Identification and ranking of barriers to the development of the photovoltaic market in Brazil

Identificação e ranking de barreiras para o desenvolvimento do mercado fotovoltaico no Brasil

Identificación y ranking de barreras para el desarrollo del mercado fotovoltaico en Brasil

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Abstract

In Brazil, photovoltaic energy represents only 2.7% of the electric matrix (EPE, 2019), despite high levels of solar radiation, high residential tariffs and lower photovoltaic panel prices. This low amount characterizes this kind of generation as unexplored and underutilized in the country. Therefore, in this study, an extensive bibliographic review was conducted and interactions with stakeholders were carried out aiming to identify barriers that are hindering the expansion of the photovoltaic market in Brazil. The Analytic Hierarchy Process (AHP) method was applied to classify these barriers. The 42 barriers found were classified into six categories: socio-cultural, environmental, technical, economic, market, and political-governmental. The results indicated that the economic and political-governmental are the most relevant categories of barriers. The lack of paying capacity, removal of incentives and difficulty in accessing credit were the most impactful barriers. A sensitivity analysis revealed that the removal of incentives would become a strong barrier if small changes occurred in the current situation. The adoption of the Feed-in tariff and the development of business models are measures that could improve the current scenario.

This study provides information that helps decision-makers on how to act to boost the growth of photovoltaic generation in Brazil.
Keywords: Analytic Hierarchy Process (AHP). Barriers. Photovoltaic Systems.

Resumo

No Brasil, a energia fotovoltaica representa apenas 2,7% da matriz elétrica (EPE, 2019), apesar dos altos níveis de radiação solar, das altas tarifas residenciais e dos menores preços dos painéis fotovoltaicos. Esse baixo valor caracteriza esse tipo de geração como inexplorado e subutilizado no país. Portanto, neste estudo, foi realizada uma extensa revisão bibliográfica, além de interações com as partes interessadas com o objetivo de identificar as barreiras que estão dificultando a expansão do mercado fotovoltaico no Brasil. O método Analytic Hierarchy Process (AHP) foi aplicado para classificar esses gargalos. Os 42 gargalos encontrados foram classificados em seis categorias: socioculturais, ambientais, técnicos, econômicos, mercadológicos e político-governamentais. Os resultados indicaram que as categorias de gargalos econômicos e político-governamentais são as mais relevantes. A falta de capacidade de pagamento, a retirada de incentivos e a dificuldade de acesso ao crédito foram os gargalos mais impactantes. Uma análise de sensibilidade revelou que a remoção de incentivos se tornaria uma forte barreira se pequenas mudanças ocorressem na situação atual. A adoção da tarifa feed-in e o desenvolvimento de modelos de negócios são medidas que podem melhorar o cenário atual. O estudo traz informações que auxiliam os tomadores de decisão sobre como agir para impulsionar o crescimento da geração fotovoltaica no Brasil.
Palavras-chave: Processo de Hierarquia Analítica (PHA). Gargalos. Sistemas Fotovoltaicos.

Resumen

En Brasil, la energía fotovoltaica representa solo el 2,7% de la matriz eléctrica (EPE, 2019), aunque hay altos niveles de radiación solar, las altas tarifas residenciales y los menores precios de los paneles fotovoltaicos. Esa baja cantidad caracteriza a este tipo de generación como inexplorada y subutilizada en el país. Por ello, en este estudio se realizó una extensa revisión bibliográfica y se realizaron interacciones con los grupos de interés con el objetivo de identificar las barreras que obstaculizan la expansión del mercado fotovoltaico en Brasil. Se aplicó el método Analytic Hierarchy Process (AHP) para clasificar estas barreras. Las 42 barreras encontradas se clasificaron en seis categorías: socioculturales, ambientales, técnicas, económicas, de mercado y político-gubernamentales. Los resultados indicaron que lo económico y político-gubernamental son las categorías de barreras más relevantes. La falta de capacidad de pago, la eliminación de incentivos y la dificultad para acceder al crédito fueron las barreras de mayor impacto. Un análisis de sensibilidad reveló que la eliminación de incentivos se convertiría en una fuerte barrera si se produjeran pequeños cambios en la situación actual. La adopción de la tarifa feed-in y el desarrollo de modelos de negocio son medidas que podrían mejorar el escenario actual. Este estudio proporciona información que ayuda a los tomadores de decisiones sobre cómo actuar para impulsar el crecimiento de la generación fotovoltaica en Brasil.
Palabras clave: Proceso de Jerarquía Analítica (PJA). Barreras. Sistemas Fotovoltaicos.

Introduction

The increase in the demand for electricity, driven by populational growth and technological and industrial development, in addition to environmental issues and the potential depletion of fossil fuels used for the production of electricity, has encouraged the use of renewable generation sources. In this context, photovoltaic (PV) generation has become increasingly competitive, mainly due to the reduction in the production costs of the equipment used (RAMOS; RUIZ; RABASSA, 2018). Consequently, this type of generation has grown sharply and contributed to the decline of greenhouse gas (GHG) emissions and the creation of jobs (ONU, 2015).

In Brazil, photovoltaic energy represents only 2.7% of the electric matrix, despite high levels of solar radiation, high residential tariffs and lower photovoltaic panel prices (EPE, 2019). Currently, the installed capacity of PV solar energy in Brazil is 4.94 GW, of which 2.26 GW is from micro and mini distributed generation (PVDG) (ANEEL; ABSOLAR, 2020). As highlighted by (DE FARIA; TRIGOSO; CAVALCANTI, 2017), this low amount of solar energy characterizes this kind of generation as unexploited and underutilized.

Given the benefits and trends favorable to PV energy generation in Brazil and the low number of installed systems, there is a need for studies aimed at identifying obstacles that hinder the growth of this type of energy source. According to (PRASAD; KIM, 2018), these obstacles can be identified through bibliographic reviews of the literature and by interacting with stakeholders (manufacturers, suppliers, installers, consumers, and the government). It should be emphasized that the literature review is an essential tool to obtain reliable information on the constraints to the expansion of this technology.

Some studies have assessed the opportunities and barriers to the development of renewable energies in the world by means of a literature review (EDOMAH, 2016; SEN; GANGULY, 2017; YAQOOT; DIWAN; KANDPAL, 2016). Sen and Ganguly (2017) discussed global investment needs, investment strategies for the power sector, and actions to accelerate the transition to a sustainable energy future. The appropriate mix of instruments is even more important where energy infrastructure is not yet developed. Yaqoot, Diwan, and Kandpal (2016) identified barriers to the dissemination of decentralized renewable energy systems and presented recommendations to mitigate them, such as long-term conducive policies, financial incentives and withdrawal of subsidies presently being given to fossil fuels. Edomah (2016) investigated the main problems of renewable energy in Nigeria, subdividing them into cost, regulatory and market barriers. The author also highlighted certain key policies that could help solve these problems.

On the other hand, several studies have focused on identifying the current barriers hindering the diffusion of PV systems (BAWAKYILLENUO, 2012; KARAKAYA; SRIWANNAWIT, 2015; ZHANG; SHEN; CHAN, 2012). Karakaya and Sriwannawit (2015) presented a state-of-the-art review to identify the current barriers hindering the diffusion of PV systems. The study considered publications from 28 countries and found that barriers are not exclusive to developing countries. According to the authors, the United States of America, Austria, Canada, and South Korea are examples of countries facing difficulties in adopting PV systems. They concluded that the involvement of all stakeholders is crucial to foster the adoption of PV systems. Zhang (2012) identified the main obstacles linked to the development of solar photovoltaic energy systems in Hong Kong. The authors also presented recommendations to address barriers such as financial support and training services from the Government, provision of incentives to various stakeholders and the designing of specific legislation. Bawakyillenuo (2012) compared the barriers and different stages of solar energy consolidation in Ghana, Kenya, and Zimbabwe using the Social Construction of Technology (SCOT) theory. The authors recommended the steps that Ghana needs to follow to achieve the success of Kenya and Zimbabwe, such as the introduction of a Feed-in Tariff and assurance of a long-term political stability (BAWAKYILLENUO, 2012).

Certain studies used the Analytic Hierarchy Process (AHP) to rank barriers to renewable energies worldwide (LUTHRA et al., 2015; PRASAD; KIM, 2018; PUNIA; NEHRA; LUTHRA, 2016) The results presented by Prassad (2018) and Luthra (2015) showed that the economic and political barrier categories were the most important in Nepal, and the ecological and geographical barrier categories were reported as the most important in India. Punia et al. (2016) were more specific and focused the study only on solar generation technologies and consequently reached different results. They identified and prioritized the barriers to solar energy in India using the AHP method. The study showed that "Political and Regulatory Barriers" were the most influential. A sensitivity analysis was performed to examine the challenge ranking stability faced by solar industry. Some recommendations for the eradication of the barriers were also suggested. Sindhu et al. (2016) used the Interpretive Structural Modeling (ISM) method integrated with Fuzzy MICMAC (Matrix Cross-Impact-Multiplication Applied to Classification) to identify the inter-relationship between the barriers to solar energy in the rural sector of India and to rank them. Marketing and policy barriers emerged as independent barriers which need to be addressed.

Concerning Brazil, only one study was found that addressed barriers to distributed PV generation. This paper covered the Southern region of the country, and the authors did not rank the barriers found (GARLET *et al.*, 2019). There is thus a lack of studies on the identification and ranking of barriers involving all regions in Brazil.

Considering the aforementioned aspects, it is possible to conclude that no studies have assessed the identification and ranking of barriers involving all regions in Brazil. In this regard, this work aims to identify the barriers hindering the PV market's expansion in Brazil and rank them using the AHP method. Barriers are identified by i) reviews of studies carried out in several countries, ii) an assessment of the current national scenario (technical reports and resolutions), and by iii) interactions with stakeholders. Additionally, a sensitivity analysis is conducted to evaluate the impact of changes in the weights of the most impacting categories on the overall ranking of barriers. This type of study allows the detailed evaluation of each barrier linked to the source of solar PV generation. In addition, the proposed study presents some recommendations that can significantly impact the development of the PV market in Brazil, thus contributing to the growth of this type of generation source in the country.

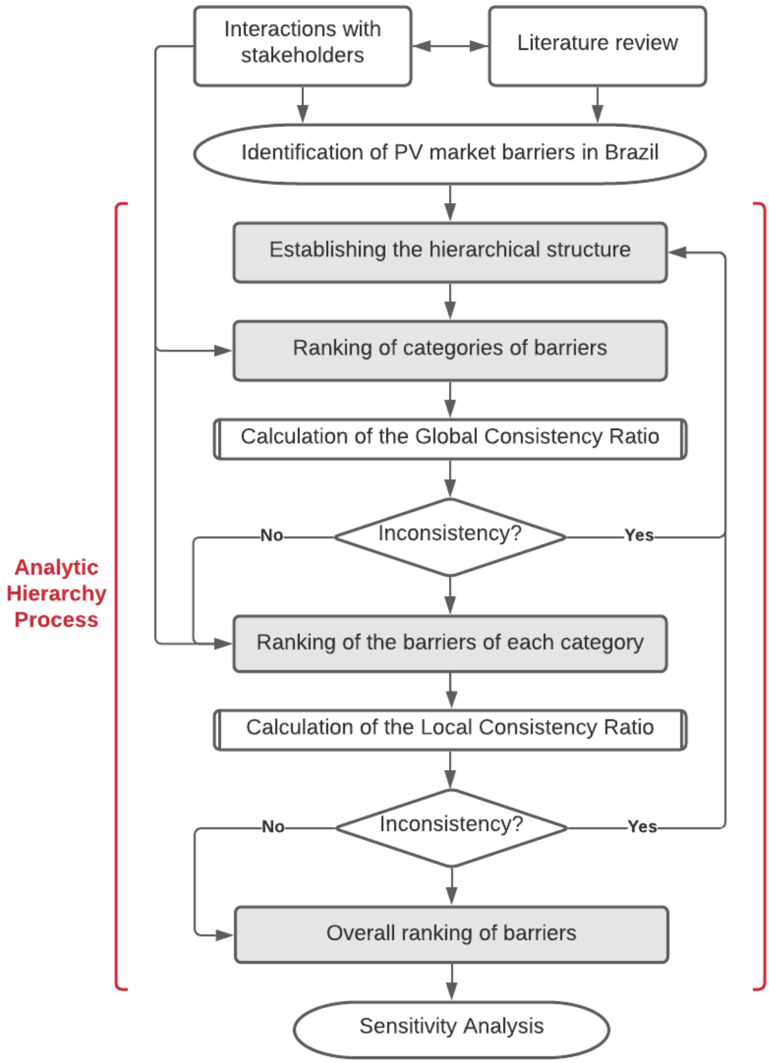

Figure 1 - Flowchart of the methodology to identify and rank the barriers to the PV market in Brazil.

In the next section, the methodology employed is presented, including details on the steps followed in AHP method. The results obtained and their assessment are then presented. Finally, the paper's conclusions are discussed.

Methodology

In this section, the methodology used to identify and rank the barriers to the PV market in Brazil is structured in the flowchart in Figure 1. Then, the 4 steps of Saaty methodology are presented. Finally, a sensitivity analysis is suggested.

In Figure 1, it is possible to observe that the methodology begins with a literature review and with interaction with stakeholders regarding obstacles that are hindering the development of the PV market in Brazil. These interactions were made through questionnaires which were sent by email and completed by experts. Participants compared categories and barriers in pairs. From the analysis of the results of these two actions, it is possible to identify the existing barriers.

The AHP method is then employed to classify the barriers found. The application of this method consists of 4 steps, as described below (SAATY; VARGAS, 2001).

In this first step, the process is broken down into three strategic levels to facilitate its visualization. The first level is represented by the purpose of the decision. The second level consists of the categories into which the alternatives are classified. The third level contains the alternatives (barriers) that should be prioritized (SAATY; VARGAS, 2001).

The second step is ranking categories of barriers. With the hierarchical structure established, experts from the university, industry and government are required to make comparisons between the defined categories. In this way, it is possible to identify the most impactful barriers from the perspective of each sector. These comparisons are made in pairs, assigning weights ranging from 1 to 9 to the categories (SAATY, 2000). Then, the terms of the pair comparison matrix are obtained by applying the geometric mean of the evaluation of each specialist (SAATY, 2000). The Auto Vectors (AV) of this matrix are then calculated and normalized to obtain the global priority weighting (LU*THRA et al*, 2015; PRASAD; KIM, 2018; PUNIA; NEHRA; LUTHRA, 2016).

To test the consistency of each specialist's assessment, the Global Consistency Ratio (CR_G) is calculated according to Equation 1.

$$CR_G = \frac{(\lambda_{max} - D)}{(D-1) * RI} \quad (1)$$

Where: λmax is the consistency vector resulting from the multiplication between the sum memories of the columns and the priority weightings; D is the order of the pair comparison matrix; and RI is the random index, which varies according to the order of the matrix (N), as shown in Table 1 (SAATY, 2000).

The maximum acceptable value of Consistency Ratio is 10%. In this study, it was considered that values higher than 10% indicate the existence of inconsistencies in judgments, as suggested by Saaty (SAATY, 2000). In this case, the process needs to be reviewed.

Table 1 – The possible values of RI (Random Index).

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

In this step 3, for each group, the experts compare the barriers with each other, assigning weights from 1 to 9. The pair comparison matrix, as well as the values of AV, local priority weighting, and Local Consistency Ratio (CR_L) are calculated as in the procedure presented in Step 2.

With the results obtained from steps 2 and 3, it is possible to find the overall ranking of barriers determined in step 4, i.e., the overall weight of barriers. This weight is obtained by multiplying the global priority weighting and the local priority weighting. The most impactful barriers are the ones with the highest overall weight values.

The classifications of barriers in different categories and the relative weights adopted are based on the individual judgments of the experts collected in the questionnaire, which may be inaccurate. Therefore, a sensitivity analysis is proposed to evaluate how the change in the weight of each criterion impacts the final result. In this study, the weight of the most impactful category varies between 0.1 and 0.9 (SAATY; VARGAS, 2001).

Results

In this section, the barriers found with the literature review and the interactions with stakeholders are distributed in the categories. Then, the barriers are classified according to the AHP method. Finally, the results of the sensitivity analysis are presented.

Categorization of Barriers

The application of the AHP method begins with the structuring the problem into hierarchies. From the literature review and interactions with stakeholders, 42 barriers that prevent the development of the PV market in Brazil were identified. Most of these barriers are common in most countries and others are specific to Brazil. These barriers were distributed into six different categories: sociocultural, economic, technical, environmental, market, and political-governmental. Figure 2 presents the hierarchical structure of the barriers hindering the expansion of the PV market in Brazil.

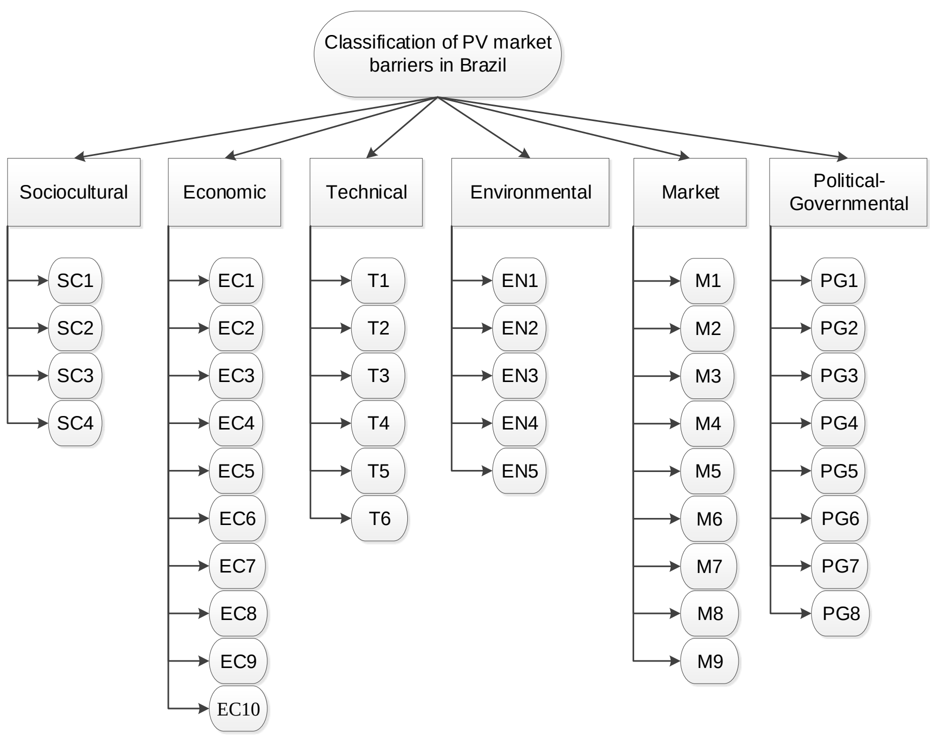

Figure 1 - Hierarchical structure of the barriers to the PV market in Brazil.

Figure 2 shows that of the 42 obstacles which prevent the development of the PV mar-ket in Brazil, four are sociocultural (SC), ten economic (EC), six technical (T), five environmental (EN), nine market (M) and eight political-governmental (PG). In the sequence, these barriers are presented by categories.

Sociocultural barriers

The preference for traditional sources and the lack of social acceptance (SC1) are cha-racterized as a socio-cultural barrier that prevents the dissemination of alternative sources. Several authors cite resistance to change and society's inertia as factors that are difficult to overcome. Changes in behavior patterns can take decades to materialize (PRASAD; KIM, 2018; PUNIA; NEHRA; LUTHRA, 2016; STRUPEIT; PALM, 2016; YAQOOT; DIWAN; KANDPAL, 2016).

Lack of awareness of technology (SC2) among consumers adopting this source may result in improper use and the inability to maintain these systems. This creates a nega-tive perception and makes new accessions difficult. Also, potential consumers who are unaware of the benefits of using solar energy will not make this investment. Sindhu, Nehra, and Luthra (2016) cite consumer awareness as the biggest challenge to the ex-pansion of solar energy (CARSTENS; CUNHA, 2019; EDOMAH, 2016; GARLET et al., 2019; RAI; BECK, 2015; RAI; ROBINSON, 2013; SAMPAIO; GONZÁLEZ, 2017; SEN; GANGULY, 2017; SINDHU; NEHRA; LUTHRA, 2016).

The perception of the high initial cost (SC3) of PV systems is also a significant chal-lenge. Even with the guaranteed economic viability, some consumers fail to invest be-cause they consider the cost high. However, this perception is relative and may be lo-wered when solar panels are installed during the construction of buildings (KARA-KAYA; SRIWANNAWIT, 2015; KOINEGG et al., 2013; STRUPEIT; PALM, 2016; YAQOOT; DIWAN; KANDPAL, 2016).

According to a survey by the Organization for Economic Cooperation and Deve-lopment (OECD), Brazil ranks 27th of 30 countries evaluated in the financial educa-tion item. The data show that only 30% of the population are active savers, a better ra-te only than Hungary. According to this survey, the lack of financial education (SC4) results in the absence of planning and conscious consumption and reduces the financial security of Brazilians. This scenario is not favorable to the adoption of sustainable technologies (CARSTENS; CUNHA, 2019; PUNIA; NEHRA; LUTHRA, 2016; RIBEI-RO, 2016).

Economic barriers

Costs linked to innovations often decrease over time and vary by location. The prices of operating and maintaining renewable energy are low when compared to fossil fuel sources. However, the high initial cost (EC1) is the most cited economic barrier in the literature (GARL*ET et al*., 2019; KARAKAYA; SRIWANNAWIT, 2015; PUNIA; NEHRA; LUTHRA, 2016; SINDHU; NEHRA; LUTHRA, 2016).

In addition to the high initial cost, the foreign exchange risk (EC2) also impacts the return on investment and may make it less attractive. The increase in investment resulting from this variation is not entirely passed on to the client, after all, service costs such as sales, installation and projects do not fluctuate with exchange rate variation (GREENER, 2019).

The increase in the use of solar energy depends on the cost of other energy sources available in the region. According to (YAQOOT; DIWAN; KANDPAL, 2016), competition with traditional energy sources (EC3), which have consolidated structure and policies to encourage them, constitutes a barrier. The lower the price of electricity generation from these conventional sources, the higher the difficulty of expanding the use of alternative sources, as they are not financially attractive.

A country's economic moment is also decisive in the development of new technologies. A study in Greece showed that in times of economic downturn (EC4), the amount of medium and long-term financing and investment is reduced. Moreover, the shrinking economy generates a decrease in electricity consumption and, as a result, the reduction of interest in adhering to solar PV generation (KARTERIS; PAPADOPOULOS, 2013).

Several studies mention the lack of paying capacity (EC5) of the population, the high payback period (EC6) (GARLET *et al*., 2019), the lack of access to credit (EC7), and the high cost of capital (EC8) as decisive barriers to the evolution of installed solar PV generation (BAWAKYILLENUO, 2012; CNI, 2019; EDOMAH, 2016; FMI, 2017; HANSEN; PEDERSEN; NYGAARD, 2015; JANNUZZI; DE MELO, 2013; KARAKAYA; SRIWANNAWIT, 2015; KARTERIS; PAPADOPOULOS, 2013; MOVILLA; MIGUEL; BLÁZQUEZ,

2013; PRASAD; KIM, 2018; PUNIA; NEHRA; LUTHRA, 2016; YAQOOT; DIWAN; KANDPAL, 2016; ZHANG; SHEN; CHAN, 2012).

The availability cost (EC9), which is the minimum tariff charged for having electricity available to the consumer, is also a barrier to the development of the mentioned technology (ANEEL, 2010). Even if consumers are self-sufficient, they cannot zero their bills with the generation of solar energy, because there is a mandatory grid availability cost to be paid. Around the world, the cost of using the grid is the second factor that most influences electricity tariffs, representing, on average, 33% of the final fare, behind only the cost of generation (CASTRO *et al*, 2015).

The model of taxation of the energy generated (EC10) is considered unfair by managers and consumers since it taxes not only the portion of energy absorbed from the electricity grid but the total energy consumed (CONFAZ, 2013), (VIEIRA; SHAYANI; DE OLIVEIRA, 2016).

Technical barriers

Several studies indicate that high penetration of PVDG can provoke technical impacts on the electricity grid (T1), such as reduction in energy quality, the emergence of reverse flow, deviations in the nominal frequency of the system (GARL*ET et al*>, 2019; PUNIA; NEHRA; LUTHRA, 2016) and reduction in supply reliability (ATHARI; WANG; EYLAS, 2017; KADIR; KHATIB; ELMENREICH, 2014).

Inadequate construction architecture (T2) may also be a relevant barrier. Roofs with shadows of neighboring buildings, issues related to insufficient tilting and targeting, as well as the lack of available space on existing structures can reduce the efficiency of panels and even make it impossible to install PV systems (GARLET *et al*>, 2019; YAQOOT; DIWAN; KANDPAL, 2016; ZHANG; SHEN; CHAN, 2012).

The low efficiency of PV systems (T3) is also highlighted as an obstacle. Today, most solar panels are between 15% and 20% efficient. Panels built using advanced ‘Interdigitated back contact’ or IBC cells are the most efficient and can exceed 22% (CER, 2021). Increases in temperature, dirt on the surface of the panels, and the voltage drop in the connecting wires and protective diodes cause losses, further reducing the efficiency of the generation (CARVALHO, 2012; SINDHU; NEHRA; LUTHRA, 2016).

The lack of skilled manpower (T4) impacts the speed of expansion of this technology in the country. Some articles also highlight the absence of training institutes and courses (BAWAKYILLENUO, 2012; CARSTENS; CUNHA, 2019; GARLET *et al*, 2019; HANSEN; PEDERSEN; NYGAARD, 2015; ONDRACZEK, 2013).

Also concerning technical capacity, the incipient exchange of knowledge between researchers and legislators (T5) hinders the elaboration of effective laws and incentives that may contribute significantly to the development of the technology in question (PUNIA; NEHRA; LUTHRA, 2016).

The difficulty in collecting data (T6) regarding the portion of the energy consumed instantly at the distributed generation units is a barrier, since the two-way meters installed in the country collect only the energy injected and the consumption of the grid. The energy injected is the difference between the energy produced and the energy consumed instantly by the prosumer. The absence of this information can impact statistics and also the planning and operation of the system (ANEEL, 2018; DE FARIA; TRIGOSO; CAVALCANTI, 2017).

Environmental Barriers

One of the most significant advantages of solar PV energy is the absence of polluting emissions during its operation. However, it is crucial to evaluate the composition of the energy matrix of the solar panel producing country, as it has a direct impact on greenhouse gas (GHG) emission levels. China is the largest producer of solar panels since 2007. In this country, 79% of energy matrix is comprised of coal, implying higher amounts of GHG emissions in PV equipment manufacturing (EN1) as this process requires energy that, in this case, it is fossil and emits pollutants (ADRIANO, 2015; TSOUTSOS; FRANTZESKAKI; GEKAS, 2005).

The first phase of PV panel production is the extraction of silica, abundant both in Brazil and worldwide. However, large-scale production can affect the availability of certain raw materials (EN2), such as silver. Solar photovoltaics are the fastest growing electricity source. In 2020, around 139 GW of global capacity was added, bringing the total to about 760 GW and producing almost 3% of the world's electricity (BP, 2021). According to (ADRIANO, 2015), to meet 5% of the world's demand for electricity through PV systems, it would be necessary to use about 1/3 of the global silver production.

To increase the efficiency of solar PV generation, photovoltaic cells must be strategically placed. Such placement causes a visual impact (EN3) and represents an obstacle since most panels are not considered aesthetically appropriate. This obstacle is even more relevant in historic buildings, where rooftops and facades are listed as historical heritage and cannot be modified and covered (SÁNCHEZ-PANTOJA; VIDAL; PASTOR, 2018; TSOUTSOS; FRANTZESKAKI; GEKAS, 2005).

At the end of the life of PV systems, it is expected that 80% of their components can be recycled. However, the encapsulation of the panels makes it difficult to remove the silicon wafers and may cause recycling difficulties and improper disposal (EN4). Non-recycled materials are disposed of in dumps and landfills (ADRIANO, 2015; TSOUTSOS; FRANTZESKAKI; GEKAS, 2005).

According to (BEZERRA; LIRA; SILVA, 2018), PV equipment causes marine and freshwater ecotoxicity (EN5), freshwater eutrophication, and human toxicity. That is due to the use of large amounts of heavy metals and compounds such as SO_2, CO_2, particulate matter, and volatile organics. The characterization factor for ecotoxicity takes into account environmental persistence (destination), accumulation in the food chain (exposure) and the toxicity of a chemical (effect).

Market barriers

Due to the reduction of the utility power market (M1) resulting from the increase in the number of consumers who generate electricity, utilities do not feel favored by the growth in the number of PV systems connected to the electricity grid. As a result, they tend not to stimulate this type of generation (ANEEL, 2018).

The decrease in revenue arising from this market reduction affects consumers who have not yet installed PV systems. The fixed costs of providing the network with quality requirements for all costumers remains. The part of this fixed cost not paid by prosumers is redistributed among all clients, increasing tariffs (M2) (ANEEL, 2018; CABELLO; POMPERMAYER, 2013).

It is also worth highlighting market uncertainties (M3), since discussions about possible changes in Brazilian regulations may culminate in the removal of the incentives currently granted. These uncertainties discourage new investments in the short term (DE FARIA; TRIGOSO; CAVALCANTI, 2017; KOLOSZUK; SAUAIA, 2018; SINDHU; NEHRA; LUTHRA, 2016).

The lack of definition and clarity of business models (M4) regulated in Brazil represents a barrier that hinders the mass adoption of PV systems. In addition to the existing technical challenges, innovative, sustainable, and fair business models for renewables fail in some cases due to corruption and shortcomings in legal frameworks (SINDHU; NEHRA; LUTHRA, 2016; STRUPEIT; PALM, 2016). To overcome this barrier, business model options that address a large number of situations with standardized and rapidly deployable solutions should be available.

The low quality of the services (M5), especially in regions far from large metropolises, is also characterized as a barrier to the development of the PV market. The companies responsible for the installation of PV systems must provide continuous monitoring and maintenance services to ensure the life of the equipment. However, the costs involved in providing these services are high, which may make them impossible. Utilities are also responsible for most complaints involving the quality of services, especially non-compliance with legal deadlines (MATTAR, 2014).

The lack of diversification and differentiation of the products offered (M6) to consumers in the solar energy market is also an obstacle. Studies reveal that sufficient and appropriate business strategies for each region are essential to accelerate the growth of the number of PV systems in specific markets, such as low-income consumers (KOINEGG *et al.*, 2013; STRUPEIT; PALM, 2016).

The gap between civil construction and photovoltaic generation companies (M7) can hinder market growth, as happened in Austria. As well as in Japan, new structures in the state of California - USA are being built with PV systems, in accordance with the bill of the Assembly Bill 178 (KOINEGG *et al>*, 2013; SEN; GANGULY, 2017; STRUPEIT; PALM, 2016).

The existence of monopoly in the energy sector (M8) can be considered a barrier that prevents the advance of the PV market. With few participating agents, the system becomes highly centralized, reducing the need to develop technologies and to provide quality services, in addition to increasing the amount charged to the consumer (SEN; GANGULY, 2017).

The inefficiency of marketing strategies and educational campaigns (M9) is an obstacle to the growth of the PV market. In this sense, efforts should be made seeking to propagate information related to investments in PV systems and their environmental, social, and economic benefits. In addition, the existence of incentive policy should be announced. Otherwise, the lack of awareness regarding this technology will not be overcome (GARLET *et al*>, 2019; ISLAM; MEADE, 2013; MIAN, 2015).

Political-Governmental barriers

The lack of political commitment (PG1) is highlighted as a barrier for the development of renewable energies. A strong political will is paramount to face the already established system, overcome inertia, and boost solar PV generation (KEELEY; MATSUMOTO, 2018; SINDHU; NEHRA; LUTHRA, 2016).

Corruption (PG2) is also listed among the barriers to the advance of renewable energies, worldwide. Some authors warn that carelessness of public funds and corruption can cause delays in public policy approval and implementation procedures aimed at the PV market. (PRASAD; KIM, 2018).

There are several cases currently in the Brazilian courts involving state tax incentives that have not yet been tried. If they are declared unconstitutional, consumers lose the right to ICMS exemptions. Also, they may be charged for back unpaid taxes. This scenario generates legal uncertainty (PG3), which is considered a barrier to solar energy (CASTILHO; PIMENTEL, 2017).

The lack of incentives to the national industry (PG4) for the production and assembly of the components of PV systems is a significant barrier in Brazil. Because of this, the great majority of PV system components employed in the country are imported from China. Several countries have taken measures to stimulate the growth of the national PV industry, such as China itself and Sri Lanka, which reduced domestic tariffs from 30% to 10% (GARLET *et al*>, 2019; SINDHU; NEHRA; LUTHRA, 2016).

Political instability (PG5) is also an obstacle that affects investor and consumer confidence, hampering spending and postponing new installations of solar PV generation systems (BAWAKYILLENUO, 2012; GARLET *et al*., 2019; PRASAD; KIM, 2018; PUNIA; NEHRA; LUTHRA, 2016).

Lack of adequate government policies (PG6) makes PV systems less attractive. Thus, it is impossible to expand this type of technology rapidly. It was found that in regions where funding was an incentive policy there was faster growth in solar energy accessions than in those providing only credits in kWh (SARZYNSKI; LARRIEU; SHRIMALI, 2012). In Brazil, the current incentive is a net metering system (JANNUZZI; DE MELO, 2013; MIAN, 2015).

On the other hand, nations that have already succeeded in the spread of solar energy have begun the removal of incentives (PG7). Such removals is characterized as a barrier that negatively impacts the renewable energy market, as occurred in Germany in 2008, and in Italy in 2013 (DINER, 2011; EDOMAH, 2016; HANSEN; PEDERSEN; NYGAARD, 2015; KUMAR SAHU, 2015; LUTHRA *et al*., 2015; MIAN, 2015; MOVILLA; MIGUEL; BLÁZQUEZ, 2013).

In the Brazilian resolution that deals with distributed generation, there is a prohibition of the sale of surplus energy generated (PG8) (ANEEL, 2015). As a result, it is not economically feasible to create more power than is consumed. Because of this, consumers are discouraged to invest in larger-scale plants.

Application of the AHP Method

In this section, the results of the ranking of the barriers that hinder the PV market advancement in Brazil are shown. In this study, 27 invited experts were able to answer a questionnaire, 1/3 from the university, 1/3 from industry and 1/3 from the government.

Ranking of categories of barriers

Table 2 presents the global priority weighting values and the ranking of the categories of barriers obtained from the application of step 2 of the AHP method.

Table 2 – Ranking of the categories of the barriers to the implementation of solar PV energy in Brazil.

Category of barriers	Global priority weighting	Rank
Economic	35.51%	**1st**
Political-Governmental	31.09%	**2nd**
Market	12.81%	**3rd**
Technical	8.57%	**4th**
Sociocultural	7.68%	**5th**
Environmental	**4.34%**	**6th**

Table 2 shows that the economic barrier category (35.51%) was the most significant, followed by the political-governmental category (31.09%). The environmental category (4.34%) ranked 6th in the table. This means that the impacts of this category are not decisive when consumers decide to install solar PV generation, according to the experts who participated in the survey.

Classification of barriers in each category

Tables 3 shows the local priority weighting values and the ranking of the socio-cultural, economic, technical, environmental, market and political-governmental categories. The classification of the barriers in each group was obtained by applying step 3 of the AHP method.

Table 3 – Ranking of barriers in socio-cultural category.

Category	Barriers	Local priority weighting	Rank
Socio-cultural	Lack of financial education	40.79%	1st
	Perception of the high initial cost	38.34%	2nd
	Lack of awareness of technology	15.25%	3rd
	Preference for traditional sources and the lack of social acceptance	5.63%	4th

Economic	Lack of paying capacity	20.63%	1st
	Lack of access to credit	15.68%	2nd
	High payback period	12.60%	3rd
	High cost of capital	12.51%	4th
	High initial cost	11.48%	5th
	Economic downturn	9.11%	6th
	Taxation of the energy generated	6.48%	7th
	Foreign exchange risk	4.19%	8th
	Competition with traditional energy sources	4.06%	9th
	Availability cost	3.26%	10th
Technical	Lack of skilled manpower	23.46%	1st
	Incipient exchange of knowledge between researchers and legislators	23.28%	2nd
	Low efficiency of PV systems	20.32%	3rd
	Inadequate construction architecture	14.65%	4th
	Technical impacts on the electricity grid	11.23%	5th
	Difficulty in collecting data	7.05%	6th
Environmental	GHG emissions in PV equipment manufacturing	35.42%	1st
	Availability of certain raw materials	21.35%	2nd
	Difficulties in recycling and improper disposal	20.40%	3rd
	Ecotoxicity	14.46%	4th
	Visual impact	8.36%	5th
Market	Market uncertainties	23.09%	1st
	Reduction of the utility power market	19.11%	2nd
	Increase in tariffs	16.23%	3rd
	Inefficiency of marketing strategies and educational campaigns	9.42%	4th
	Lack of definition and clarity of business models	8.36%	5th

	Low quality of the services	6.75%	6th
	Gap between civil construction and photovoltaic generation companies	6.51%	7th
	Lack of diversification and differentiation of the products offered	5.56%	8th
	Monopoly in the energy sector	4.99%	9th
Political-governmental	Removal of incentives	19.25%	1st
	Lack of adequate government policies	17.14%	2nd
	Prohibition of the sale of surplus energy generated	15.50%	3rd
	Lack of political commitment	13.89%	4th
	Lack of incentives to the national industry	13.60%	5th
	Political instability	8.88%	6th
	Legal uncertainty	7.64%	7th
	Corruption	4.09%	8th

Table 3 shows that lack of financial education (40.79%) is the most impactful in the sociocultural category, followed by the perception of the high initial cost (38.34%).

The lack of paying capacity (20.63%) is the most significant in the economic category, followed by the lack of access to credit (15.68%). The most impactful barriers in technical category are lack of skilled manpower (23.46%) and incipient exchange of knowledge between researchers and legislators (23.28%). It is possible to observe that GHG emissions in PV equipment manufacturing (35.42%) are the most relevant environmental barrier, followed by availability of certain raw materials (21.35%). The market uncertainties (23.09%) are the leading barrier in market category. The reduction of the utility power market (19.11%) is considered the second most significant obstacle.

Table 3 also shows that the difference between the top ranked political-governmental barrier, removal of incentives (19.14%), and the fifth, lack of incentive to national industry (13.60%), is only 5.65%. This shows that there are many impacting barriers in this category.

Construction of the overall ranking of barriers

Table 4 shows the global and local weights values and the overall ranking of barriers. The barriers identified as the most impactful are in the economic and political-governmental categories.

Table 4 - The priority weighting and ranking of barriers to adopting solar energy.

Categories of barriers	Global weights of dimension	Barriers to adopting solar photovoltaic energy in Brazil	Local weight of barriers	Overall weight of barriers	Overall ranking of barriers
Socio-cultural	7.68%	Lack of financial education	40.79%	3.13%	12th
		Perception of the high tial cost	38.34%	2.95%	14th
		Lack of awareness of technology	1525%	1.17%	29th
		Preference for traditional sources and the lack of social acceptance	5.63%	0.43%	41st
Economic	35.51%	Lack of paying capacity	20.63%	7.32%	1st
		Lack of access to credit	15.68%	5.57%	3rd
		High paybak period	12.60%	4.47%	6th
		High cost of capital	12.51%	4.44%	7th
		High initial cost	11.48%	4.08%	10th
		Economic downturn	9.11%	3.24%	11th
		Taxation of the energy generated	6.48%	2.30%	18th
		Foreign exchange risk	4.19%	1.49%	24th
		Competition with traditional energy sources	4.06%	1.44%	25th
		Availability cost	3.26%	1.16%	30th
Technical	8.57%	Lack of skilled manpower	23.46%	2.01%	20th
		Incipient exchange of knowledge between researchers and legislators	23.28%	1.99%	21st
		Low efficiency of PV systems	20.32%	1.74%	22nd
		Inadequate construction architecture	14.65%	1.26%	27th
		Technical impacts on the electricity grid	11.23%	0.96%	32nd

		Difficulty in collecting data	7.05%	0.60%	40th
Environmental	4.34%	GHG emissions in PV equipment manufacturing	35.42%	1.54%	23rd
		Availability of certain raw materials	21.35%	0.93%	33rd
		Difficulties in recycling and improper disposal	20.40%	0.89%	34th
		Ecotoxicity	14.46%	0.63%	39th
		Visual impact	8.36%	0.36%	42nd
Market	12.81%	Market uncertainties	23.09%	2.96%	13th
		Reduction of the utility power market	19.11%	2.45%	16th
		Increase in tariffs	16.23%	2.08%	19th
		Inefficiency of marketing strategies and educational campaigns	9.42%	1.21%	28th
		Lack of definition and clarity of business models	8.36%	1.07%	31st
		Low quality of the services	6.75%	0.86%	35th
		Gap between civil construction and photovoltaic generation companies	6.51%	0.83%	36th
		Lack of diversification and differentiation of the products offered	5.56%	0.71%	37th
		Lack of competition	4.99%	0.64%	38th
Political-Governmental	31.09%	Removal of incentives	19.25%	5.99%	2nd
		Lack of adequate government policies	17.14%	5.33%	4th
		Prohibition of the sale of surplus energy generated	15.50%	4.82%	5th
		Lack of political commitment	13.89%	4.32%	8th
		Lack of incentives to the national industry	13.60%	4.23%	9th
		Political instability	8.88%	2.76%	15th
		Legal uncertainty	7.64%	2.38%	17th
		Corruption	4.09%	1.27%	26th

Sensitivity analysis

In this analysis, the global priority weighting of the economic category, which is the most impactful among the six under evaluation, varied from 0.1 to 0.9. Figure 3 illustrate the position of each barrier in the overall ranking according to the weight attributed to the economic category.

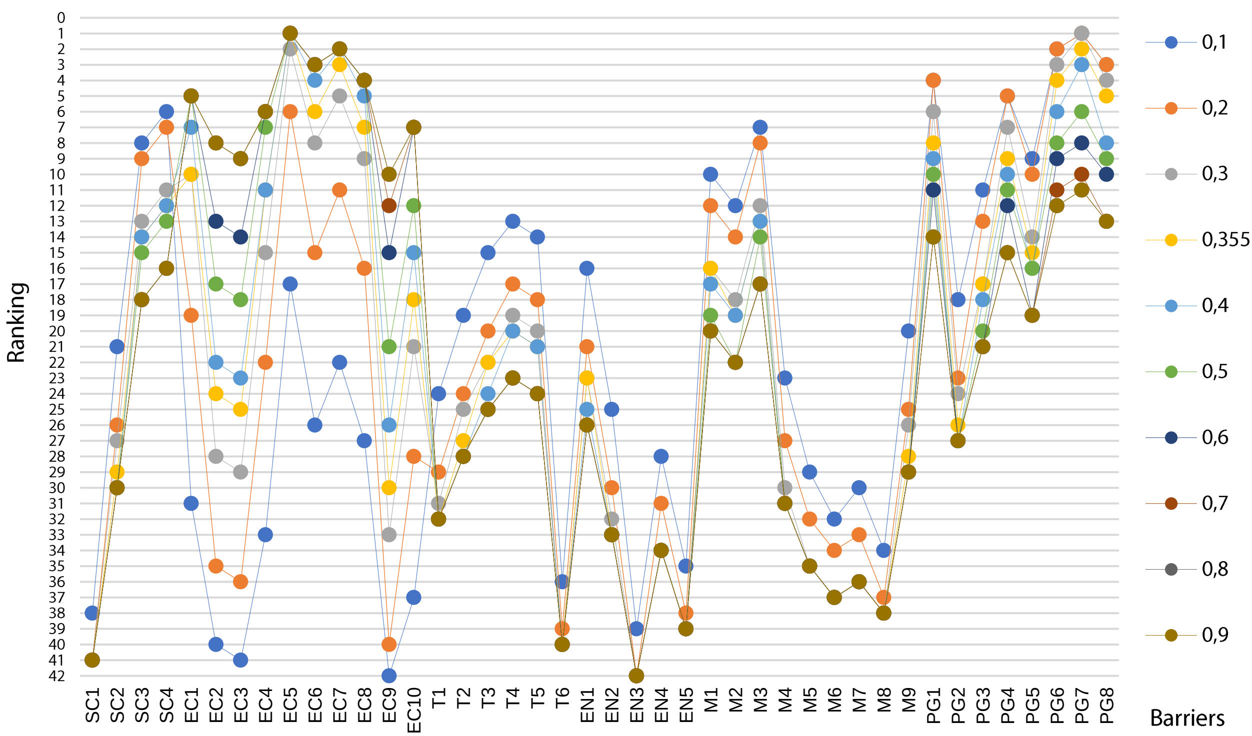

Figure 3 - Sensitivity analysis of barriers of the PV market in Brazil.

In Figure 3, it is possible to verify that with the variation of the global priority weighting from 0.1 to 0.9 of the economic category, the barrier <u>lack of paying capacity</u> (E5) remains the most important if the weight of the economic category is greater than or equal to its original value (35.51%). When the weight of this category is reduced from 35.51% to 30%, said barrier then ranks second, behind the <u>removal of incentives</u> (PG7).

Conclusions

In this work, we carried out a review of the literature, analyzed Brazilian standards and regulations, and interacted with experts from the university, industry, and government to identify and classify barriers hindering the expansion of the Brazilian PV market. By applying the AHP method, the six categories found were ranked. The barriers belonging to each group were ranked in order of importance. Then, an overall ranking of the 42 identified barriers was performed. The ranking of barriers help address the most significant obstacles to solar PV generation development in Brazil. Finally, a sensitivity analysis was executed to evaluate the impact of the weight change of the most impacting category on the overall ranking of barriers.

From the ranking process, it can be concluded that the economic and political-governmental categories are the most relevant in this order. The lack of paying capacity (E5), the removal of incentives (PG7) and the lack of access to credit (E7) are the most impactful barriers in the overall ranking. All the top ten are economic or political-governmental barriers.

From the sensitivity analysis, it was possible to conclude that the variation in the weight of the economic category produces changes in the overall ranking of barriers. It is worth noting that with the reduction of the weight of this category, the barrier removal of incentives (PG7) became the most impactful in the ranking.

In possession of the results of this study, it is possible to identify certain recommendations that can significantly impact the development of the PV market in Brazil. The first is that the government plays a crucial role in this process. It must promote a robust political articulation and be active in all areas. The Federal and State governments can reduce tariffs on equipment, installation, and assembly. At the municipal level, local governments can encourage new adhesions through partial deductions in the Urban Property Tax, benefiting consumers who install PV systems. In this regard other measures that have proved effective in several countries could be highlighted: the possibility of implementing the Feed-in Tariff, the dissemination of funding, and the escalation of new business models adapted to the Brazilian reality.

This study provides information which may help decision and policy makers to make effective and efficient decisions on where resources should be allocated to drive the growth of solar PV distributed generation in Brazil. This paper could be a guide for the study of solar photovoltaic generation barriers worldwide.

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