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Paths and barriers to the diffusion of distributed generation of photovoltaic energy in southern Brazil

Taís Bisognin Garlet[a,*], José Luis Duarte Ribeiro[b], Fernando de Souza Savian[c], Julio Cezar Mairesse Siluk[d]

[a] Federal University of Rio Grande do Sul (UFRGS), Post-Graduate Program in Production Engineering, Brazil
[b] Federal University of Rio Grande do Sul (UFRGS), Department of Production and Transportation Engineering, Brazil
[c] Federal University of Santa Maria (UFSM), Post-Graduate Program in Production Engineering, Brazil
[d] Federal University of Santa Maria (UFSM), Department of Production and Systems, Brazil

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ABSTRACT

Photovoltaic (PV) energy has been identified as one of the main energy sources in transition from generation of electricity from non-renewable sources to renewable sources. In the Southern region of Brazil, despite the favorable conditions for implementation of distributed generation of photovoltaic energy, the installed capacity is much lower than the existing generation potential, evidencing the presence of factors that hinder the greater adoption and diffusion of this technology. Thus, this article identifies the panorama of distributed generation of photovoltaic energy and barriers that compromise its greater diffusion in the Southern region of Brazil, based on existing literature and qualitative interviews with professionals of the electricity sector. Results showed that this source of solar energy is expected to grow, but much remains to be done to consolidate it in the energy matrix, given the existence of technical, economic, social, managerial and political barriers. Among the main barriers identified are the poor quality of photovoltaic systems, the high cost of initial investment, the dependence on financing for purchase of solar panels, consumer culture, lack of knowledge about photovoltaic technology, the inefficient after-sales services, the dependence on imports of solar panels from China and lack of policies to encourage photovoltaic generation. The results of this study allow the understanding of the diffusion of the distributed generation of photovoltaic energy in countries of emerging economies or in regions where the implementation of PV systems is still incipient.

1. Introduction

The increase of population, accompanied by technological and economic progress, causes people to need more electricity to sustain a better living environment [1]. Increases in electricity demand and consumption are seen as a result of the economic recovery of developing countries, and are considered the most important factors in the acceleration of climate and environmental changes observed and described by the scientific community. In order to improve socioeconomic parameters in emerging countries, the current growth trend indicates that energy consumption in these countries will exceed consumption in developed countries in the coming decades [2].

The significant increase in the consumption of electric energy requires investments and alternative sources for the demand to be met, since the non-renewable environmental resources are more scarce [3]. In addition, burning traditional fossil fuels presents high potential for disaster, causing a number of environmental problems, such as climate change, pollution and global warming [4]. Thus, the current challenge of developing economies is to address increased consumption and reduce the impact of using non-renewable sources, stimulating advancement of technologies that exploit renewable energy sources, in order to address the political, economic and environmental factors involved in the generation of electricity [1,5].

Given this scenario, renewable energy alternatives have become the focus of many studies on environmental and economic issues, with some European countries at the forefront of technological and

Abbreviations: ANEEL, National Electric Energy Agency; BNDES, National Bank for Economic and Social Development; FIERGS, Federation of Industries of the State of Rio Grande do Sul; FIESC, Federation of Industries of the State of Santa Catarina; ICMS, Tax on the Circulation of Goods and Services; PV, Photovoltaic; R&D, Research and Development; SIN, National Interconnected System; TUSD, Distribution Service Utilization Fee

* Corresponding author.
E-mail addresses: tais_garlet@hotmail.com, tais.garlet@ufrgs.br (T.B. Garlet).

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regulatory investments in cleaner energy generation, enabling emerging countries to learn from their experiences [6]. Ref. [7] and Ref. [8] point to solar energy as one of the main energy sources in the transition from generation of electric energy by non-renewable resources to generation based on renewable energy sources. This emphasis is because the solar source has the potential to adequately satisfy the energy demands of the whole world, as long as technologies for its use are readily available [9]. Due to its rapid growth prospects and high levels of investment, the photovoltaic market is being held worldwide, especially in Europe, China and the United States. In Brazil, advances are becoming significant, especially after the insertion of solar energy in national energy matrix and the beginning of solar energy auctions in response to a period of difficulties due to the reduction of hydroelectric energy and the increase in electric energy prices [1].

Brazil stands out in the capture of solar energy by having a large geographic area with favorable conditions, leading to high irradiation rates [10]. In addition, other factors converge to make Brazil an ideal place for the production of solar energy, including the existence of large reserves of quartz that can generate competitive advantages for production of silicon, a component of photovoltaic cells [11]. These aspects may pave the way for an important role of photovoltaic technology in the diversification of the electric energy matrix [12].

Brazilian energy matrix is mainly composed of hydraulic and natural gas sources, which require large investments and often more than five years to be fully operational [6,13]. This means that the matrix of electricity is, for the most part, renewable, but also that the country depends on the stochastic availability of water to generate the largest share of its electricity [12]. High dependence on hydroelectric power is hampered by low rainfall during dry seasons, and natural gas supplies are directly affected by political and diplomatic instabilities [14]. Thus, studies indicated the future growth of photovoltaic solar technology in the country as an alternative source of energy, especially in the distributed generation of this energy modality [15].

Through the initiatives to access the micro and mini distributed generation of photovoltaic energy and the energy compensation system published by the National Electric Energy Agency (ANEEL) [16], it was possible to project a reduction of 9% of the energy usage from the National Interconnected System[1] until 2050, with great contribution coming from the generation of the residential and commercial sector [17]. Despite the lower number of hours of sunshine in the coldest months, the Southern region has good irradiance, with levels higher than those in the north, although slightly below the southeast, central-west and mainly northeast [18]. The southern states contain the second largest number of photovoltaic distributed generation systems, with 8204 connections, representing 28.24% of the systems connected to the Brazilian grid [19]. However, the installed capacity is still much lower than the generation potential of the region, evidencing the existence of factors that hinder the greater adoption and diffusion of this technology.

In the Southern region of Brazil there is still no significant deployment of photovoltaic systems connected to the grid with relevant installed power, compared to countries such as Germany, Italy and Spain [20]. Although smaller than in the past, solar generation costs continue to be higher than some of the main sources of renewable energy used in electric power generation. However, the learning curve of the industry is evolving and the associated costs have had significant reductions, which may mean that the source will become competitive in the future [2].

In the academic literature, it was possible to observe that the studies are focused on the mapping of diversity in the solar photovoltaic industry and understanding of the technical progress in terms of innovation and diffusion to mitigate climate change [21], as well as the understanding of the ways of obtaining energy, costs, advantages and disadvantages [1]. In addition, there are studies that investigate the barriers to adoption of photovoltaic systems through a systematic literature review [22] and seek to understand the development of technology in different countries, such as Tanzania [23], India [24], Finland [25] and Bangladesh [26]. In the Brazilian scenario, studies analyze the future perspectives of photovoltaic energy in the state of Minas Gerais [27], identify how market research is fundamental for photovoltaic projects in the country [11], analyze Brazilian policy of the generation of distributed photovoltaic energy and compare results with the experience of other countries [28], and discuss scenarios for photovoltaic applications in Brazil through feasibility analysis [29]. Thus, none of the studies presented the same focus of this study, evidencing the uniqueness of this research.

Some researchers say that the growth of the participation of photovoltaic energy in the energy matrix is a complex process, since the effective adoption of the innovation involves several interconnected factors [30,31]. In this way, this article aims to identify the panorama of the distributed generation of photovoltaic energy, emphasizing the barriers that compromise the greater adoption and diffusion of this technology in the Southern region of Brazil, whose main socioeconomic statistics are presented in Fig. 1. Considering the exploratory nature of the research, a qualitative method is used to conduct this study. Thus, semi-structured interviews were conducted with 12 professionals from energy concessionaires, association of companies and production chains of the photovoltaic sector, academic researcher, client, PV provider, member of the government, and consultant in the area of energy of the region. The study provides information on future expectations about photovoltaic technology, as well as a table explaining how barriers can be classified and evaluated according to five fundamental aspects related to the adoption of this technology: technical, economic, social, managerial and political.

This article is structured in five sections. In section two, the relevant literature describing the process of adoption and diffusion of photovoltaic technology is identified. Section three presents the research method, describing the steps required to conduct the qualitative study. Section four presents the description of the interviews conducted and the analysis of the information obtained, while section five establishes the final considerations, emphasizing the implications of the study.

2. Determinants of diffusion of photovoltaic energy

Determinants of the diffusion and adoption of new technologies have been of great interest to scientists from different areas [33]. Diffusion is commonly used to explain the process by which individuals and firms in a society or economy adopt a new technology or replace a technology lagged by a new one [34,35]. In the scope of distributed generation of photovoltaic energy, the slow diffusion process is highlighted, mainly due to the conflict between the economic costs, environmental benefits of carbon emission reduction and the incongruity with the existing energy systems [36]. Moreover, Ref. [37] argue that the process of diffusion of renewable sources is not a trivial task, because it involves uncertainties arising from technological, economic and social aspects. Meanwhile, the articles based on the diffusion of innovation theories [38] and photovoltaic technologies [31,33,36] indicate that the investigation of the growth of distributed generation of photovoltaic energy and the barriers to its adoption must consider five dimensions: technical, economic, social, managerial and political. These five dimensions were selected because they comprehend a wide range of aspects that influence the diffusion of PV systems.

The technical dimension encompasses limiting aspects that affect the quality of the photovoltaic system, the durability of the panels, the failure of the components and reliability in the operation, as well as the maintenance and service ignored and not included as part of the project development [39]. Ref. [24] notes that key technical barriers included

[1] The National Interconnected System (SIN) is a set of facilities and equipment that allow the supply of electricity in the regions of Brazil electrically interconnected [86].

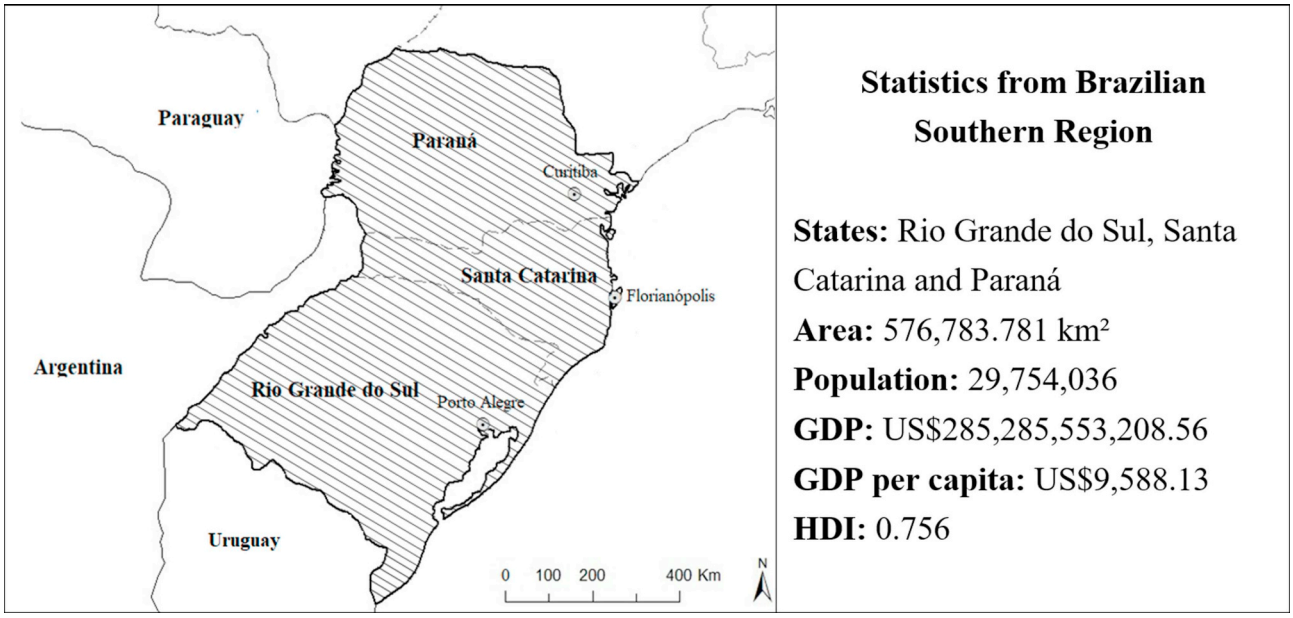

Fig. 1. Socioeconomic statistics of Southern Brazil. Source: Adapted from Ref. [32].

low conversion efficiency of photovoltaic modules, performance limitations of system components such as batteries and inverters, and inadequate supply of raw materials. In addition, although there are technical standards for the installation of photovoltaic systems, explicit requirements for conducting research, development and innovation projects in the sector have not yet been defined [40].

The economic dimension is of greater importance for the potential users of the photovoltaic system, since, when installing the system, the consumer is concerned with the economic benefit [31]. Thus, consideration should be given to payback, financing for the purchase of the photovoltaic system, cost of materials and installation, and tax on the circulation of goods and services (ICMS) on solar energy [41]. In addition, Ref. [42] stated that the variation of energy tariffs influences the economic analysis of the investment, and the net present value and the internal rate of return are important parameters for economic feasibility analysis of projects of distributed generation of photovoltaic energy.

The transition to energy from renewable resources faces a number of sociocultural challenges related to renewable energy project planning, acceptance of local change and adoption of new technologies. In this context, the importance of citizens and communities for the success of a sustainable transition is highlighted [43]. Ref. [5] argue that photovoltaic energy generation is a discontinuous innovation, that is, an entirely new product, which leads clients to divide in relation to the perception of implied risk to the process and that requires a change of behavior and culture of consumers so that the benefits can be realized. In addition, the lack of specific knowledge of potential investors regarding the adoption of renewable energy technology is one of the main obstacles to the diffusion of photovoltaic generation [44].

Insufficient and inadequate management is one of the main barriers in the diffusion of new technologies, especially for photovoltaic systems. The managerial aspects limiting the adoption of photovoltaic generation included inefficient after-sales services, such as technical assistance, monitoring and maintenance, as well as ineffective marketing approaches and education campaigns [22].

The political aspect involves feed-in tariffs, tariff models, interest rate policies, subsidy policies for the purchase of photovoltaic systems and import taxes [31]. According to Ref. [10], there is a need for changes in Brazilian legislation so that photovoltaic technology expands, given the high taxes imposed on companies for transmission and distribution systems and consumers who use alternative energy sources. In addition, the deficiency in energy compensation systems, established through a normative resolution that allows micro and mini generation owners to receive credits for the active energy generated beyond the level of user consumption, is highlighted [12].

3. Method

Methodologically, this research was organized in three stages, presented in Fig. 2. The study was based on a qualitative exploratory approach, using semi-structured interviews conducted in person and online, depending on the availability of the interviewees. Semi-structured interviews create a guideline for defining the key topics to be

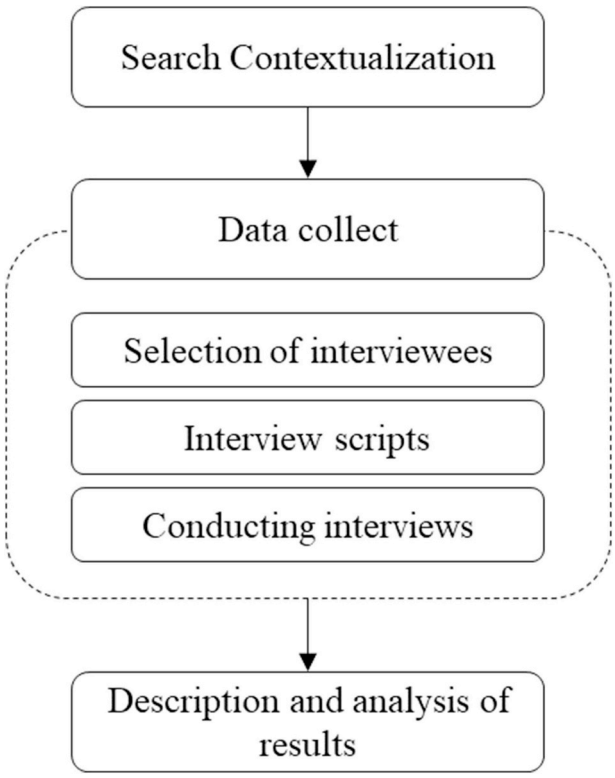

Fig. 2. Methodological steps.

addressed, while allowing the flexibility needed for respondents to provide their individual perspectives and create opportunities for new ideas to be expressed [33,45]. Qualitative interviews have already been shown to be useful in a large number of researches that analyze barriers and drivers for investments in renewable energy sources [46].

The first stage comprised the theoretical contextualization about the main concepts related to the generation of photovoltaic energy and the determining factors for the adoption of this technology. Data collection included selection of interviewees, preparation of questionnaires and conducting interviews to obtain information about the context of photovoltaic generation in Southern Brazil, which are presented and discussed at the stage of description and analysis of results.

The following subsections detail the three methodological steps adopted for the research development.

3.1. Search contextualization

From the definition of the problem and the objectives of the study, a systematic review of the literature was conducted to support and justify the importance of the project. To do so, the combinations of the keywords “photovoltaic energy”, “solar home system”, “Brazilian energy matrix”, “barriers” and “trends” in the Science Direct, Emerald and Scopus databases were searched during the period of 2008–2018, resulting in 11 articles relevant to the study.

In the academic literature, it was possible to identify a study that focuses on the status and potential of the development of photovoltaic solar energy in Tanzania, as well as limitations to the dissemination of this technology [23]. Another article discusses energy scenarios for photovoltaic applications in Brazil and performs a feasibility analysis for energy generation [29], while Ref. [27] provides future perspectives of photovoltaic energy in Brazil, specifically in the state of Minas Gerais. Ref. [11] discusses how market research has been fundamental in the development of the first photovoltaic project in Brazil, and Ref [22] investigates the barriers to the adoption of photovoltaic systems in several contexts based on a systematic literature review.

Literature also presents studies discussing the progress of photovoltaic solar energy in India [24], as well as the benefits and problems related to the use of solar systems in Bangladesh [26] and Finland [25]. In addition, Ref. [21] maps diversity in the photovoltaic solar industry and contributes to understanding the role of diversity in stimulating technical progress in terms of innovation and diffusion to mitigate climate change. Ref. [28] analyzes the Brazilian policy of distributed PV generation, while Ref. [1] presents the state of the art of photovoltaic solar energy through a systematic bibliographic research.

Through the information obtained in the main articles identified, it was observed the increase in the consumption of electric energy due to its growing need for daily activities of the population and companies. In addition, the transition scenario of energy generation based on non-renewable resources for renewable energy was highlighted, with photovoltaic energy as one of the main generating sources. It was also identified the Brazilian solar potential, pointing out the growth of photovoltaic participation in the national energy matrix, but also the existence of barriers that compromise the greater adoption of this technology.

3.2. Data collect

Considering the exploratory characteristic of the research, a qualitative approach was used, involving semi-structured interviews conducted in person and online. The selection of respondents was made intentionally, including professionals from the southern Brazilian states involved in the process of generation, transmission and distribution of electricity and distributed generation of photovoltaic energy. The sample consisted of 12 interviewees: a professional from an association of companies and production chains of the photovoltaic sector, six professionals from energy distribution companies, an academic researcher, a client, a PV provider, a member of the government and a consultant in the area of energy in the Southern region. Thus, this sample is representative, since it covers diverse perspectives within the same context, besides counting on the participation of interviewees linked to institutions of high renown and strategic impact for the region under study.

The interview script was adapted for each group of respondents to take into account the different types of involvement in the process of adopting photovoltaic power generation system, as can be seen in Appendices A.1 to A.5. The topics were based on a review of the literature on the panorama of photovoltaic generation at world, national and state levels, as well as existing frameworks and categorizations derived from the analysis of barriers to the diffusion of this technology [31,33,46]. Semi-structured interview script provided space for new topics to be addressed during interviews. The purpose of using open-ended questions was to allow respondents to spontaneously elaborate their responses about energy generation and barriers to adoption of photovoltaic technology, avoiding constraints imposed by the interviewer. The face-to-face interviews lasted between 15 and 65 min, and the information acquired was recorded in audio and later transcribed into a document, in which they were grouped with the interviews obtained online.

3.3. Description and analysis of results

In the step of describing and analyzing results, as presented in Fig. 3, the information was analyzed and coded according to categories and subcategories of responses, defined according to the interview

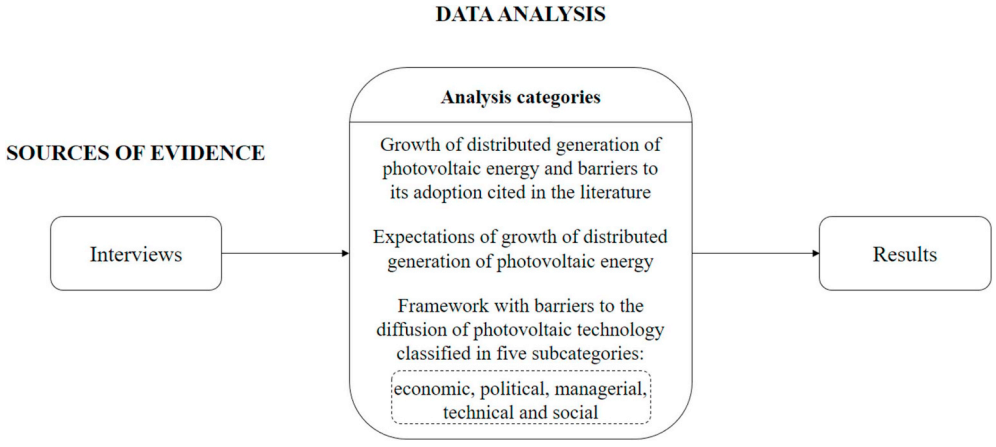

Fig. 3. Structure for data analysis.

script and the identified themes. The frequency of subcategories was verified and served as the basis for assessing the importance of a topic, such as the expectations and barriers that were cited several times by the interviewees.

According to the flow chart shown in Fig. 3, sources of evidence used were analyzed according to three categories. Initially, a comparison was made of the growth data of the distributed generation of photovoltaic energy and the barriers identified with the theoretical background, and the interviews were contrasted with the information verified in the literature. It should be emphasized that the interviews are data sources whose perception of growth and barriers arises from different contexts and situations, and aim to contribute to the identification of similar perspectives in the different responses.

Subsequently, fragments of the interviews were used to identify the growth expectations of the distributed generation of photovoltaic energy and the barriers to the diffusion of this technology, through discourse analysis. Finally, a table containing the barriers identified through interviews and literature was elaborated, classifying them into five subcategories of analysis: technical, economic, social, managerial and political. Moreover, to encourage the diffusion of photovoltaic technology, measures to overcome the barriers are suggested.

4. Description and analysis of results

Table 1 shows the profile of interviewees selected to compose the research sample. In order to preserve the identity of the respondents and possible conflicts of interest, the codes “Ai” were used for the responsible of the association of companies of the photovoltaic sector, “Ci” for the professionals of the energy concessionaires, “CLi” for the client who installed the PV system, “MGi” for the member of the government, “Oi” for the PV provider, “Ri” for the researcher in the field of PV energy and “SCi” for the strategic consultant in the area of energy.

The following subsections describe and analyze in detail the results of the interviews conducted in the present research.

4.1. Description of results

Initially, the interviewees were questioned about the composition of the energy matrix and the annual growth rate of energy consumption of their states in the Southern region of Brazil. C3 reported that “the energy matrix is predominantly hydroelectric, followed by thermoelectric. There is great generation growth through renewable energy such as wind and solar, but still with small representation near the more traditional forms of generation”. C2 supplemented the information by saying that “we use the same energy supplied to SIN. However, we have thermoelectric power plants, hydroelectric plants, wind farms, small hydroelectric plants and small distributed solar projects”. This information is corroborated by Ref. [47] and Ref. [48]. Annual growth rate of energy consumption in southern states according to C4 ″was 3.1%", information that is confirmed by Ref. [49].

When questioned about the growth forecast for some specific source of energy generation, C3 said “to have great space for solar energy, especially through distributed micro generation”, while C1 argued that “the source that grew the most was wind”. C2 and O1 complemented the opinions of other professionals, pointing out that there is a national trend of growth in solar energy generation and also in the generation of wind energy, due to the call for cleaner energies, which is why CL1 adopted the PV system. Interviewees also highlighted the rise of distributed energy generation as a solution to “dependence on generation through hydropower plants, contributing to the reduction of losses in the circuits and the increase in the amount of energy generated” (C3). Thus, C2 and C4 point out that “currently the main source of distributed generation is medium-sized wind and photovoltaics in the micro generation part".

Respondents stated that in Southern Brazil, photovoltaic energy “corresponds to a small part of the generation of energy” (C3), and “the market did not reach 2% of the existing photovoltaic potential” (A1). However, despite “the difficulty of forecasting the amounts” (C5), the expectation is significant growth (C4, CL1, O1, R1, SC1), noting “the interest of the installation of photovoltaic micro generators in the market and with consumers” (C3). In addition, C2 pointed out that, in order to predict the distributed generation of photovoltaic energy, “it is necessary to define several parameters, related to solar irradiation, power of installed modules, solar orientation and system area”. SC1 stated that the Solar Industry Program, created by the Federation of Industries of the State of Santa Catarina (FIESC) and the Federation of Industries of the State of Rio Grande do Sul (FIERGS), was created to encourage the growth of residential and industrial solar energy consumption. It began in September 2018 and provides residential and industrial generation kits with pre-defined powers and aims to promote a more modern, efficient, sustainable and competitive production sector in the region.

For the development and expansion of the photovoltaic sector, A1 pointed out that “amounts in research, development and innovation have been invested in panel and inverter improvement projects”, while C1 stated that “the concessionaire is creating an experimental photovoltaic plant to verify the behavior of the feeder in the face of the oscillations of that energy source”. The other concessionaires pointed out the largest investments in the energy sector for “loss control and energy efficiency projects” (C5, C6), “energy conservation” (C4), “fault detectors, inspection equipment and maintenance assistance, besides of electrical mobility” (C2). Since Brazil does not have an industrial policy

Table 1
Profile of respondents.

Code	Profile
A1	Bachelor of Business Administration, with 3 years of experience in photovoltaic energy generation. Currently, he is part of an association of companies and productive chains of the photovoltaic sector of the Southern region of Brazil.
C1	Electrical engineer at a large electricity distribution service concessionaire in the Southern region of Brazil. He currently works in the company's special projects sector.
C2	Electrical engineer for 6 years in a large electricity distribution service concessionaire in the Southern region of Brazil. He operates in the research and development, energy efficiency and planning of the company's electrical system.
C3	Electrical engineer for 1 year in a cooperative of electricity distribution of the Southern region of Brazil.
C4	Technical director of an electricity distribution concessionaire in Southern Brazil, where he has been working for 32 years.
C5	Commercial technical director of an electricity distribution company in the Southern region of Brazil, where he has been working for 30 years.
C6	Electrical engineer for 14 years in a distribution and commercialization concessionaire of electric energy in the Southern region of Brazil.
CL1	Client who installed the photovoltaic system in his company and residence for 3 years and intends to install in his rural property in Southern Brazil.
MG1	Member of the government, acting for 5 years as manager of energy planning, as well as Director of Innovations, Energy Sources and Mining of one of the states of the Southern region of Brazil.
O1	Owner of a metallurgical company located in Southern Brazil, providing solutions for 16 years in renewable energy through the installation of photovoltaic panels for homes, condominiums and companies.
R1	PhD in Electrical Engineering and researcher in the field of photovoltaic solar energy for 10 years at a federal university in the Southern region of Brazil.
SC1	Strategic consultant in the area of energy and infrastructure adviser of a federation linked to a state in the Southern region of Brazil, playing a crucial role in the development of the photovoltaic sector.

focused on distributed photovoltaic generation, R1 said that most of the research in the country focuses on the use and impact of this type of generation on the electricity system, and, in order to circumvent this factor, educational institutions are training human resources, promoting technological development and providing advanced technological services to the company as a way to acquire greater expertise in the field and contribute to the sector. Moreover, O1 stated that large investments have been earmarked for residential automation projects and optimization of the use of energy while it is generated, a factor that R1 said was a mandatory direction to solve problems related to energy storage, making possible the reduction of payback.

When asked about the main factors that limit the greater adoption of distributed photovoltaic power, A1 stated that “the biggest bottleneck is the financial issue, since the Brazilian is accustomed to financing”. In addition, there is a consumer cultural barrier, as well as the fact that universities, for example, carry out isolated research and development (R&D) projects in the photovoltaic sector with different approaches. Another major problem is the fact that people are putting installation systems on sale, without the presence of professionals and after-sales support, which may damage the image of PV system. CL1 corroborated this information, claiming that “the population's lack of money, the need for financing, convenience and cultural factors are limiting the greater adoption of photovoltaic technology.” C1 said that “in addition to financial factors and bureaucracies with municipal, state and federal governments in environmental issues and investment licensing, there is dependence on imports of photovoltaic cells from China, because, although there are Brazilian companies that manufacture these materials, the value does not pay. In addition, the panels have a useful life of approximately 20 years and photovoltaic generation gives a payback of about eight years if all goes well and if it does not spoil an inverter before. On the part of the concessionaire there are concerns regarding the load dispatch, considering that the photovoltaic source is quite oscillating".

In C2's view of the barriers to photovoltaic diffusion, “the technical unfeasibility of the residences is verified, since many of them do not have good solar orientation and the architecture of the roofs causes them to have shade in part of the day. In the area covered by the energy concessionaire, 40% of consumers who were willing to pay for the equipment had their requests denied by the concessionaire for issues such as roof orientation, roof size or shady parts”. For C3, C4 and C6, the main barriers are the investment value, time of return of investment, cost of implementation and cost of equipment, while for C5 ″there are ill-defined rules for implementation of the photovoltaic system, suppliers of photovoltaic accept to sell only the whole package (design, material and labor) and there are few financing options for the residential customer”. R1 pointed out that “the greatest technical barriers correspond to the intermittency and variability of solar generation, with the absence of local storage”. In addition, R1 highlighted as barriers the regulatory policy, technical developments and the need for a cultural change of the population of the Southern region of the country in the medium term. R1 and SC1 said that the distribution service utilization fee (TUSD) is another limiting factor for raising the cost to the consumer. The tariff is charged by the concessionaires and regulated by ANEEL, being a value to compensate the use of the system by customers who also generate their own energy and inject it into the grid.

When questioned about the energy scenario in Southern Brazil, MG1 commented that the government has expectations of expansion of the distributed generation market. Regarding the policies that regulate the photovoltaic sector, MG1 pointed out that one of the incentives for the adoption of photovoltaic solar energy is related to “the ICMS tax only on the net difference in energy consumed, as well as the exemption of this tax on operations with various equipment and components for the use of solar and wind energy”. ICMS is the Brazilian tax on operations related to the movement of goods and services [50]. Other government incentives refer to “exemption of environmental licensing for self-generation and distributed generation of electricity from solar sources” and to the facilitation of financing to residential and industrial customers through banks and development agencies. MG1 pointed out that a Solarimetric Atlas was published with detailed information on the solar radiation potential of the region, being a “fundamental tool to attract enterprises in the sector, to identify the potential of solar energy, to promote the knowledge inherent to the use of this energy source, in addition to generating a database for future ventures in the region".

4.2. Analysis of results

This topic analyzes the results obtained considering the interviews with professionals in the energy sector and the information obtained in the academic literature. Initially the panorama of the distributed generation of photovoltaic energy is presented, explaining the future expectation of its participation in the energy matrix of the Southern region of Brazil. In addition, we discussed the identified factors that limit the greater adoption and diffusion of photovoltaic technology in the region under the technical, economic, social, managerial and political dimensions.

4.2.1. Panorama of distributed generation of photovoltaic energy

From the point of view of the interviewees, there is a great expectation of growth of the distributed generation of photovoltaic energy, which currently represents approximately 83% of all sources of distributed generation in the Southern region of Brazil [19]. From 2011 to 2017, there was a high growth in the installed power of the technology. This growth may be associated with the S diffusion curve of innovations, where some more courageous investors have decided to rely on the new market conception, and gradually observing that the investment was positive for early investors, others are investing in this new technology, until in the future only a few will have resisted change.

Despite the significant growth, the number of units with distributed photovoltaic generation is still small, mainly when verifying the Brazilian potential of solar energy utilization and the way in which this source is used in other countries. In the Southern region of Brazil, only one in a thousand energy-consuming units, such as houses and commercial establishments, has photovoltaic panels installed, while in Australia one in five households has photovoltaic systems [51]. Fig. 4 presents the evolution of the participation of the distributed generation of photovoltaic energy in the energy matrix of Southern Brazil, taking into account data extracted from the portal of the National Electric Energy Agency [19] and of the National Energy Balances of Energy Research Company from 2012 to 2017 [13,52–56]. The figure shows the relation between the installed power of micro and mini photovoltaic generation and the total installed power of electricity over the period of time analyzed.

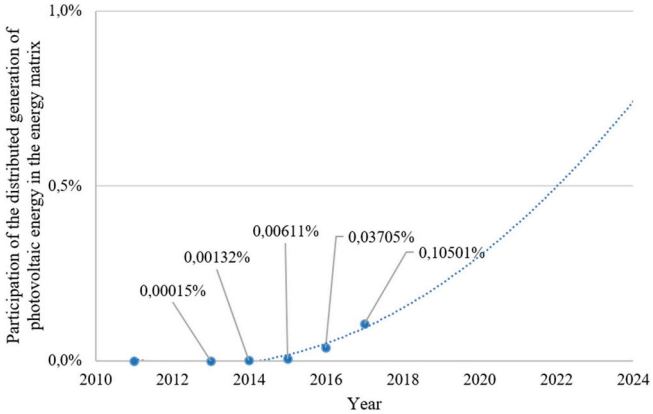

Fig. 4. Evolution of the participation of the distributed generation of photovoltaic energy in the energy matrix of the Southern region of Brazil.

Fig. 4 shows a growth in the share of distributed PV generation in the energy matrix of the Southern region of Brazil, pointing, through a trend line, to a representation of approximately 0.75% in 2024. A polynomial trend line was used, since it was the model that best fitted the data, with coefficient of determination of 0.9299. Although it corresponds to a small generation, it is highlighted that it is a significant participation, considering that the generation comes exclusively from residential and commercial units with small installed power. Moreover, as mentioned by the interviewees, the region studied has a unique relief, with large rivers that make the hydroelectric source predominant in the energy matrix, unlike countries such as Germany, whose lack of resources induces the need for several sources to obtain a significant amount of installed energy capacity [57].

Although there are incentives for the development of solar photovoltaic generation, the use of this source is still unexplored and underutilized, highlighting that there is much to be done to consolidate the energy matrix of the Southern region of Brazil. The systems connected to the photovoltaic grid have a great potential to assist in the diversification of the Brazilian energy matrix and in the reduction of dependence on hydroelectric resources, due to the favorable natural conditions that exist [12]. However, some barriers that hamper its widespread use are identified, as the next topics present. Thus, it is important that the Brazilian states are prepared and accumulate experience with photovoltaic solar energy in order to take full advantage of the benefits of this benign technology [58,59].

4.2.2. Barriers to the diffusion of distributed generation of photovoltaic energy

This topic describes the barriers to the adoption of the distributed generation of photovoltaic energy that have been identified. Limiting factors are grouped according to the previously introduced dimensions: technical, economic, social, managerial and political. Information obtained through the interviews is validated and complemented by data from the photovoltaic energy literature.

4.2.2.1. Technical dimension. Although photovoltaic technology has advanced significantly in recent decades [60], respondents reported that there are still several technical barriers to the diffusion of distributed generation of photovoltaic energy. Institutional sustainability requires technical standards and system durability [61], representing a limiting factor cited by the interviewees. Even though photovoltaic modules have a relatively long life cycle, system power can be significantly influenced by degradation phenomena that can reduce system efficiency [62]. To circumvent this barrier, the materials that can be used for the development of photovoltaic cells and modules must be analyzed in order to choose those with a longer shelf life [63].

It was identified that the quality of photovoltaic systems is fundamental for the adoption of this technology. This quality can be influenced not only by the local conditions of the user environment, but also by the political and financial arrangements that may change from country to country [22]. Ref. [63] stated that material defects are one of the major causes of failure of the device. These defects are potentiated by energy from high electric fields, high current densities, temperature increases and tensions at the interfaces of the material layer. For Ref. [31], the quality of the panels depends on the companies that work with the photovoltaic system and the care that the adopter has with the materials that make up this system. In addition, the panel energy depends on its efficiency, power, number of panels and solar resources. Moreover, end users need to understand how to manage the PV system carefully, understanding its limitations, and avoiding damaging solar panels and other component material, since many failures are caused by excessive power consumption or user negligence [39].

Another limiting factor to the diffusion of the distributed generation of photovoltaic energy in the Southern region of Brazil refers to the installations of systems realized without professional accompaniment. Lack of awareness of advanced technologies and disqualified manpower result in problems associated with the implementation and maintenance of renewable energy projects [64]. In addition, since these installations are carried out in areas already connected to the grid, a scenario of irresponsibility in the operation and maintenance of the technology has been identified, often done by inexperienced people, since customers have the option to use the electricity provided directly of the grid [22].

The execution of isolated R&D projects, with different approaches, was mentioned by the interviewees as a barrier to photovoltaic adoption. This evidence points to the need of a R&D strategy based on integrated planning and articulation of ongoing projects. Ref. [65] argued that the best distribution of R&D investments in the photovoltaic sector is geared towards the development of mature technologies such as crystalline silicon and thin film photovoltaic, since they are more likely to overcome bottlenecks and become competitive in terms of cost.

Other technical barriers cited by the interviewees are the oscillation of this energy source, poor solar orientation of the homes and roofs architecture. Sun exposure is a basic requirement for the proper functioning of photovoltaic systems, and panels exposed to the external environment result in an operation disturbed by variable climatic conditions, which can cause various types of faults that affect its normal operation and lead to a considerable loss of energy [66]. From the concessionaires' point of view, the oscillation of the photovoltaic source is cause for concern, since they are not prepared to receive large amounts of generation or to revert energy flows in circuits, without having to reinforce or invest in control and protection [12].

In addition, the architectural dimension of the areas is also an important factor to consider because the performance of solar collectors depends on their location and orientation, and panels need to be tilted in the right direction to maximize sun exposure [67]. In the Southern region of Brazil, the roof area available for installation of correctly oriented photovoltaic systems is 268.27 km^2 [68]. Ref. [22] states that, for urban areas, the surface for integration of photovoltaic panels on the roofs is very limited in old constructions. However, through public policies, it is possible to encourage the planning and design of new buildings with integrated photovoltaic systems in their structure to maximize the installation space.

4.2.2.2. Economic dimension. Initial cost of a photovoltaic system comprises high values of photovoltaic panels, mounting hardware, circuit breakers and cables, as well as the cost of labor, which is an important component of the total cost of the installation [67]. Although high initial investment costs represent the main obstacle to the large-scale deployment of photovoltaic systems, the cost of an innovation usually decreases with time, and in this case, specifically in Brazil, the deployment costs of photovoltaic solutions tend to annually decrease in the range of 3.3–6.5% until 2030 [6]. According to Ref. [69], a lower retail price for photovoltaic systems can increase the speed of potential investors to acquire them. This is corroborated by Ref. [2], which states that the costs associated with photovoltaic generation have been significantly reduced and this trend will be maintained over the years, leading to an increase in its competitiveness in the future.

The factor of long payback of the investment is an important barrier to the use of solar systems. Payback time is an economic measure used to evaluate the viability of an investment. It is the time of return of the initial investment up to the moment in which the accumulated gain equals the value of this investment. Considering the high costs for production and supply of solar photovoltaic electricity and low annual consumption in homes, the payback of the investment can be very long, making the use of photovoltaic energy not financially viable [67]. In Brazil, the average payback time is 7.06 years, while in the Southern region it is 8.5 years, since it presents a lower index of solar irradiation [70]. However, since raw material costs are expected to be reduced and systems production will grow, generating gains in scale, it is possible that the payback period will be lower in the coming years.

One barrier mentioned by the interviewees is the fact that the

Brazilian population is heavily dependent on financing for the purchase of photovoltaic systems. Even though the development of specific credit lines for the generation of solar energy is important for the expressive entry of this source into the Brazilian energy matrix, there are still no attractive financing lines available in all the states of the country [2]. Special financing conditions encourage a greater number of agents to invest in photovoltaic generation, since they allow a lower capital expenditure by the agent and a higher return on capital investment. This incentive measure is feasible for industry and commerce, but it needs to be extended to residential customers and the bureaucracy to obtain the benefit be reduced [12]. As mentioned by the member of the government in the interview, measures are already being taken to increase the benefit of financing the residential class, boosting the application of photovoltaic generation.

ICMS tax is another economic aspect limiting the adoption of photovoltaic technology, as it compromises the performance of local industries and hampers the advance of new businesses. Some Brazilian states have already adopted the ICMS exemption policy in order to increase the likelihood of photovoltaic investment becoming viable [71]. In addition, the distribution service utilization fee (TUSD) is seen as a barrier by the interviewees, since it consists of an additional amount determined by ANEEL to effect the monthly billing of users of the electricity distribution system, raising the cost to be paid by consumers for the energy surplus injected into the distribution grid [72]. It is therefore important for the governments and authorities of the energy sector of the Southern region of Brazil to come forward with incentives and subsidies that enable the adoption of the technology, so as to take advantage of its solar potential, converting it into benefits for the population [42,73].

4.2.2.3. Social dimension. The sociocultural context determines the extent to which a technology is adopted and depends on the community's ability to integrate photovoltaic generation into existing social structures [61]. Thus, consumer culture is seen as a negative influence on the diffusion of photovoltaic technology in Southern Brazil, since the population feels insecure about the reliability of this kind of electricity generation and is accommodated in receiving the electricity of the grid without having to make a great investment in PV system for this [74]. In addition, home and business culture is not heavily concerned with the environment and sustainable development [5].

The lack of adequate knowledge about photovoltaic technology is a crucial barrier, since potential adopters feel insecure about the performance of the technology and lack information relevant to their individual cases [22]. Ref. [44] argued that the fear of experiencing something new as a consequence of not having enough knowledge about it is a factor that prevents people from taking a step toward change. This highlighted the importance of dedicating efforts to carry out educational campaigns aiming to provide clear information to consumers on the environmental benefits of renewable energies, increasing their awareness. Ref. [69] point out that people with higher education levels make decisions about purchasing a photovoltaic system based on various information, and contacting specialists to identify advantages and disadvantages of the facility is effective in motivating them to generate their own energy.

The purchase of a photovoltaic system is a decision of high involvement, in which potential users usually invest substantial time and consideration before making a decision [75]. Due to the complexity of the decision, people find it difficult to obtain complete information on the subject, as there are several factors involved in the decision making process [76]. The difficulty in finding reliable information on microgeneration is therefore a major obstacle to adoption, particularly for those who consider PVs, despite the efforts of government and microgeneration interest groups to reduce this barrier [77,78].

4.2.2.4. Managerial dimension. Inadequate management can hinder innovation diffusion process in a variety of contexts. Weak or neglected after-sales service provided by companies, which installs photovoltaic systems is an important managerial barrier to the diffusion of technology in the Southern region of Brazil. As mentioned by the interviewees, there is a big problem regarding the existence of inexperienced people performing the installation of photovoltaic systems, aiming only the product sale, without offering adequate and reliable maintenance services. In view of the lack of information and knowledge of most adopters, a functional service is needed to continue the monitoring and maintenance of the systems. This represents a challenge for the costs and manpower to manage and ensure the sustainability of the system, and the problems with the service can jeopardize the quality generation [22].

Another limiting aspect to the adoption of photovoltaic technology is related to negative publicity and ineffective marketing approaches. For example, a lack of adequate knowledge among adopters and inexperienced installers of systems can result in improper use and inability to maintain efficient operation, creating a negative perception and preventing potential customers from making the decision to adopt systems [79]. Ref. [80] argued that information and knowledge, through effective marketing approaches and educational campaigns, are more likely to accelerate the energy conservation and diffusion behavior of renewable technologies.

4.2.2.5. Political dimension. Due to the high prices of equipment and installations, photovoltaic systems are generally not profitable without the support of policies in several countries. Thus, government actions to facilitate the business creation process in this segment are of vital importance for the rapid diffusion of this innovation [12]. However, the political instability that exists in Brazil, resulting from cases of corruption by special interests and inadequate social and economic benefits, can lead to the poor performance of the electricity sector, due to practical restrictions in the period to carry out electricity reforms.

As can be seen in countries such as Nepal [81], whose corruption index due to political instability is similar to that of Brazil [82], any reform that extends beyond government life becomes politically infeasible and postpones the progress of the reform as a whole.

In recent years, few new energy policies or programs have been created in Brazil, most of which are focused on biodiesel and ethanol. The program that encompasses solar and wind energy sources is seen by the market as bureaucratic, superficial and hostile to the deployment of new technologies [6]. Ref. [46] clarify the importance of strong political support at the national, regional or local levels through softened bureaucratic application procedures, goal setting and development planning, so that distributed generation of photovoltaic energy is widespread more quickly.

In view of the high prices of photovoltaic systems, incentive mechanisms are needed to be used on a large scale. High production of such equipment in Brazil would be a major advance for the photovoltaic sector, but this requires political measures to be able to compete with other countries on equal terms. Tax exemptions and reduced loans are incentives that must be adjusted at the federal and state levels to promote the adoption of solar systems [12]. For Ref. [10], although the National Bank for Economic and Social Development (BNDES) offers attractive financing options for large companies, it does not benefit small consumers. In this way, the government could promote a greater incentive to the PV micro generation, so that people perceive financial advantage and the benefits of the technology.

Lack of well-defined rules for the implementation of photovoltaic systems was another barrier to the diffusion of technology in Southern Brazil. This factor points to the need of strategies and political plans for the development of the renewable energy sector, establishing clear guidelines for the planning, development and execution of a project of distributed generation of photovoltaic energy [65]. For Ref. [83], a well-defined plan is needed to quantify the benefits of its implementation, including the economic and environmental benefits of

achieving targets set by a solar program.

For the generation of electric energy in the configuration of micro and mini distributed generation, it is necessary to have the photovoltaic module and the inverter, which converts the electric power from direct current to alternating current and equalizes frequency, voltage and current with the electric grid. However, since domestic production is still not sufficient for the market, these two devices are usually imported from China, representing a limiting factor to the greater adoption of photovoltaic technology. Strategically, state and federal government policymakers should seek ways to encourage local production of essential components of the photovoltaic system so that the country can gain independence from imported technologies and incorporate into its market the whole production cycle, research and personal experience [57]. This information is corroborated by Ref. [2], who states that the development of the domestic market allows the country to participate in some stage of the value chain of a high value-added industry in the world. In addition, Brazil has raw materials and industries that can be adapted for the production of components for photovoltaic systems. Thus, the strengthening of local industry can reduce costs and boost the participation of this energy source in the national electricity matrix.

Although the international market for photovoltaic components is extremely competitive [2], Ref. [84] says that Brazil has the potential to develop the entire production chain through governmental policies, techno-economic initiatives, an opening and competitive market activity and the national industry development with technology adaptation to meet national conditions. Even if China represents the gravitational center of global manufacturing of photovoltaic components, the interconnected characteristics of the industry must be dialectically identified as cooperation and competition. Brazil is favored by international research and development of solar panels, and its industry will initially begin as an element of a transnational chain of photovoltaic energy manufacturing. By overcoming fiscal obstacles and relatively higher production costs, Brazil may no longer be subordinate and dependent on global photovoltaic circuits to become a strategic and potentially competitive location [85].

Normative Resolution 482/2012, published by ANEEL, established the general conditions for access to micro and mini distributed generation and regulates its net measurement. In addition, it defines that an electric energy compensation system allows micro and mini generation owners to receive credits for the active energy generated in addition to the user's consumption. These credits are valid 60 months after the billing date and there is no payment for the energy injected into the distribution network [16]. However, this incentive is not strong enough to boost distributed generation of photovoltaic energy, representing a limiting factor to its adoption. This reflects the fact that distribution concessionaires are not prepared to accommodate large amounts of generation [12].

Based on the above mentioned results of the observations and factors that compromise the greater diffusion of distributed generation of photovoltaic energy, the findings are summarized in Table 2. This table presents a summary of the results analyzed and shows the barriers identified and measures to overcome them within each one of the studied dimensions, being: technical, economic, social, managerial and political.

Based on the literature review of the distributed PV and on the qualitative study conducted with professionals from electric power concessionaires, associations of photovoltaic companies, entrepreneurs, policy makers, academic researcher and user of photovoltaic systems, it was possible to verify that the barriers are evident for emerging economies such as Brazil, Bangladesh and Nepal, as well as for developed countries such as Germany, the USA and China [22]. Although barriers must be assessed in a particular context, in relation to a similar country or region, they are commonly encompassed in five interrelated dimensions: technical, economic, social, managerial and political.

Brazil, compared to European and Asian countries with higher installed capacity, presents greater obstacles to the adoption of photovoltaic technology, since it is still incipient in the culture of implantation of solar energy systems [20]. This fact points to the need to create specific programs to encourage the research and development of this important source of renewable energy, diversifying the national energy matrix and reducing environmental impacts.

5. Conclusions

Even though many studies claim that photovoltaic systems are sufficiently developed to compete with other conventional energy sources [1,8], this research showed that there are still several barriers that prevent the wider adoption and diffusion of this technology. Based on a qualitative approach, this research investigated the growth of the photovoltaic sector in the Southern region of Brazil and the factors limiting its expansion. The study was performed using semi-structured interviews conducted with professionals from large and small electricity distribution service concessionaires, responsible by an association of companies and productive chains of the sector, academic researcher, client, PV provider, member of the government, and consultant in the area of energy of the region. Thus, for distributed PV generation the present research confirms an existing pattern, since several barriers mentioned by the interviewees were identified by diverse studies around the world and specifically in Brazil. It provides new structured insights about the evolution of the participation of the distributed generation of photovoltaic energy in the energy matrix of the region under study and supplies future growth expectations, discussing and structuring the determining factors for the adoption of technology in the technical, economic, social, managerial and political dimensions.

Through information obtained from the interviewees and in the literature, it was possible to verify that, although the Southern region of Brazil is at the beginning of the adoption of the solar PV technology, there is an expectation of growth of this kind of distributed generation. In 2017, the number of photovoltaic systems connected to the grid corresponded to approximately 0.1% of all distributed generation sources, representing a 766-fold increase compared to 2011. According to the trend line, it is expected that in 2024 the installed capacity reaches 285 MWp (Mega Watt Peak), which would represent 0.75% of all the electricity generated. These are small numbers and clearly much remains to be done for photovoltaic energy to develop and consolidate in the energy matrix of Southern Brazil. However, to modify the trend line it is necessary to understand the main factors that limit the adoption of photovoltaic technology and to devise a strategic plan together with the state and federal governments oriented to overcome the barriers and help in the growth of this sustainable energy technology.

From the technical point of view, the major concerns are the durability and quality of photovoltaic systems, since the materials are subject to degradation phenomena, which reduces the efficiency of the system. In the economic dimension, the cost of the initial investment is generally perceived as high and represents the main obstacle to the deployment of large-scale photovoltaic systems. Moreover, the access of the Southern Brazil population for financing for the purchase of panels is pointed out as another limiting factor for the diffusion of the technology, requiring special incentives to boost photovoltaic generation.

In the social context, consumer culture and the lack of adequate knowledge about photovoltaic technology are presented as crucial barriers, indicating the importance of conducting educational campaigns that provide information on the benefits of this energy source. From the management point of view, there are problems related to inefficient after-sales services and negative publicity due to the lack of experience of system installers. In the political dimension, the dependence on imports of panels from China, the political instability in Brazil

Table 2
Barriers to the adoption of distributed generation of photovoltaic energy and measures to overcome them.

Dimension	Barriers to distributed PV generation	Measures to overcome the barriers
Technical	Low durability of the photovoltaic system	Materials that can be used for the development of photovoltaic cells and modules must be analyzed to choose those with a longer shelf life
	Poor quality of photovoltaic system	Encourage cooperation between business, university and government for the development of quality photovoltaic materials and systems
	Installations without professional support	Conduct of audits by a supervisory body
	Implementation of isolated R&D projects with different approaches	Implement a R&D strategy that is based on integrated planning and articulates ongoing projects
	Oscillating nature of the photovoltaic source	Concessionaires should invest in grid control and protection to receive larger generation amounts or to reverse energy flows in circuits
	Poor solar orientation of homes and roof architecture	Install hybrid power generation systems, combining another energy source with distributed PV generation
Economic	High cost of materials and installation	Lower retail price for photovoltaic systems can increase the speed of potential investors to acquire them
	Long payback	Reduce raw material costs, increase production of systems and seek solutions for the storage of generated energy
	Dependence of financing to purchase the photovoltaic system	Special financing conditions should be created for residential customers to boost photovoltaic generation
	Tax on the circulation of goods and services (ICMS)	Governments and authorities of the energy sector of Southern Brazil should come forward with incentives and subsidies that enable the adoption of the PV technology, such as ICMS exemption
	Distribution service utilization fee (TUSD)	Optimize the customer consumption curve to match as much as possible with the photovoltaic generation curve
Social	Consumer culture weakly engaged with PV systems	Carry out educational campaigns to provide clear information to consumers about the environmental benefits of renewable energy
	Lack of knowledge about photovoltaic technology	
Managerial	Weak or neglected after-sales service provided by companies installing photovoltaic systems	Companies must provide a functional service to continue monitoring and maintaining systems
	Ineffective marketing approaches and negative publicity	Create effective marketing approaches and educational campaigns to convey information and knowledge about photovoltaic systems
Political	Political instability	Propose legislation that will perpetuate the support and incentive to photovoltaic generation independent of governmental management
	Excessive bureaucracy	Reduce bureaucracy for deployment of PV systems to be more rapidly diffused
	Lack of incentive policies for photovoltaic generation	The government should promote incentives for the PV sector at the federal and state levels, such as tax exemptions and reduced loans
	Lack of well-defined rules for the implementation of photovoltaic systems	Create strategies and policy plans for the development of the renewable energy sector, establishing clear guidelines for the planning, development and execution of a PV project
	Dependence on the import of panels from China	State and federal government policymakers should encourage local production of essential components of the photovoltaic system so that the country can gain independence from imported technologies
	Deficiency in energy compensation systems	Create complementary resolution to encourage greater adoption of photovoltaic systems

and the lack of attractive mechanisms and incentives for consumers are highlighted, pointing to the need for the government to define plans for the development of the renewable energy sector.

Results indicate the need to create a collaborative environment, with the involvement of companies from the photovoltaic sector, government, financial institutions, researchers and community. Such collaboration is necessary to overcome existing barriers, allowing distributed generation of photovoltaic energy to become a technology present in Southern Brazil. This may reduce the environmental impacts associated with climate change and dependence on fossil fuels while taking advantage of the conditions favorable to the capture of solar energy in the country. It is worth noting that this study was conducted in Southern Brazil, but we believe many of the findings are relevant for underdeveloped countries or for regions of developed countries where the presence of solar panels is still incipient.

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Appendix A.1Questionnaire for associations and entrepreneurs in the sector of distributed generation of photovoltaic energy in the Southern region of Brazil (English version)

1. Overview of photovoltaic distributed generation in the state of the organization
   - 1.1. Photovoltaic energy corresponds to which part of the distributed generation in the state? What is the installed capacity of this type of energy today?
   - 1.2. What is the organization's expectation regarding the generation of photovoltaic energy for the coming years?
   - 1.3. Which factors limit the greater adoption of distributed generation of photovoltaic energy?
   - 1.4. Are there forecast models of distributed generation of photovoltaic energy?
     - 1.4.1. Which factors should be taken into account when forecasting the distributed generation of photovoltaic energy?
   - 1.5. How does the system of compensation of the concessionaire for residential, business and industrial generating units by the surplus electric energy inserted in the network by means of distributed generation occurs?
   - 1.6. From what consumption does it become feasible to install photovoltaic panels in residential, business and industrial units?
   - 1.7. What is the cost of deploying a photovoltaic kit in residential, business and industrial units?
   - 1.8. How has the cost of deploying photovoltaic kits evolved?

1.9. What is the forecast of reducing the cost of implementation in the coming years?
1.10. In the photovoltaic sector, for which projects are the largest investments in research, development and innovation destined?
2. Identification
2.1. Name of organization
2.2. State where the organization is located
2.3. Respondent's role in the organization
2.4. How long have you been working in the organization?

Appendix A.2Questionnaire for concessionaires and cooperatives of generation and distribution of electric energy of the Southern region of Brazil (English version)

1. Overview of the energy matrix of the organization's scope of state
1.1. What is the composition of the state's energy matrix?
1.2. What is the state's annual growth rate of energy consumption?
1.3. Is there forecast growth for any specific source of energy generation? If so, what is the source and why?
1.4. Why can there be instability in the energy that the consumer receives from the grid?
1.5. Could distributed generation be a solution to lessen the instability of the energy distribution?
1.6. Currently, what is the main source of distributed power generation in the state?
1.7. For which energy projects are destined the largest investments in research, development and innovation of the organization?
2. Overview of photovoltaic energy generation in the state of the organization
2.1. Photovoltaic energy corresponds to which part of the distributed generation in the state? What is the installed capacity of this type of energy today?
2.2. What is the organization's expectation regarding the generation of photovoltaic energy for the coming years?
2.3. Which factors limit the greater adoption of distributed generation of photovoltaic energy?
2.4. Does the organization have a forecast model for the supply of electricity?
2.4.1. Does the organization have a forecast model of distributed generation of photovoltaic energy?
2.4.2. Which factors should be taken into account when forecasting the distributed generation of photovoltaic energy?
2.5. How does the system of compensation of the concessionaire for residential, business and industrial generating units by the surplus electric energy inserted in the network by means of distributed generation occurs?
3. Identification
3.1. Name of organization
3.2. State where the organization is located
3.3. Respondent's role in the organization
3.4. How long have you been working in the organization?

Appendix A.3Questionnaire for client who installed photovoltaic energy system in the Southern region of Brazil (English version)

1. Overview of photovoltaic distributed generation
1.1. How long have you acquired the photovoltaic system?
1.2. What did motivate you to install the system?
1.3. How satisfied are you with the installed system?
1.4. What is your expectation regarding the generation of photovoltaic energy for the next years?
1.5. Which factors limit the greater adoption of distributed generation of photovoltaic energy?
2. Identification
2.1. Name
2.2. State where the system is installed

Appendix A.4Questionnaire for the member of the government in the Southern region of Brazil (English version)

1. Overview of photovoltaic distributed generation in Southern region of Brazil
1.1. What is your expectation regarding the generation of photovoltaic energy for the next years?
1.2. Which policies encourage and regulate the photovoltaic energy sector in the region?
1.3. Is there any funding to encourage the adoption of distributed generation of photovoltaic energy?
1.4. Is there any strategic study that brings information to help the expansion of the photovoltaic sector?
2. Identification
2.1. Name
2.2. Respondent's role in the government
2.3. How long have you been working in the government?

Appendix A.5Questionnaire for photovoltaic provider, academic researcher and strategic consultant of photovoltaic energy in the Southern region of Brazil (English version)

1. Overview of photovoltaic distributed generation in Southern region of Brazil
1.1. What is your expectation regarding the generation of photovoltaic energy for the next years?
1.2. Which factors limit the greater adoption of distributed generation of photovoltaic energy?
1.3. How can these barriers be overcome?
1.4. What is the biggest motivation of customers to install the system?
1.5. In the photovoltaic sector, for which projects are the largest investments in research, development and innovation destined?
1.6. How can universities and companies foster the development of the photovoltaic sector?
1.7. Is there any program that encourages the adoption of photovoltaic technology in the southern region of Brazil?
2. Identification
2.1. Name
2.2. Respondent's role in the organization
2.3. How long have you been working in the sector?

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