BARRIERS TO EXPAND SOLAR PHOTOVOLTAIC ENERGY IN BRAZIL

Jamerson Viegas Queiroz
Universidade Federal do Rio Grande do Norte, Brazil
E-mail: viegasqueiroz@gmail.com

Kilvia Kalidja Borges
Universidade Federal do Rio Grande do Norte, Brazil
E-mail: kilviakalidja@hotmail.com

Fernanda Cristina Barbosa Pereira Queiroz
Universidade Federal do Rio Grande do Norte, Brazil
E-mail: fernandacbpereira@gmail.com

Nilton Cesar Lima
Universidade Federal de Uberlândia, Brazil
E-mail: cesarlim@yahoo.com

Christian Luiz da Silva
Universidade Tecnológica Federal do Paraná
E-mail: christianlsilva76@gmail.com

Liziane de Souza Morais
Universidade Federal do Rio Grande do Norte
E-mail: lizianemorais@hotmail.com.br

ABSTRACT

Renewable energy has promoted increasingly diffused propulsions in political, social and organizational environments because of their relevance to future climatic conditions and restrictions on natural resources that threaten environmental impacts. Brazil has enormous potential to exploit renewable energy, especially photovoltaic solar energy, since it has a daily solar incidence of between 4,500 Wh/m2 and 6,300 Wh/m2. However, the development of this energy in Brazil faces barriers that end up hindering its implementation and expansion. The objective of the research is to identify and measure the impact of these barriers to the expansion of photovoltaic solar energy in Brazil, through the modeling of structural equations. For the development of the article, interviews with managers of the solar energy sector were carried out all over the country.

2733

As for the methodology, it's an exploratory research, cross-sectional and with a qualitative-quantitative approach. Moreover, concluded that: political and knowledge barriers negatively influence the implementation and expansion of photovoltaic solar energy in Brazil.

Keywords: Renewable Energy; Photovoltaics; Energy Barriers; Solar Energy

1. INTRODUCTION

Currently there are several types of primary energy source, and fossil fuel is still the most widely used resource, according to the International Energy Agency. However, the use of fossil fuels causes many environmental impacts, contributing to global warming, acid rain formation, air pollution, and other environmental pollution (ZHANG et al., 2012).

The worldwide expansion of photovoltaic solar energy in 2016 represented 165 GW. The evolutionary history is significant, in 08 years (from 1999 to 2007) it grew 10 times, went from 1 GW to 10 GW. Growth was better still in the following years, growing 10 times in just 05 years (from 2008 to 2012), from 10 GW to 100 GW (ABSOLAR, 2018).

This accelerated growth occurred mainly in China, the USA, Africa, Latin America, the Middle East and India. Highlighting the US growth that seeks to replace Japan as the third largest producer. Overall corporate finance reached a mark of $ 23.5 billion in 2015 (KABIR et al., 2018).

In Brazil, although there are already advances in renewable energy with several wind farms and micro generation of solar energy, the country still presents great obstacles in the development of new sources of renewable energy, and this means that its energy matrix is still dependent on hydroelectric sources, which although renewable, suffers from the scarcity of rainfall and thermoelectric plants that complement the energy supply (MENDES et al., 2016).

Several factors in Brazil have been revealing the understanding that the demand for electricity in the country will increase significantly. Justifications are based on the demographic, sectorial and macroeconomic assumptions, together with self-production and energy efficiency, which are of great importance in determining the dynamics of electric energy consumption, with direct implication in the behavior of several market indicators (EPE, 2017).

Given the context presented, solar energy has been one of the alternatives for expanding renewable energies in Brazil, diversifying the country's energy production and avoiding this extreme dependence on hydroelectric and thermoelectric energies. Brazil is abundant in solar

rays and its use generates many benefits, since the solar energy can be transformed for several purposes like system of electric power generation, heating and cooling, among others.

In this sense, it's necessary to understand the incentive mechanisms for the development and expansion of solar energy in Brazil. For this to occur, it's important to preliminarily assess the barriers that prevent the expansion of photovoltaic solar energy. In this way, this article aims to identify and measure the impact of the barriers (Techniques, Policies, Financial, Environmental, Social, Cultural and Behavioral, Knowledge) in the expansion of photovoltaic solar energy in Brazil.

This research is justified because it allows to understand the influence of the barriers that prevent the implantation and expansion of solar energy in Brazil, blocking the growth of this renewable energy so important for the environment and sustainably supplying an uninterrupted projection in the country. This work is structured in three large sections: firstly, it presents the literature with the main highlights on photovoltaic solar energy and barriers.

Second, the research hypotheses and the respective conceptual model are presented, where the methodological outline adopted to reach the objective previously exposed is presented. Finally, the results and conclusions obtained through the modeling of structural equations are shown, where it's possible to quantify the barriers that impede the implementation and expansion of solar energy in Brazil.

2. RENEWABLE ENERGY

Energy is one of the primordial elements to sustain human life, its activities and necessities, such as transportation, civil and operational constructions, domestic activities, leisure, manufacturing and production among many other purposes and importance. There are several types of primary energy sources, however fossil fuels are still the most important and currently used (ZHANG et al., 2012). Approximately 80% of the primary energy supply comes from fossil fuels (JOHANSSON; THOLLANDER, 2018).

Although countries around the world are dependent on non-renewable energy, it's noted that renewable energy has gradually gained space and importance not only in the micro vision, but also in the global vision, since it's a clean and sustainable energy. Graph 1 shows this reality.

2735
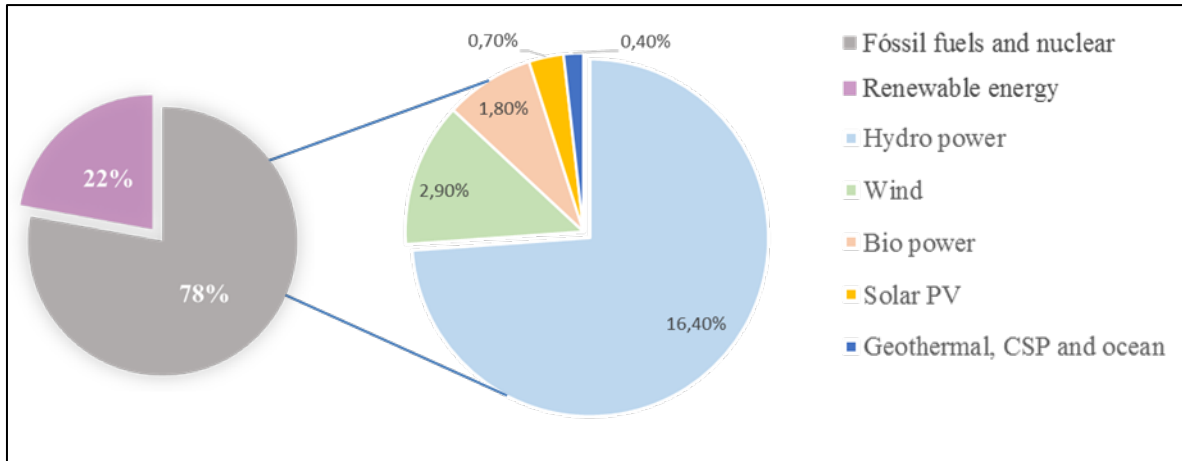
Graph 1: Global electricity production
Source: Kannan and Vakeesan (2016)

There are many countries that encourage and invest in the growth of this energy sector. For example, some countries such as Germany, Japan and the United States, despite not having the best sunrays and best winds, invest and create opportunities for further development of this segment (STRUPEIT; PALM, 2016).

Global investments in renewable energy technology have been surpassing each year; Graph 2 shows this growth and the comparison between developed and developing countries.
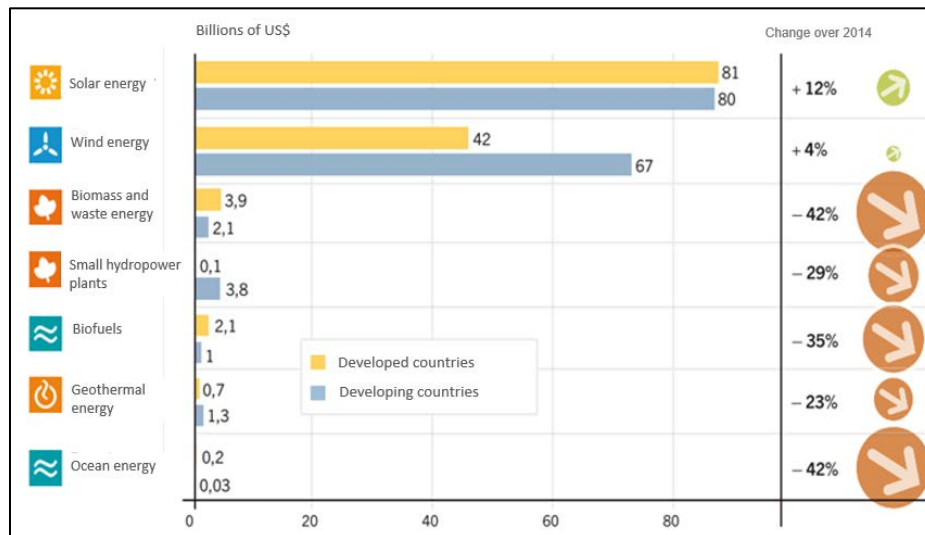
Graph 2: New global investments in renewable energy by technology
Source: Energias Renováveis (2016)

It can be noticed that solar and wind energy presents a great differential of growth in relation to the others. Showing a percentage growth of 12% and 4%, respectively, in relation to the previous year. Faced with this global trend, the country that doesn't follow can be left with its development, especially in developing countries such as Brazil. Brazil is a privileged

2736

country in renewable energy sources, such as solar, wind, geothermal and the already used hydroelectric. Graph 3 shows the distribution of the country's energy potential.
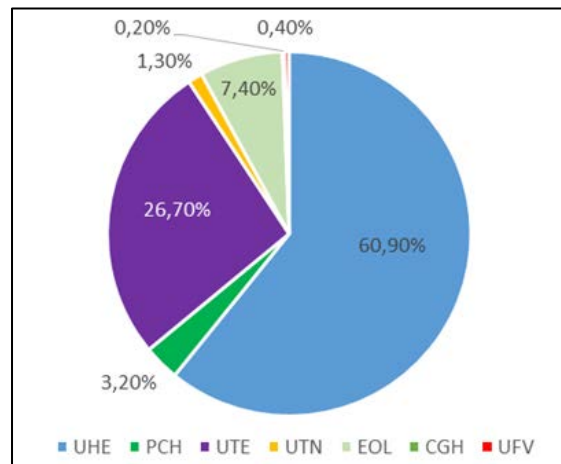
Graph 3: Installed potential (KWh) of the Brazilian energy matrix
Source: Aneel (2017) and Energias Renováveis (2016).

Brazil has a total installed capacity of 154,134,091 Kwh, of which approximately 100 thousand Kwh comes from hydroelectric power plants (HPP), hydroelectric plant (PCH) and hydroelectric generating plant (CGH), leveraging a total of 64% of all of the country's energy generation, followed by thermoelectric power plants, which are the second most used form of energy in the country with almost 27% of installed potential, while wind and solar (EOL and UFV) have only 7.4% and 0 , 4%, respectively (ANEEL, 2017).

Brazil is the second country in the ranking with respect to the world's hydroelectric power capacity (8.6%), losing only to China with its 27.9%, that is, it's still a country totally dependent on this source and subject to seasonality of rainfall, when unaffected by their lack (RENEWABLE ENERGIES, 2016).

On the other hand, the country faces the greatest structural challenge in its energy matrix, when it combines the sustainability and projection aspects of electricity. There are studies of energy demand in Brazil revealing a projection of consumption of more than 1,605 terawatt-hours (TWh) for the year 2050, that is, demand will triple in comparison to demand for 2013, which was 463.7 TWh.

Revealing that there's a horizon of challenges in innovations ahead, either in the energy matrix, production, socioeconomic habits, or even in new energy resources that could be available in this horizon (EPE, 2016). In this way, the country needs to invest in an abundant energy source that doesn't suffer from its scarcity. Photovoltaic solar energy presents itself as

2737

an excellent source of energy for Brazil, given its abundance all year round and in all regions of the country.

2.1. Photovoltaic Solar Energy

Solar energy is a constant source and can be generated individually, independently and safely for all. It's a very important energy for individuals, as well as socioeconomic sectors, such as companies, societies, states and nations (Kabir et al., 2018). Photovoltaic solar energy boils down to the conversion of radiation or sunlight into electricity. The principle of the system is to activate the electrons, offering extra energy (Kannan, Vakeesan, 2016). Table 1 shows an overview of the benefits and limitations of solar energy.

Table 1: Benefits and Limitations of Solar Energy

Solar Energy	
Benefits	Limitations
It's extremely abundant	High initial installation cost
Has the ability to meet demands around the world	Performance limitations of some components such as batteries and inverters
It's sustainable (clean)	Limited battery life
It's renewable	How to dispose of the battery safely
It's appropriate to achieve sustainable development	Solar panels are produced from rare or precious metals
Doesn't release harmful gases	Lack of basic user knowledge, especially in rural developing areas
Doesn't contribute to the greenhouse effect	
Doesn't depend on water use to operate (free of water shortage)	Lack of specialists for maintenance, inspection, repair and evaluation
Requires more labor, with more job generated	There's dependence on many lands for large-scale solar generation
Stable financial demand for long periods	Solar energy can only be produced during the day and its efficiency depends on the climate

Source: Adapted Kabir et al. (2018) and Sampaio and Gonzales (2017).

Solar energy is the one that most uses among renewable technologies. It's necessary to generate 25 to 30 direct jobs for each installed MW (ABSOLAR, 2018). In 2016, this employment rate increased by 12% to 3.1 million jobs and China accounts for more than half of these jobs and is still the country that most installs and manufactures solar panels (FERROUKHI et al., 2017).

From an installed capacity perspective, China leads 34.5 GW of photovoltaic energy, followed by the United States (14.7 GW), Japan (8.6 GW), India (4 GW), UK (2 GW), Germany (1.5 GW), Korea (0.9 GW), Australia (0.8 GW), Philippines (0.8 GW), Chile (0.7 GW), (Absolar, 2018).

In Brazil, it's notorious to highlight its potential attribute of solar energy generation, especially in regions of the northeastern semi-arid region, with direct irradiations above 2000kWh / m² and low cloudiness (PEREIRA et al., 2017). Brazil started the auctions of

renewable energy in 2013, at the time photovoltaic solar energy obtained 31 competing plants that in total added a capacity of 813MW (BRAZIL, 2013). In 2014 a specific auction for solar energy was carried out where a total installed capacity of 1048 MW was contracted at an average price of R $ 215.00 per MWh (equivalent to US $ 87 / MWh), corresponding to very competitive values when compared to the cost of electricity in Brazil (AMBIENTE ENERGIA, 2014).

These data recorded in Brazil reveal that the country is 15 years out of date compared to the main markets This fact is associated with other studies (FARIA JR. et al., 2017), where they point out that solar energy in Brazil is unexplored and underutilized, and for alternative renewable energy sources to outperform nonrenewable ones, it's necessary to overcome some barriers such as: fiscal incentives and tax credits; development and domination of the technologies involved; favorable natural conditions; favorable socio-environmental characteristics; decentralization in the generation of electricity; and shorter implementation times.

Throughout this section, Brazil was presented as one of the countries with the highest solar incidence, with a strong potential to be still projected in its energy matrix. Given this context, it becomes feasible to study the barriers that interfere in the implementation and expansion of photovoltaic solar energy, subject presented in the next section.

2.2.   Energy barriers

The contribution of solar energy to the Brazilian energy matrix isn't considerable, representing only 0.02% of the country's consuming units (ABSOLAR, 2018). This is due to numerous barriers that hinder this contribution. Therefore, it's imperative to identify the main barriers in the energy configuration of photovoltaic solar energy, which prevent large-scale implementation and expansion in Brazil, since the country has an abundance of resources to be explored. In the studied literature it was possible to identify several barriers that impede the implementation and / or expansion of photovoltaic solar energy, in this way it was possible to categorize the barriers in: Investment barriers; Institutional; Politics; Regulatory; Techniques; Financial; Market; Social; Cultural, Environmental (PUNIA et al., 2017, TIMILSINA et al., 2012). In the sequence we will highlight the barriers categorized in this study:

2.2.1. Technical Barriers (BT)

Among the energy barriers related to solar energy sources, and specifically those that cooperate under technical characteristics, have revealed that these have been concerns in

making solar energy more competitive and effective compared to other sources power (KAPOOR et al., 2014). Although solar technology has leapfrogged over the years, it has been found that suppliers need to adjust to customer needs in order to satisfy them and at the same time survive in the marketplace (KIM et al., 2014). Examples of technological problems are source intermittence, storage problem, low technological maturity (KAPOOR et al., 2014).

Such problems were specified from the understanding of structural confrontations as technical barriers (ZHANG et al., 2012). Other technical aspects of energy barriers are associated with procedures, standards, follow-up and technical descriptions of equipment, especially on occasions configured by the production chain (MATHIOULAKIS et al., 2017). It's understood that the technical capacity and even the infrastructure capacity can affect the diffusion of solar systems in a country (KARAKAYA; SRIWANNAWIT, 2015).

In this sense, it's clear that technical barriers encompass various questions and technological uncertainties of photovoltaic solar energy such as: standardization, reduction of equipment costs, storage, structure, procedures and knowledge. But to what extent do these barriers still interfere with this expansion of solar energy in Brazil?

2.2.2. Political Barriers (BP)

Among the main characteristics of these barriers, which measure political barriers to photovoltaic solar energy, the following stand out: lack of political will, responsibilities, political incentives, instability, lack of specialists in political decisions, etc. (PUNIA et al., 2017). The difference between the cost of solar technology and other technologies requires political support, this support has been more important in the past, as observed in European countries (Table 1), and many of these supports will remain active for the next few decades. These supports may be for adopting access and adoption procedures, the existence of long-term goals and investment security (DEL RÍO et al., 2018).

Describe several examples of political barriers to photovoltaic solar energy: the lack of government policy and its respective support to the sector; the lack of strategic support for the promotion of technologies; normative issues of land allocation, among others (ZHANG et al., 2012; KAPOOR et al., 2014). In addition to the organizational aspects of government, financial and financial support from the government as an incentive mechanism (LAN; YU, 2009), Li et al., 2014). In this sense, the political barrier has a strong influence on other barriers, which may or may not be determinant for the development of this technology in a given country, as can be seen in Table 2.

2740

Table 2: Examples of political incentives adopted in European countries

Parents	Type of Incentive	Brief description
Spain	Feed-in Tariffs (FIT)	Approved a clean energy law in 2013 (Royal Decree 413/2014) introducing a totally new subsidy system with gains from all existing renewable energy plants. According to the decree, generators will earn a rate of return of about 7.5% over their lifetime. This rate, which can be reviewed every three years, is based on the average interest of a sovereign bond of 10 years plus 3%, to be applied from July 2013.
France	FIT-Auctions	Contract of offer defined in a solar auction.
Italy	FIT	Italy applies a graded FIT for CSP, with bands according to size (total receiver surface) and solar fraction. FIT for large plants (> 2500 m2) is €0.32 / kWh, where the solar fraction is above 85%, €0.30 / kWh from 50% to 85% and €0,27 / kWh where is less than 50%. The FIT will be paid from 25 years and will fall 5% from 2015 and 5% from 2016. FITs for small plants (<2500 m2) have the same solar fraction rules and are 0.36 €/ kWh, €0.32 / kWh and €0.30 / kWh, respectively.
Germany	FIP/FIT	Sliding premium for> 100 kW and FIT for <100 kW.
Greece	FIT/ Grant for funding	FIT (with capacity limits e) and capital exchanges. Since April 2014, Greece has introduced FIT reductions for new operating projects (~ 25%), applied a producer remuneration discount (10 - 37.5%), defined capacity limits for adjustments and removing the annual inflation adjustment of FIT's. Greece provides a FIT of 26.5 c €/ kWh for CSP, which rises to 28.5 c €/ kWh if at least 2 hours of storage is incorporated.

Source: Adapted Del Río et al. (2018).

It can be seen that the national policy models for the implementation and expansion of photovoltaic solar energy in Europe must be relevant for countries that are under construction or want to build solar power plants. Without political support it's difficult to implement renewable energies and trigger further incentives for the sector (JESLIN; CHARLES, 2017).

It isn't only government interest and national policies that will leverage the expansion of solar photovoltaics, regional or state governments have great importance for the development of sustainable regional policies, creating opportunities and development of the economy, attracting entrepreneurs, improving infrastructure or removing bureaucracies and restrictions that hinder the implementation of solar energy (JOLLY, 2017).

Political barriers make it possible to measure measurable conditions associated with political obstacles to assess possibilities for expansion and development of photovoltaic solar energy, responsibilities, political incentives, instability, lack of policy decision-makers and so on (PUNIA et al., 2017). However, Sen and Ganguly (2017) have revealed that the energy industry in many countries is centralized and, because of this monopoly, the road to renewable energies is often difficult to consolidate, especially when it's in line with the political conditions that stimulate the sector.

2741

2.2.3. Financial Barriers (BF)

The costs of an innovation tend to decrease over time and vary with location (KARAKAYA; SRIWANNAWIT, 2015), i.e. the same technology in solar energy may present financial variations for its adoption depending on the country. Financial barriers to photovoltaic solar energy are numerous, such as lack of access to capital, lack of loans, financial education, lack of financial incentive institutions, etc. (PUNIA et al., 2017).

The costs of photovoltaic circuits depend on the size of their matrix and involve direct equipment costs such as inverters, cables, safety devices, as well as costs of direct, indirect, overhead and maintenance labor (ZHANG et al., 2012). The initial capital cost is therefore high, and access is limited to lines of credit, high interest rates, etc. (KAPOOR et al., 2014).

In Brazil it still does not use solar energy as its main energy source in its matrix, due to its high common cost. (FERREIRA et al., 2018). It also cites the comparison between costs in Germany and Brazil, where in 2013 the cost of installing the photovoltaic system in Germany reached about 1684.0 Euros per kilowatt of installed capacity (Kwp) and in the same period in Brazil it cost ranged from 7,000.00 to 10,000.00 Reais per Kwp, equivalent to 2000.00 - 3000.00 Euros. The cost of installation in Brazil is almost double the cost in Germany. For a consistent growth, strong and attractive policies for the market are indispensable, so that the investor sees low risk in the sector and isn't full of uncertainties.

2.2.4. Environmental Barriers (BA)

Solar energy becomes supreme in relation to other energies since it's abundant throughout the world and the environmental impact is almost nil (OZOEGWU et al., 2017). On the other hand, pipelines and oil pipelines, as well as vehicular transport, are vulnerable to adverse climatic conditions, natural disasters and human vandalism.

Although considered a clean energy, the extraction of raw material is the reason for warning, as an example the Chinese case, whose government has launched concerns with the photovoltaic componentes (RABE et al., 2017). For these have been related to serious environmental and health risks during their extraction and processing of rare elements, which pollute the environment with radioactivity and chemical contamination of water and soil.

Another concern of photovoltaic solar energy, despite being considered a clean and sustainable energy, it also causes environmental impacts, when installing large-scale solar panels that requires large extension of land and homeless innumerable animals of their natural habitat. In addition, it has been that solar cells are based on silicon and its manufacturing

2742

process uses chemicals as well as chemicals used in batteries. These are some of the impacts that photovoltaic solar energy has on the environment (KAYGUSUZ, 2009).

Also pointed out that in addition to the problems with storage devices another obstacle is that many manufacturers use lead-based solders and other metals to join solar cells and can cause damage to the environment (KAYGUSUZ, 2009). Another highlight is that land can be a restrictive factor in the adoption of renewable energies, especially in rural areas where subsistence agriculture is practiced (HANGER et al., 2016).

Although it's reported, by few authors during their studies about the impacts to the environment caused by solar energy, what is evident to emphasize that when compared with other sources of energy, this impact becomes practically null and therefore the sola energy is a partner of the sustainability.

2.2.5. *Social, Cultural and Behavioral Barriers (BS)*

Such barriers have more subjective characteristics. Factors such as lack of technological awareness, lack of attention in policy decisions, resistance to new technology are associated with social, cultural and behavioral barriers (KAPOOR et al., 2014). By social conditions, people will realize that solar energy can only be harnessed during the day, and will be dependent on the weather conditions. In this sense, it can reduce their level of comfort or demand changes in habits, and should promote social acceptance, even if they play a crucial role in the implantation and expansion in favor of sustainable development together with other renewable energy projects (SINDHU et al., 2016).

In developed countries where there is strong political support for renewable energies, there is a high acceptance of society driven by the desire to have a sustainable energy system (ENGELKEN et al., 2016). However, social factors such as lack of awareness among users and stakeholders in Tanzania are a strong barrier to the adoption of photovoltaic solar energy (KARAKAYA; SRIWANNAWIT, 2015).

Another example, cited by the authors as alternative comparability, is that the Chinese are more aware of solar water heater technology than of solar photovoltaic technology. The Barrier of social acceptance is well researched in developed countries, but still little studied in developing countries.

In European countries, for example, this concern is so important because it has been one of the aspects to avoid delays or failures in innovative projects, since it can put at risk an entire project that is associated with a certain innovation that isn't adept to society (HANGER

et al., 2016). Social acceptance plays an important role, over time, this acceptance will be happening gradually, and more and more people will install solar panels on their roofs with satisfaction and awareness (SEN; GANGULY, 2017).

For Del Río et al., (2018), the implantation of photovoltaic solar energy has great potential for providing value and local development, by locating the production of equipment, services, operation and maintenance, creating employment opportunities. It's for this reason that local development boosts political support. In Germany, in 2013, more than 370,000 direct jobs were created with renewable energy. If jobs related to politics, development, research, training and education are taken into account, this number goes from 1.5 million jobs (GERHARDT, 2016).

Solar energy has a very positive characteristic for a society that is located in a region where the site isn't very valued, the area of which has little vegetation or dry land. It promotes to the place the ideal development for installations of solar panels, capable of generating not only clean energy, but employment and income for the host city of solar energy (HASAPIS et al., 2017). That is, investments in photovoltaic solar energy in arid regions, provides the necessary attribute for the generation of energy (sunlight), in contrast it promotes the development of these "unproductive" lands.

2.2.6. Barriers of Knowledge (BC)

Knowledge barriers are related to the general knowledge of the technology, the benefits of photovoltaic solar energy, the lack of trained personnel, specialized companies, etc. This can impoverish confidence in technology in all sectors, whether public, private or investment (OHUNAKIN et al., 2014).

According to (RATHORE et al., 2018), the lack of knowledge, awareness and familiarity with this technology makes it impossible to obtain any financing from the banks. Such a characteristic indicates that the shortage of qualified people, information and knowledge becomes a barrier on renewable energy (ENGELKEN et al., 2016).

The lack of knowledge about who adopts and who doesn't adopt photovoltaic solar energy is worrisome because it can result in improper use of this technology and in the inability to maintain the system, thus becoming a relevant barrier to the implementation of this energy (KARAKAYA; SRIWANNAWIT, 2015).

The lack of specialized and skilled human resources for renewable energy systems is very important for the outcome of a renewable energy deployment project. It may therefore

2744

become a major barrier in developing countries, especially if the lack of public and institutional awareness also act together as barriers (SEN; GANGULY, 2017).

A study carried out in China indicated that the respondents viewed solar photovoltaic energy with a low level of application, and were also very concerned about system complexity, durability, maturity and stability (DE SENA et al., 2016). That is, knowledge isn't only in technology, but also in the diffusion of knowledge and use in society.

Solar energy promotion events, through workshops and networking sessions, are important to share knowledge, be it spreading the latest technology trends or sharing best practices (JOLLY, 2017). In addition to stimulating the link between different sectors such as solar manufacturers, equipment suppliers, developers, government representatives, consultants, investors, etc.

2.3.   Research Hypotheses And Conceptual Model

Based on the bibliographic review, the hypotheses were mapped according to the most relevant barriers found in the literature and thus formulated 06 hypotheses to be tested in the model, the following is the hypotheses:

- **Hypothesis 1 (H1)**: There's a negative effect of Technical Barriers (B1) on the deployment and expansion of solar Energy (ZHANG et al., 2012).

- **Hypothesis 2 (H2)**: There's a negative effect of the Political Barriers (B2) on the implantation and expansion of solar Energy (PUNIA et al., 2017).

- **Hypothesis 3 (H3)**: There's a negative effect of Financial Barriers (B3) on the deployment and expansion of solar Energy (PUNIA et al., 2017).

- **Hypothesis 4 (H4)**: There's a negative effect of the Environmental Barriers (B4) on the deployment and expansion of solar energy (KARAKAYA; SRIWANNAWIT, 2015).

- **Hypothesis 5 (H5)**: There's a negative effect of the Social, Cultural and Behavioral Barriers (B5) on the implantation and expansion of solar Energy (KAPOOR et al., 2014).

- **Hypothesis 6 (H6)**: There's a negative effect of Knowledge Barriers (B6) on the deployment and expansion of solar Energy (OHUNAKIN et al., 2014).

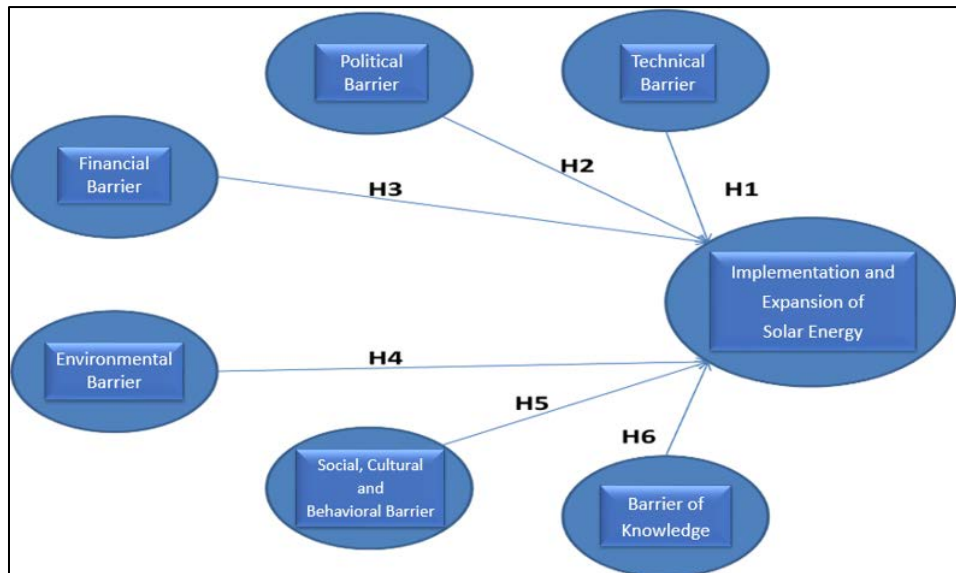Assuming the hypotheses, it was possible to elaborate a conceptual model, as shown in Figure 1.

Figure 1: Proposed Conceptual Model
Source: Prepared by the authors.

3. RESEARCH METHOD

For the development of this article the methodology adopted consisted of a literature review and identification of the research need, followed by a study using both the quantitative and the qualitative approach. The first one regarding the formulation of hypotheses, as well as the data collection and the statistical treatment. The second, by understanding the characteristics of the respondents.

The literature review assigns an exploratory character, with the theoretical basis for the identification of the barriers and the formulation of the research hypotheses. Afterwards, the work was of a descriptive confirmatory nature, where a survey was carried out with the companies that operate in the photovoltaic solar energy market in Brazil, applying a survey questionnaire composed of 23 questions, using a Likert scale of 7 points (1 - "Totally Disagree" to 7 - "Totally Agree"), a model was developed through Structural Modeling Equations (SEM) to test and evaluate the proposed model and hypotheses. Fig. 2 shows the schematic of the research methodology.
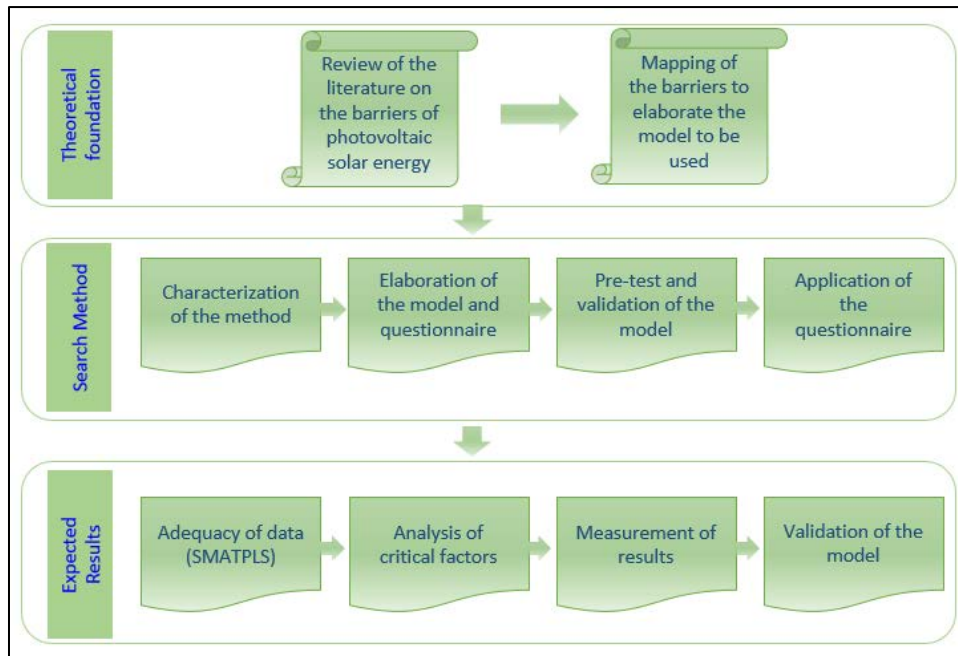
2746

Figure 2: Research methodology

3.1.1. Survey Questionnaire

The literature review was a fundamental basis for the construction of the questionnaire, through which it was possible to formulate the constructs and their main indicators determined by the most relevant authors. These indicators, in turn, were translated into questions that formulated the questionnaire and then were sent to the respondents - solar energy companies. The questionnaire was applied to the Online Survey Monkey platform, structured on a 7-point Likert scale: 1 - "Strongly disagree", 2 - "I disagree in part", 3 - "I disagree" 4 - "Indifferent", 5 - "I agree ", 6 -" I agree in part and 7 - "I totally agree." It's applied to several companies that operate in the solar energy sector in Brazil. Responses were collected within 10 days.

3.1.2. Modeling of Structural Equations - SEM

For the modeling, a model was searched for the evaluation of the barriers of the implantation of solar photovoltaic energy. However, in view of the non-existence of this model, we tried to construct one based on the hypotheses and correlations that were referenced by the main authors. The proposed final model is presented later in the research results, according to Figure 3.

4. Results

This chapter shows the results of the survey, where the questionnaire obtained a total of 146 answers, being 25 partials and 121 complete, which satisfies the research since the

model has 23 indicators and for each indicator needs at least 05 answers per indicator, totalizing the need for at least 115 responses (HAIR JR. et al., 2014). With the data validated, the analysis of the results follows:

For the evaluation of the structural model, the Explained Variance was analyzed through the Pearson determination coefficients (R^2). The value of R^2 varies between 0 and 1, with those closest to 1 indicating higher levels of predictive accuracy (HAIR JR. et al., 2009). Table 3 shows the values of the Pearson determination coefficients.

Table 3: Pearson determination coefficients

R values		
	R²	**Adjusted R²**
Solar Energy Implementation	0,318	0,288

Source: SmartPLS.

It's necessary to the research also to evaluate the Stone-Geisser Q2 value (Geisser, 1974; Stone, 1974), which is a Predictive Relevance Indicator of the model, where it's assumed that the model predicts each indicator of the constructs (HAIR JR. et al., 2011). The reference values for this analysis are 0.02; 015 and 0.35 for small, medium and high explanatory power indicators (HAIR JR. et al., 2014).

Table 4: Predictive Relevance Indicator - Q²

Indicators Q²	
Latent variable	**Q²**
BA	
BF	
BP	0.135
BS	
BC	
I	

Source: SmartPLS.

We can observe, through the Pearson Determination Coefficients (R^2), Table 3, and the Predictive Relevance Indicator (Q^2), Table 4, that the proposed model has predictive relevance. Finally, the last indicator to estimate the measurement model is the analysis of the statistical values T and P. T values above 1.96 and P above 5% of significance prove the existence of the causal relationship between two constructs (HAIR JR. et al., 2011).

Table 5: Path Coefficients (T) and Significance Level (P)

T and P Values			
Latent variable	**T Statistics**	**P Values**	**Situation**
BA	0.480	0.631	Rejected
BF	1.603	0.109	Rejected
BP	2.584	0.010	Accepts
BS	0.890	0.374	Rejected

2748

| BC | 2.852 | 0.004 | Accepts |

Source: SmartPLS.

As we can see are two accepted hypotheses, considering the adequate adjustment for two constructs with reference to T values higher than 1.96. After the model adjustments, it was necessary to eliminate 7 indicators and 1 construct (Technical Barriers - BT), thus repeating the structural and measurement model estimates. Fig. 3 shows, therefore, the final model.
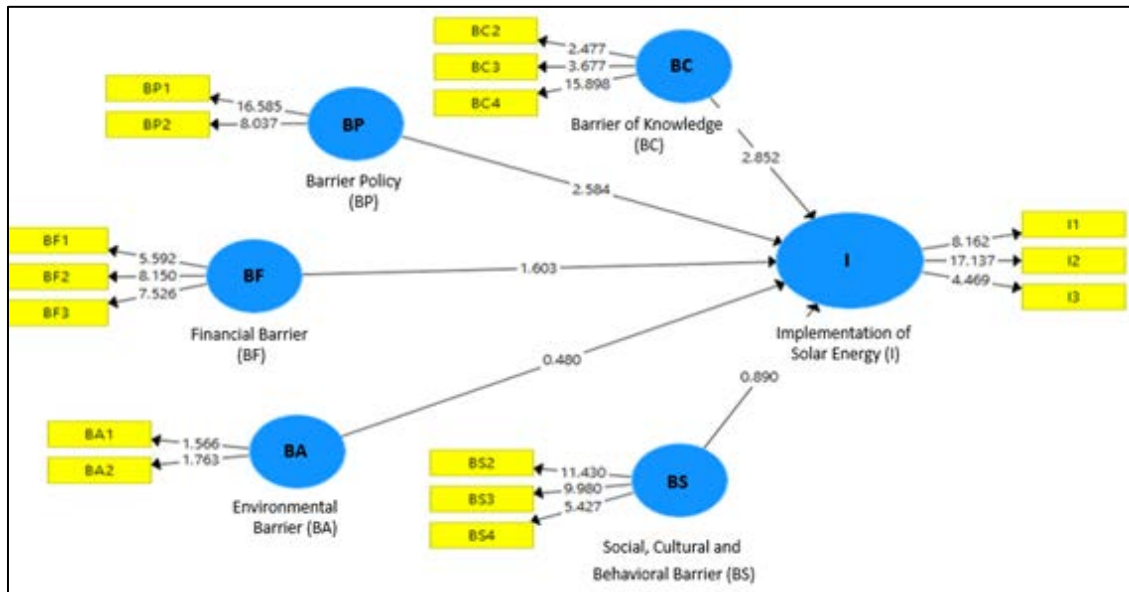

Figure 3: Final Model with Path Coefficient (T)
Source: SmartPLS.

Some aspects were observed such as the standard loads (Outer Loadings); Cronbach's Alpha and Compound Reliability; Descending Validity; Variance Inflation Factor (VIF); Redundancy and Commonwealth of the Construct, to validate and guarantee the reliability of the data collected (HAIR JR. et al., 2014).

The first evaluation of the model took place in the analysis of the standardized loads of the indicators, where each one is analyzed individually, whose reference values are higher than 0.7. However, values between 0.4 and 0.7 are also acceptable for exploratory research (HAIR JR. et al., 2014). After all the adjustments made in the initial model and adapted to the quality criteria, AVE> 5, Cronbach's Alpha> 6 and Compound Reliability> 6.

It was observed that the discriminant validity, since it represents an important evaluation criterion of the model, is used in the model, in order to guarantee that the relation of the construct itself is superior to the relation with the other constructs and also in relation to its indicators (HAIR JR. et al., 2014).

2749

For this analysis, we started with cross load analysis of the indicators (Cross Loadings), where it was evaluated whether the load of the indicator is superior for its construct in relation to the others, allowing, therefore, the final adjustment of the model, according to Figure 3.

5. CONSIDERATIONS

This study showed the main barriers to the expansion of solar energy in Brazil. This shows how much the country lags behind the innovations in renewable energies, since solar energy is still underutilized and under-exploited. Although there are presumptions that technical, political, financial, environmental, socio-cultural and behavioral aspects, and knowledge, are aspects that guide obstacles to its expansion.

It has been realized that, although there are studies indicating fiscal factors, in favor of incentives or tax exemptions, and the debureaucratization are a means to sanitize and to prosper development for the sector of solar energy. In this study, the need was met through a metric modeling by structural equations, and a broad empirical basis for the case of Brazil, to demonstrate that among several obstacles there are in fact some barriers that are the effective reasons for impeding the expansion of energy in Brazil.

To this end, the model proposed and tested, in order to demonstrate the Brazilian Solar Energy Barriers in a representative way, was initially based on a literature that indicated the main guidelines that limit the photovoltaic energy expansion. In order to propose a model, whose indicators were validated in order to be consistent with the reality of the photovoltaic solar energy sector in Brazil. The initial model was proposed with 23 indicators and 6 constructs, using PL-SEM (Partial Least Squares Strutural Equation Modeling) that also followed criteria of the literature. When the need for adjustments, such as the elimination of indicators, which were made following the criteria of the PL-SEM methodology.

With respect to the hypotheses tested, hypothesis 2 and hypothesis 6, which deal with the effect of the Political Barrier and Knowledge Barrier respectively, were accepted. Assumptions 3, 4 and 5, Financial Barriers, Environmental Barriers and Social, Cultural, and Behavioral Barriers were rejected. Finally, hypothesis 1 was not tested because the BT construct (Technical Barrier) was removed from the initial model. Therefore, it doesn't appear in the adjusted final model. Perhaps this result was influenced by the fact that the research was carried out with the vast majority of respondents being businessmen of the sector and already with the development of the technological area developed.

2750

The rejection of the Financial, Environmental and Social Barriers shows us its low influence in the face of the Political and Knowledge Barriers, considering the current context of the country, where there's a strong policy of incentives to thermoelectric, while the efforts for solar energy deserves better attention from both national and regional governments. This is evidenced by the examples presented by countries that have this well-developed and widespread technology whose characteristics are to have a good acceptance and great political incentives, something that isn't yet evident in Brazil. Therefore, political and knowledge barriers make a quantitative analysis of the low expansion of photovoltaic solar energy in Brazil.

REFERENCES

ABSOLAR - Associação Brasileira de Energia Solar Fotovoltaica. (2018) **A aceleração da energia solar fotovoltaica no mundo**.

ANEEL - Agência Nacional de Energia Elétrica. (2017) **Boletim de Informações Gerenciais**.

DE SENA, L. A.; FERREIRA, P.; BRAGA, A. C. (2016) Social acceptance of wind and solar power in the Brazilian electricity system. **Environment, Development and Sustainability**, v. 18, n. 5, p. 1457–1476. DOI: https://doi.org/10.1007/s10668-016-9772-0

DEL RÍO, P.; PEÑASCO, C.; MIR-ARTIGUES, P. (2018) An overview of drivers and barriers to concentrated solar power in the European Union. **Renewable and Sustainable Energy Reviews**, v. 81, n. 1, p. 1019-1029. DOI: https://doi.org/10.1016/j.rser.2017.06.038

ENERGIAS RENOVÁVEIS (2016) **Relatório da situação mundial**, Ren21-2016.

ENGELKEN, M.; RÖMER, B.; DRESCHER, M.; WELPE, I. M.; PICOT, A. (2016) Comparing drivers, barriers, and opportunities of business models for renewable energies: a review. **Renewable and Sustainable Energy Reviews**, v. 60, p. 795-809. DOI: https://doi.org/10.1016/j.rser.2015.12.163

EPE - Empresa de Pesquisa Energética. (2016) Nota Técnica DEA 13/15. **Estudos da demanda de energia**. Demanda de Energia 2050.

EPE - Empresa de Pesquisa Energética. (2017) **Nota Técnica DEA 01/17**. Projeção da demanda de energia elétrica para os próximos 10 anos (2017-2026)

FARIA Jr., H.; TRIGOSO, F. B. M.; CAVALCANTI, J. A. M. (2017) Review of distributed generation with photovoltaic grid connected systems in Brazil: challenges and prospects. **Renewable and Sustainable Energy Reviews**, v. 75, p. 469-475. DOI: https://doi.org/10.1016/j.rser.2016.10.076

FERREIRA, A.; KUNH, S. S.; FAGNANI, K. C.; DE SOUZA, T. A.; TONEZER, C.; SANTOS, G. R.; ARAÚJO, C. H. C. (2018) Economic overview of the use and production of photovoltaic solar energy in Brazil. **Renewable and Sustainable Energy Reviews**, v. 81, p. 181–191. DOI: https://doi.org/10.1016/j.rser.2017.06.102.

FERROUKHI, R.; KHALID, A.; GARCÍA-BAÑOS, C.; RENNER, M. (2017) **Renewable Energy and Jobs**: Annual Review.

2751

GERHARDT, C. (2016) Germany's Renewable Energy Shift: addressing climate change. **Capitalism Nature Socialism**, 103-119. DOI: https://doi.org/10.1080/10455752.2016.1229803

HAIR Jr., J. F.; BLACK, W. C.; BABIN, B. J.; ANDERSON, R. E. (2009) **Multivariate Data Analysis**. Pearson, v. 7, p. 1-785.

HAIR Jr., J. F.; RINGLE, C. M.; SARSTEDT, M. (2011) PLS-SEM: indeed a silver bullet. **J. Mark Theory Pract**, v. 19, p. 139–152.

HAIR Jr., J. F.; HULT, G. T. M.; RINGLE, C.; SARSTEDT, M. (2014) **A primer on partial least squares structural equation modeling (PLS-SEM)** Los Angeles: SAGE.

HANGER, S.; KOMENDANTOVA, N.; SCHINKE, B.; ZEJLI, D.; IHLAL, A.; PATT, A. (2016) Community acceptance of large-scale solar energy installations in developing countries: evidence from Morocco. **Energy Research & Social Science**, v. 14, p. 80-89. DOI: https://doi.org/10.1016/j.erss.2016.01.010

HASAPIS, D.; SAVVAKIS, N.; TSOUTSOS, T.; KALAITZAKIS, K.; PSYCHIS, S.; NIKOLAIDIS, N. P. (2017) Design of large scale prosuming in Universities: the solar energy vision of the TUC campus. **Energy and Buildings**, v. 141, n. 15, p. 39-55. DOI: https://doi.org/10.1016/j.enbuild.2017.01.074

JESLIN, D. N. P.; CHARLES, R. S. (2017) The drive of renewable energy in Tamilnadu: status, barriers and future prospect. **Renewable and Sustainable Energy Reviews**, v. 73, p. 115-124. DOI: https://doi.org/10.1016/j.rser.2017.01.123

JOHANSSON, M. T.; THOLLANDER, P. (2018) A review of barriers to and driving forces for improved energy efficiency in Swedish industry: recommendations for successful in-house energy management. **Renewable and Sustainable Energy Reviews**, v. 82, n. 1, p. 618-628. DOI: https://doi.org/10.1016/j.rser.2017.09.052

JOLLY, S. (2017) Role of institutional entrepreneurship in the creation of regional solar PV energy markets: contrasting developments in Gujarat and West Bengal. **Energy Sustain Development,** v. 38, p. 77–92. DOI: https://doi.org/10.1016/j.esd.2016.10.004

KABIR, E.; KUMAR, P.; KUMAR, S.; ADELODUN, A. A.; KIM, K. H. (2018) Solar energy: potential and future prospects. **Renewable and Sustainable Energy Reviews**, v. 82, n. 1, p. 894-900. DOI: https://doi.org/10.1016/j.rser.2017.09.094

KANNAN, N.; VAKEESAN, D. (2016) Solar energy for future world: a review. **Renewable and Sustainable Energy Reviews**, v. 62, p. 1092-1105. DOI: https://doi.org/10.1016/j.rser.2016.05.022

KAPOOR, K.; PANDEY, K. K.; JAIN, A. K.; NANDAN, A. (2014) Evolution of solar energy in India: a review. **Renewable and Sustainable Energy Reviews**, v. 40, p. 475-487. DOI: https://doi.org/10.1016/j.rser.2014.07.118

KARAKAYA, E.; SRIWANNAWIT, P. (2015) Barriers to the adoption of photovoltaic systems: the state of the art. **Renewable and Sustainable Energy Reviews**, v. 49, p. 60-66. DOI: https://doi.org/10.1016/j.rser.2015.04.058

KAYGUSUZ, K. (2009) Environmental impacts of the solar energy systems. **Energy Sources**, Part A: Recovery Utilization, and Environmental Effects, p. 1376-1386. DOI: https://doi.org/10.1080/15567030802089664

KIM, H.; PARK E.; KWON, S. J.; OHM, J. Y.; CHANG, H. J. (2014) An integrated adoption model of solar energy technologies in South Korea. **Renewable Energy**, v. 66, p. 523-531. DOI: https://doi.org/10.1016/j.renene.2013.12.022

LAN, O. U.; YU, R. (2009) The development of wind-solar energy systems in China. 2009 Int. **Conf. Energy Environ. Technol. ICEET**, v. 3, p. 626–627.

LI, D. H.; CHONG, B. L.; CHAN, W. W.; LAM, J. C. (2014) An analysis of potential applications of wide-scale solar energy in Hong Kong. **Building Services Engineeging Research Technology**, v. 35, n. 5, p. 516-528. DOI: https://doi.org/10.1177/0143624414522133

MATHIOULAKIS, E.; BABALIS, S.; KALOGIROU, S.; BELESSIOTIS, V. (2017) Energy labelling and ecodesign of solar thermal products: opportunities, challenges and problematic implementation aspects. **Renewable Energy**, v. 101, p. 728-736. DOI: https://doi.org/10.1016/j.renene.2016.09.034

MENDES, M. A.; MUNIZ, P. R.; MARQUES, J. C.; DONADEL, C. B.; FARDIN, J. F. (2016) **Analysis of financial impacts caused by pollution from thermal power plants in Brazilian public health system**. 12° IEEE/IAS International Conference on Industry Applications: INDUSCON.

OHUNAKIN, O. S.; ADARAMOLA, M. S.; OYEWOLA, O. M.; FAGBENLE, R. O. (2014) Solar energy applications and development in Nigeria: drivers and barriers. **Renewable and Sustainable Energy Reviews**, v. 32, p. 294-301. DOI: https://doi.org/10.1016/j.rser.2014.01.014

OZOEGWU, C. G.; MGBEMENE, C. A.; OZOR, P. A. (2017) The status of solar energy integration and policy in Nigeria. **Renewable and Sustainable Energy Reviews**, v. 70, p. 457-471. DOI: https://doi.org/10.1016/j.rser.2016.11.224

PEREIRA, E. B.; MARTINS, F. R.; ABREU, S. L.; RÜTHER, R. (2017) **Atlas Brasileiro de Energia Solar**.

PUNIA, S. S.; NEHRA, V.; LUTHRA, S. (2016) Recognition and prioritization of challenges in growth of solar energy using analytical hierarchy process: Indian outlook. **Energy**, v. 100, p. 332–348. DOI: https://doi.org/10.1016/j.energy.2016.01.091

RABE, W.; KOSTKA, G.; SMITH, S. K. (2017) China's supply of critical raw materials: risks for Europe's solar and wind industries? **Energy Policy**, v. 101, p. 692-699. DOI: https://doi.org/10.1016/j.enpol.2016.09.019

RATHORE, P. K. S.; RATHORE, S.; SINGH, P. R.; AGNIHOTRI, S. (2018) Solar power utility sector in india: challenges and opportunities. **Renewable and Sustainable Energy Reviews**, v. 81, n. 2, p. 2703-2713. DOI: https://doi.org/10.1016/j.rser.2017.06.077

SAMPAIO, P. G. V.; GONZALEZ, M. O. A. (2017) Photovoltaic solar energy: conceptual framework. **Renewable and Sustainable Energy Reviews**, v. 74, p. 590-601. DOI: https://doi.org/10.1016/j.rser.2017.02.081

SEN, S.; GANGULY, S. (2017) Opportunities, barriers and issues with renewable energy development: a discussion. **Renewable and Sustainable Energy Reviews**, v. 69, p. 1170-1181. DOI: https://doi.org/10.1016/j.rser.2016.09.137

SINDHU, S.; NEHRA, V.; LUTHRA, S. (2016) Identification and analysis of barriers in implementation of solar energy in Indian rural sector using integrated ISM and fuzzy

2753

MICMAC approach. **Renewable and Sustainable Energy Reviews**, v. 62, p. 70-88. DOI: https://doi.org/10.1016/j.rser.2016.04.033

STRUPEIT, L.; PALM, A. (2016) Overcoming barriers to renewable energy diffusion: business models for customer-sited solar photovoltaics in Japan, Germany and the United States. **Journal of Cleaner Production**, v. 123, n. 1, p. 124-136. DOI: https://doi.org/10.1016/j.jclepro.2015.06.120

TIMILSINA, G. R.; KURDGELASHVILI, L.; NARBEL, P. A. (2012) Solar energy: markets, economics and policies. **Renewable and Sustainable Energy Reviews**, v. 16, n. 1, p. 449-465. DOI: https://doi.org/10.1016/j.rser.2011.08.009

ZHANG, X.; SHEN, L.; CHAN, S. Y. (2012) The diffusion of solar energy use in HK: what are the barriers? **Energy Policy**, v. 41, p. 241-249. DOI: https://doi.org/10.1016/j.enpol.2011.10.043