was repeated.

3.5. Factors for practical application

3.5.1. Incentive from the state of São Paulo

For the government of the state of São Paulo, the development of this sector is one of the main lines of action of the government, which already has tax incentives. The state has the following main incentives (Secretaria de Energia e Mineração, 2019); DECREE 60.298/2014 (Brazil, 2014); DECREE 61.439/2015 (Brazil, 2015); (Resolução et al., 2017); (Brasil, 1998) DECREE nº 63.095, of December 22, 2017 (Brazil, 2017).

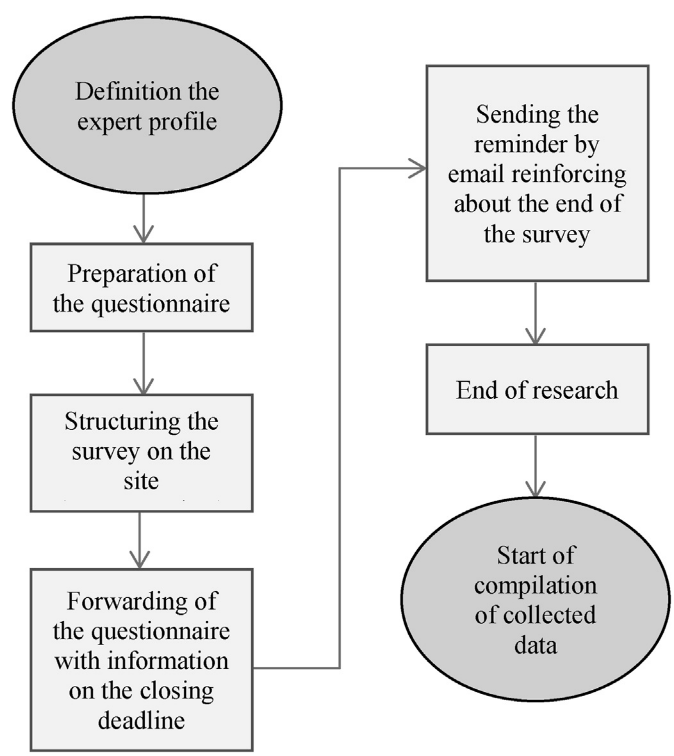

Fig. 2. Questionnaire application process (Adapted from Buccieri, 2014).

Among the mentioned incentives, Decree 61.439/2015 had a relevant impact. With the measure, the energy produced by SFCR is exempt from taxes. Before the Decree, 30% of the Tax on Circulation of Goods and Services (ICMS) was levied on the surplus energy produced in the residence, which was offered on the network itself (Brasil, 2015). For example, when energy is generated in the residential system and that energy is not fully consumed at that time, the surplus is transferred to the local distributor's network and is stored as energy credits, when the energy returned to the residence in order to be consumed, consumers were taxed on this excess energy.

3.5.2. Levelized cost of electricicty

Equation (1) presents the Levelized cost of electricicty (LCOE) formula (Hansen, 2019) which includes the investment costs in t (It), maintenance costs in year t (Mt), fuel costs (Ft), energy generation in year t (Et), discount rate (R) and technology lifetime (N).

$$LCOE = \frac{\sum_t n = 1\ (It + Mt + Ft) \Big/ (1+r)^t}{\sum_t n = 1 (Et) \Big/ (1+r)^t} \tag{1}$$

It = Investment expenditures in year t
Mt = Operations and maintenance expenditures in year t
Ft = Fuel expenditures in year t
Et = Energy generation in year t
R = Discount rate
N = Life time of the technology

In the calculation methodology part, the cost of production of the PV system, expressed in US $ for each kWh produced, is equated. The final value generated by the formula includes all costs and factors that influence the PV system throughout its useful life. The calculation can be used to compare with the energy tariff of the energy concessionaire, since its final value is expressed in the same way.

4. Case study, results and discussion

4.1. Collected data

The study aimed to search for empirical knowledge, through a questionnaire specially designed to carry out the activity, about the implementation of photovoltaic systems in residences. Each specialist initially answered the first questionnaire that sought the most relevant aspects to be observed when deciding whether or not to implement a photovoltaic system in a home. The aspects obtained were analyzed and unified when they obtained the same meaning to decrease the quantity. Table 3 shows the list of aspects obtained without an order of priority and their description.

The responses obtained had characteristics that could be subdivided into two groups: Internal factors and external factors (Table 4). The division made it possible to obtain the experts' opinions with the second questionnaire in a more objective way. Before submitting the second questionnaire, partial tests were performed with the AHP.

Table 4
Aspects divided by groups.

	Aspect number	
Internal factors	1	Lack of knowledge on the subject
	2	Lack of priority
	3	Cultural
External factors	4	Standardization of standards
	5	Lack of influencers
	6	Costs

Table 5
Matrix 1 for comparison and normalization of aspects of the Internal Factors Group.

Internal Factors	1	2	3	Auto vector	Weight
1	1	3	9	3	67%
2	1/3	1	5	1,18	27%
3	1/9	1/5	1	0,28	6%
Totals	1,44	4,2	15	4,46	100%

The second questionnaire, which was submitted to the same specialists as in the first survey, had six questions in total about the aspects scoring according to their opinions and experiences the weights of each other, to obtain individual comparison matrices.

The questionnaire was designed using the nine-point method recommended by Saaty and complies with the AHP requirement for paired comparison. Thus, five questionnaires completed effectively generated twenty comparison matrices in total. Each questionnaire generated four 3 × 3 matrices due to the division of aspects into two groups.

The results of the AHP method are demonstrated by weighting indicators and analyzing consistency. Based on the experts' judgment, who filled out the participation questionnaires, the twenty comparison and normalization matrices and ten consistency analysis matrices for each evaluation were obtained to obtain the individual weighting of the aspects. Then, the analysis of all aspects was carried out, involving the individual analyzes of the specialists and generating the general classification by relevance. All calculations in this work were performed using the MS Office - Excel application due to the number of matrices.

As an example, an expert's individual analysis will be demonstrated. Based on Table 4 in relation to the identified number of aspects, Tables 5 and 6 refer to the experts' judgments and the weights obtained from each aspect and Tables 7 and 8 to the consistency tests.

The matrices in Tables 5 and 6 were filled out according to the responses to the second questionnaire. With the degree of importance of one aspect over the other, it was possible to calculate the "Auto Vector" and the "Weight" of each aspect.

The tests shown in Tables 7 and 8 are used to verify that the

Table 3
Most relevant aspects.

Aspects	Description
Costs	All costs related to the purchase and implementation of the system.
Standardization of standards	Great diversity of standards among states on the implementation of photovoltaic systems.
Lack of influencers	Lack of informational dissemination about the source of solar energy by the government.
Lack of knowledge on the subject	Consumers have little or no knowledge of the solar source and its characteristics for their own implementation.
Lack of priority	Consumers do not invest in solar systems as the first option of monetary savings, even though they obtain significant long-term benefits.
Cultural	In Brazil it is not common to practice the search for sustainability in a significant way and this directly confronts implementation.

Table 6
Matrix 2 for comparison and normalization of aspects of the External Factors Group.

External factors	4	5	6	Auto vector	Weight
4	1	1/3	1/9	0,33	7%
5	3	1	1/5	0,84	18%
6	9	5	1	3,55	75%
Totals	13	6,33	1,31	4,73	100%

Table 7
Matrix 1 consistency tests.

ʎ-max	IC	CR	Test
3,02	0,01	0,025	Ok

Table 8
Matrix 2 consistency tests.

ʎ-max	IC	CR	Test
3,02	0,01	0,025	Ok

values are consistent. The consistency rate (CR) must be less than 0.10 to be considered valid. In the ten tests performed, the values obtained were less than or equal to 0.10 (Shimizu, 2006).

For a visual demonstration of the Consistency Rates (CR) obtained, a dispersion chart was created (Fig. 3) with all 10 individual judgments (two tests for each questionnaire). It is possible to verify that the judgments were considered acceptable for this work because all the results were equal to or less than 0.10.

Based on the values generated by the result of the parity comparison matrices, the priorities for each aspect were obtained. Fig. 4 shows the relative priorities of each aspect of the Internal Factors group and Fig. 5 shows the relative priorities of the External Factors group. In Figs. 4 and 5, we chose to demonstrate the relative priorities in the form of a bar graph, as the quantitative values differ.

From Figs. 4 and 5, it can be seen that the “Cost” aspect of the External Factors group and the “lack of knowledge on the topic” aspect of the Internal Factors group present the maximum relative priorities of 0.68 and 0.65, respectively, considered as the most important for the decision to implement a photovoltaic solar system in residences; the “Lack of influencers” aspect of the External Factors group and the “Lack of priority” aspect of the Internal Factors group present the maximum relative priorities of 0.23 and 0.28, respectively, considered as the most important in second place for the decision of implementing a photovoltaic solar system in residences and the “Standardization of standards” aspect of the External Factors group and the “Cultural” aspect of the Internal Factors group present the maximum relative priorities of 0.08 and 0.06, respectively, considered as the most important in third place

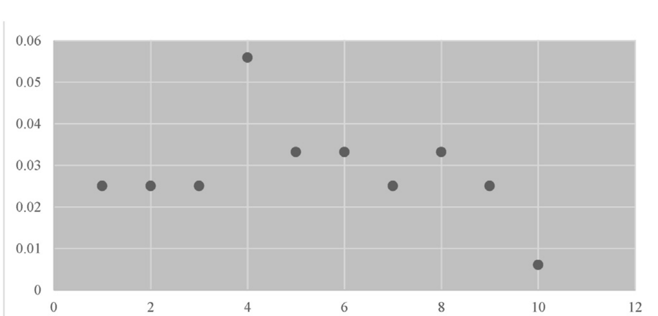

Fig. 3. Consistency rates of the parity comparison matrices.

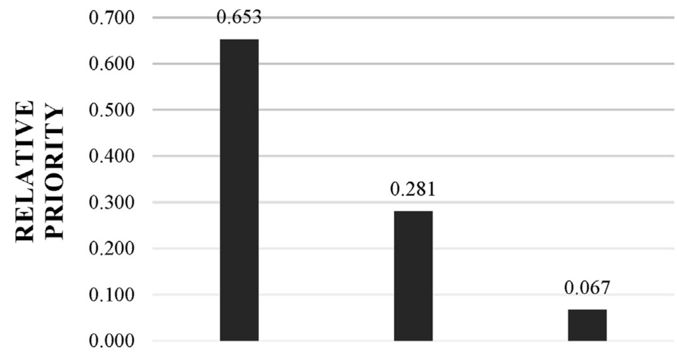

Fig. 4. Relative priorities: internal factors.

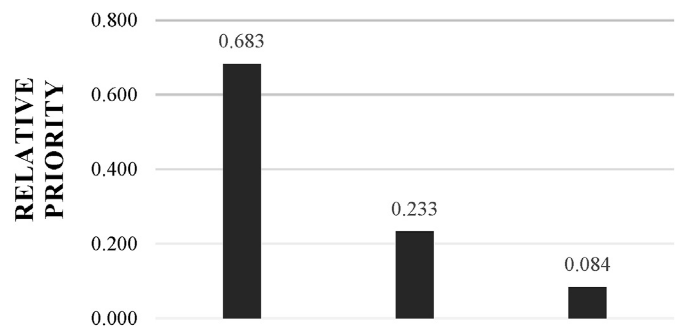

Fig. 5. Relative priorities: external factors.

for the decision to implement a solar photovoltaic system in residences.

4.2. Proposition of guidelines

With the results obtained with the work, it is possible to identify guidelines about the most relevant aspects raised. The most important aspect of the Internal Factors group, “lack of knowledge on the topic”, obtained a high relative property index, that is, a significant weight for the implementation of photovoltaic systems in residences. The superficial or nonexistent knowledge that energy consumers have of the solar source generates distrust to acquire. Structured enforcement through digital media that objectively highlights the source and its contribution to sustainable development can positively change this scenario.

The second most important aspect of the Internal Factors group, “Lack of Priority”, concerns the choice of the energy consumer to implement or not a photovoltaic system in a residence, collaborating with the information obtained with companies in the sector that for every 100 people contacted by companies for the implementation of photovoltaic systems, only in the range of 7 of them acquire, even though the project obtaining energy savings between 85% and 95%. Because of consumers feeling insecure with the solar source (due to lack of knowledge or distrust of the technology) and not feeling safe with those who buy (companies specialized in budgets and projects), the imposition of the establishment of certification of specific quality standards for solar energy photovoltaic for specialized companies as well as the creation of lower financing interest rates for individuals (according to Law 13,203, of 2015, there are differentiated rates for the installation of systems for generating electricity from renewable sources and for energy efficiency in hospitals and public schools) could summarize this aspect, with an average of 5% per year (Brazil, 2015; BB, 2019; BNDES, 2019; BNB, 2019).

The third most important aspect of the Internal Factors group, the "Cultural", corroborates in the same sense as the aspect "Ignorance about the Theme". An action that could contribute to this aspect is the dissemination of the solar source in schools, preferably in early childhood education, in which children would have an energetic awareness about the subject from an early age, contributing to their social development. In addition to the development itself with the information obtained from the lectures, there would have been the triggering of information when the children directed to people closer to them as country and siblings. The dissemination could be through lectures, illustrative items, and any other characteristic that would make it interesting for the age of the public.

The most important aspect of the External Factors group, "Costs", also obtained a high relative property index. According to the Renewable Energy Policy Network for the 21st Century - REN21 (2018), investment costs are still considered high for photovoltaic systems, however, when balanced this aspect with other factors this can be controversial, such for example the bad sizing of a project: numbers of photovoltaic plates above what is necessary for customer consumption, inverters and Stringbox of a wrong specification or even installation problems of the physical arrangement of the system and the short-term analysis of a project, one of which photovoltaic system has an efficient life span of over 25 years.

An energy saving strategy and to reduce the associated investment costs, which does not take directly into account the solar source, is the management of energy consumption demand (based on strategic actions and measures imposed on a consumer through incentives). With the creation of new habits, the consumer providing information about energy consumption, consumption usage patterns and the implementation of a photovoltaic system in a home, significant savings would be obtained, in addition to contributing to the decrease in peak demand during some critical periods (Vega et al., 2020; Blakers et al., 2019; Cho; Valenzuela, 2019).

Still in relation to the "Costs" aspect, recent studies show that economic barriers do not directly affect implementation, but are interrelated to social, technological and regulatory barriers, indirectly affecting the deployment of renewable energy (Seetharaman et al., 2019).

The second most important aspect of the External Factors group, "Lack of Influencers", could be found with government programs as mentioned in Decree No. 5793 (Brazil, 2006), which discusses the establishment of guidelines for specific solar energy programs, as well as other sources. The feed-in tariff system (FIT) implemented by Germany is an example of this type of government program, in which it is characterized by the purchase of each kWh injected into the network by the energy producer, proving to be an incentive due to the characteristic of the monetary consideration (Trennepohl, 2014). Another aspect to be explored is the tax incentive, since in certain places the mode of selling the energy surplus may not be considered (Zeng; Chen, 2019).

And finally, the third most important aspect of the External Factors group, "Standardization of standards", is characterized by the great diversity of standards among states in Brazil for the implementation of photovoltaic systems. An example is the state of Minas Gerais that totally exempts ICMS from photovoltaic arrangements of up to 5 MW (Brazil, 2017), unlike other states that exempt only photovoltaic arrangements from 1 MG. A study applied to standardize the norms referring to solar energy among Brazilian states with a national norm for example that would contribute for companies to follow the same guideline and not each state follow its own norm, could contribute to the dissemination of the solar source. The standardization of the rules would provide credibility because a detailed analysis of the states would be necessary to avoid arbitrariness. Legislative divergence and inconsistency in the energy sector is a historical feature in Brazil, the adoption of innovative institutional and regulatory processes in the sector with the significant inclusion of the photovoltaic solar source is a necessity (Moriggi, 2017).

One way to be explored would be a national standard for photovoltaic solar energy with a scope similar to NBR ISO 50001: 2018 that deals with "Energy management systems - Requirements with guidelines for use" and its scope is based on the requirements to establish, implement, maintain and improve an energy management system (SGE) in an organization, giving guidelines to achieve continuous improvement of energy performance and Energy management systems (ABNT, 2018). A similar standard for photovoltaic solar energy could explore planning to implement the renewable source for different types of consumption profiles, as well as describe the impacts arising from the implementation in minimal terms (such as energy savings for the consumer, demand management) or maximum terms (such as environmental impact). The current NBR standards on photovoltaic solar energy deal with "Electrical installations for photovoltaic arrays - NBR 16690 project requirements" (ABNT, 2019); "Low voltage electrical installations NBR 5410" (ABNT, 2004) and "Photovoltaic systems connected to the grid - Minimum requirements for documentation, commissioning tests, inspection and performance evaluation NBR 16274" (ABNT, 2014).

Another aspect would be the review of PRODIST and Normative Resolution 687 of ANEEL, as well as the review of existing ones that compromise different interpretations in certain projects. In PRODIST, for example, which is characterized by the Electricity Distribution Procedures in the National Electric System, in Module 3 (Access to the Distribution System) (ANEEL, 2017) the deadlines for completing the implementation stages vary from one state to another. Fig. 6 shows a scheme in order to implement the proposed guidelines in stages.

Studies correlated with the theme of the work corroborate the results obtained in the article. In Nigeria, for example, some of the barriers and challenges in order to develop solar energy resources extensively are based on the need for strong enforceable policies in the following areas: training of labor with knowledge of skills in solar technology; financial support for research and analysis of solar data; financial and subsidy incentives for individuals, communities and private organizations to invest in the development of solar energy; financial compensation and training for individuals and communities whose land is acquired by the government and/or investors for the development of the solar energy project; and encouraging community participation/ownership in solar energy projects for security and infrastructure protection (Ohunakin et al., 2014).

Providing reliable information to potential consumers encourages the adoption of photovoltaic solar energy. It is also noteworthy that the normative aspect remains the most influential among families with higher income. A third factor refers to the level of education of potential consumers, individuals with higher education have higher environmental values and are more sympathetic to technologies that respect the environment. And with regard to investment time, when it is less than a year, it is a great incentive for adoption (Arroyo, Carrete, 2019; Zander, 2020).

Photovoltaic solar energy has grown significantly in Brazil in recent years and in view of the data exposed as obstacles in the sector to increase the reach of the source, actions that favor the scenario are increasingly necessary. The proposed guidelines aim to implement the source in a macro way in the country, weaving on aspects of various segments of the sector such as economic, environmental and social.

In relation to the economic sector, an aspect not mentioned

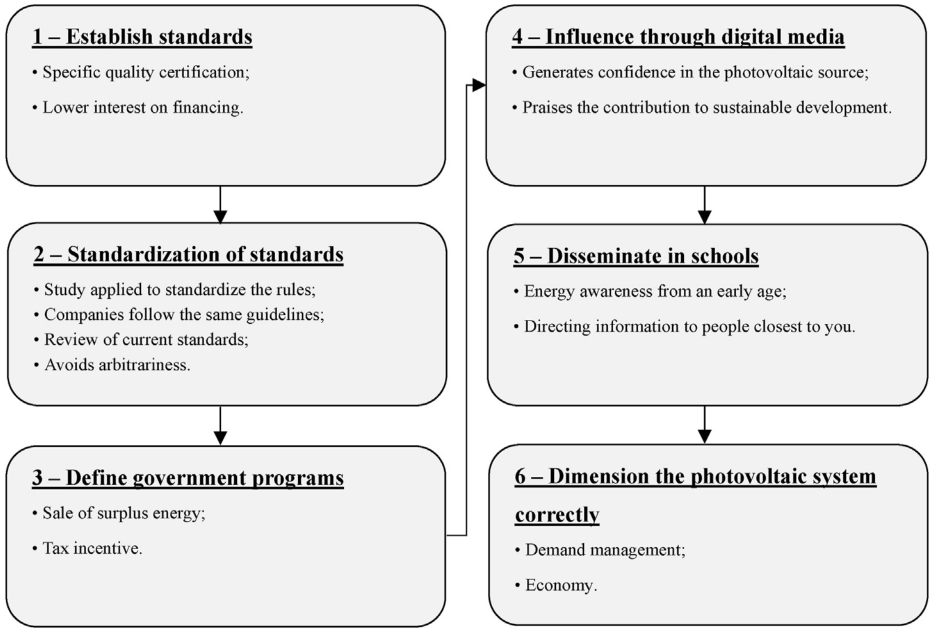

Fig. 6. Implementation of the proposed guidelines.

concerns the current issues of subsidies granted to those who install the system in a residence by the resolution of ANEEL 682, which is characterized by the energy compensation system. In a commission on the Brazilian Electricity Code, held on October 29, 2019, there were questions raised about the minimum benefits granted by the government. The ANEEL representative justifies the taxation of energy injected into the network, among several factors, due to the fact that the payment of sector charges by consumers with DG does not occur, however, there is a divergence in the information in view of the charges being paid through the availability cost charged by the energy utility. Still in reaction to sector charges, the energy injected by GD into the network is consumed by neighbors, through the neighborhood effect. During solar hours, the distributor uses the energy injected by GD, delivers this energy to neighboring consumers, and fully bills these consumers as if the energy had come from the national system. The energy that is injected into the network does not go to the national system to be redistributed, this is done instantly as soon as the exceeded energy is injected into the network, it is transferred to the consumer without the nearest DG, avoiding various sectoral distribution charges and not obtaining losses (Canal Energia, 2019).

In this sense, there is a divergence of opinions and information about the photovoltaic solar source in the national territory, so the creation of guidelines also aims at mitigating disputes, which may occur with such changes happening in the DG sector. A study done for Italy shows complaints related to performance or failures about contractual aspects in the construction of solar plants for example, and the authors suggest guidelines to address the various critical issues (Provenzano; Iddas, 2020).

4.3. Case study

As a way to apply the method used in the work, an analysis was made in a real case of a consumer taking as an objective to design a residential microgeneration system through a photovoltaic system. For the dimensioning of the project, all the average consumption of the owner was collected as well as environmental data of the location.

The consumer has an annual demand of 30,027 kWh. In view of any eventual production of energy below the expected due to environmental factors, for example, 30% more demand for dimensioning was added, thus obtaining an annual demand of 39,035 kWh or 3252.91 kWh monthly or 107 kWh daily. Other relevant factors for the project were solar irradiation at 4.58 h/day, the photovoltaic arrangement used of 23.36 kWp, and the final tariff that the consumer pays the energy concessionaire of US $ 0.14 for each kWh.

The feasibility analysis of a photovoltaic system project depends on the combination of the investment cost, the energy tariff, solar irradiation, and the panel temperature (Rodrigues et al., 2016; Du et al., 2016). Another calculation that needs to be seen is related to the production cost of the photovoltaic system, which is expressed in reais for each kWh produced. Called the Levelized cost of electricity (LCOE) (Hansen, 2019), the calculation can be used to compare with the energy concessionaire's energy tariff, since its final value is expressed in the same way. For this calculation, it is necessary to identify all annual expenses incurred with the implementation of the system, which includes the total cost, the cost of annual availability (US$ 668.03), the cost with tariff flags, a discount rate of 6% and a technology lifetime of 30 years. Thus, the LCOE obtained was US$ 0.07 for each kWh.

About the cost of tariff flags, the average of the additions charged since their effectiveness in 2015 was calculated according to the energy concessionaire EDP Bandeirante (Edp Bandeirante, 2019). The calculation was dimensioned by month and multiplied by the sum of kWh used, thus obtaining the amount referring to the annual increase.

In comparison with India, the calculation of the LCOE with a lower discount rate, 5%, and the lifetime also 30 years, was obtained at US $ 0.036 per kWh. The lower value of almost 50% of the LCOE, although India is economically similar to Brazil, is the result of government programs by the country's Ministry of Renewable Energy, which reduced in 2018 the cost of photovoltaic systems connected to the grid, which include the CT and installation and maintenance costs (Yadav and Bajpai, 2019; Country Economy, 2020).

In comparison to the Brazilian concessionaire's tariff, as a preliminary inference, there is a high difference between the cost of each generation, reaching a 50% difference in benefit of the level electricity cost paid by the photovoltaic system.

A high observed value of costs concerns the installation cost, in which companies charge 30%–50% of the total value of the photovoltaic system (Sultan et al., 2018). Specifically for the case study, if the LCOE calculation had been calculated with a percentage of the installation cost of 50%, the capped cost would have been approximately $ 0.085. When making a correlation with the aspect with the highest relative priority of the External Factors group, the "Costs", it is observed how the associated costs interfere in the final cost of the photovoltaic systems.

5. Conclusion

This article develops a method capable of identifying and prioritizing the most important aspects regarding the implementation of photovoltaic solar systems in residences in Brazil. Based on the results obtained with the research, it was possible to conclude the discovery of six important aspects of solar photovoltaic systems in residences, which result from market, legislative, environmental, social and economic factors. The aspects of: "lack of knowledge about the topic"; "Lack of priority"; "cultural"; "Standardization of standards"; "Lack of influencers" and "costs") divided into two groups (internal and external factors) for classification. The aspects "costs" and "lack of knowledge about the topic" present the maximum relative priorities, considered as the most relevant. The "lack of influencers" and "lack of priority" aspects have intermediate priorities and the "standardization of standards" and "cultural" aspects have the lowest relative priorities.

Through the identification of the most important aspects of solar photovoltaic systems in residences, it was possible to propose guidelines: the dissemination of the solar source in schools; the standardization of standards between states and a national standard for photovoltaic solar energy with a scope similar to ISO 50001 (energy management systems - requirements with guidelines for use); correct dimensioning of the system and management of energy consumption demand.

The purpose of the guidelines is to improve social and economic aspects of cleaner production. Even though the study focused on the residential sector, these guidelines can be reflected in the commercial and industrial sectors. If such identified aspects were demystified, significant reductions in gases harmful to the environment would be obtained, social development for the common cause that this group of solar energy adopters would become aware of and also the way in which Brazilian energy management is treated undergo changes that would reflect quality for consumers.

With the development of the case study, there was a practical application of the whole theory of this work, resulting in a 50% reduction in monthly energy costs. The value obtained from the level cost of energy from the solar source, US$ 0.07, is considered high compared to another case study developed in India, US$ 0.036, even though India is a country that is economically similar to Brazil. The difference is the result of government programs in the country, which reduce the costs of photovoltaic systems and other secondary costs.

The main limitations addressed in the research to elaborate the work were: i) obtaining information about photovoltaic systems projects in specialized companies; ii) the search for information and data in the national and international scientific literature with a practical focus, as it is an empirical study; iii) the divergence of information found in the literature about solar photovoltaic systems, regarding sizing and other technical information; iv) and the lack of information about the opinion of consumers, considering that of all the people contacted by companies for the implantation of photovoltaic systems, only in the range of 7% acquire, even the project obtaining significant energy savings.

Future studies may take into account in your requirement the aspects raised in this work, in addition to proposing empirical studies regarding dimensioning, joint analysis of demand management, energy efficiency, smart meters, tariff change, as well as the implementation of a system case. photovoltaic.

Finally, it is worth mentioning that the proposed methodology is considered interdisciplinary and provides a comprehensive and useful reference for assessing the implementation of photovoltaic systems connected to the network in residences in Brazil and other equivalent countries contributing to the scientific society.

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CRediT authorship contribution statement

Thamyres Machado David: Conceptualization, Methodology, Data curation, Formal analysis, Writing – original draft. **Gilberto Paschoal Buccieri:** Conceptualization, Methodology, Data curation, Formal analysis, Writing – original draft, Writing – review & editing. **Paloma Maria Silva Rocha Rizol:** Conceptualization, Methodology, Data curation, Formal analysis, Writing – original draft, Writing – review & editing.

Declaration of competing interest

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

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