

ECONOMIC FEASIBILITY FOR PHOTOVOLTAIC SOLAR ENERGY PROJECTS: A SYSTEMATIC REVIEW

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Abstract:

Purpose: This paper presents a systematic literature review regarding economic feasibility studies and photovoltaic solar energy production.

Methodology/Approach: To this end, publications from 2015 to 2019 were collected in two journal databases: Web of Science and Science Direct. In order to create a corpus more relevant to the aim of this research, a selection among the papers found was made respecting some established filters. Subsequently this refinement, the resulting corpus consisted of seventeen papers.

Findings: A current matter discussed by the researchers was identified, regarding the study on the best photovoltaic system to be used for each user: whether batteries are the best option as a storage source, or the connection of the system to the network is the most adequate guarantee to meet demand.

Research Limitation/implication: This review gives the present study a characteristic of bringing together what, within the mentioned period and in the searched bases, has been approached in different works that deal with the economic feasibility analysis regarding the photovoltaic solar energy production.

Originality/Value of paper: can support the implementation of solar systems in peripheral locations where the technology is still little used.

Keywords: prism, solar energy, economic feasibility, photovoltaic systems.

VIABILIDADE ECONÔMICA PARA PROJETOS DE ENERGIA SOLAR FOTOVOLTAICA: UMA REVISÃO SISTEMÁTICA

Abstract:

Propósito: Este trabalho apresenta uma revisão sistemática da literatura a respeito de estudos de viabilidade econômica e a produção de energia solar fotovoltaica.

Metodologia: Publicações de 2015 a 2019 em duas bases de dados de periódicos: Web of Science e Science Direct. Ao final de uma seleção, alguns filtros de seleção, elegibilidade e inclusão foram estabelecidos, tendo sido selecionados 17 trabalhos como de maior relevância ao tema proposto.

Resultados: A current matter discussed by the researchers was identified, regarding the study on the best photovoltaic system to be used for each user: whether batteries are the best option as a storage source, or the connection of the system to the network is the most adequate guarantee to meet demand.

Limitações: Essa revisão confere ao presente estudo uma característica de reunir aquilo que, dentro do período citado e nas bases buscadas, tem sido abordado em diferentes trabalhos que versam sobre a análise de viabilidade econômica referente à produção de energia solar fotovoltaica.

Originalidade: pode apoiar a implementação de sistemas solares em locais periféricos onde a tecnologia ainda é pouco utilizada.

Palavras chaves: prisma, energia solar, viabilidade econômica, sistemas fotovoltaicos.

Introduction

Currently, the implementation of energy efficiency strategies (EES) and renewable energy sources (RES) is on the political agenda of many countries (Chévez et al., 2019). The need to seek more sustainable ways of producing energy (Terrell and Theegala, 2019; Zaidi, Hou and Mirza, 2018) has been intensifying over the years, since the impacts of human development and the growing influence of human on the environment can already have its effects perceived in nature through the worsening of the greenhouse effect, due to the increasing of society's interference. The use of solar energy can be a promising way to mitigate this problem as it is a clean energy source, or in other words, it has no environment impact (Dantas & Pompermayer, 2018).

The drop in installation costs and the search for renewable energy sources is one of the factors that may explain the increase in the production of photovoltaic solar energy. Between 2010 and 2015 there was an addition of more than 450 percent in the installed photovoltaic capacity, going from less than 41GW to something around 230 GW (INTER SOLAR, 2016). According to the projections of the same report, in the period from 2016 to 2020, Brazil should enter the Top 10 countries with the highest production of photovoltaic energy with an increase of 150 percent of its capacity.

It is possible to establish that there is a great potential related to the solar resource to be explored (Cunha et al., 2019). To encourage the development of photovoltaic systems, in April 2012 the National Electric Energy Agency (In Portuguese: Agência Nacional de Energia Elétrica - ANEEL) published the Normative Resolution No. 482/2012, which regulates distributed energy generation through the definition of the net metering system. This system has an arrangement in which the active energy injected into the network by a unit is assigned to the distributor and subsequently compensated with energy consumption. If there is more generation than consumption, the user receives the energy credit, which is the remaining balance that can be used to reduce consumption later in other months. If consumption exceeds generation, the difference is paid by the consumer to the distributor (Aneel, 2012).

This study presents a systematic literature review regarding economic feasibility studies and the production of photovoltaic solar energy. In this sense, publications from 2015 to 2019 were collected in two databases of journals: Web of Science and Science Direct. It is expected that this study will help to carry out analysis regarding the financial trade-off in the use of photovoltaic energy panels, resulting from the benefits obtained by the users of this form of energy generation.

Management tools are essential in the monitoring and evaluation activities of organizations, as it allows to keep track of the achievement of goals, identifying progress, quality improvements, correcting problems and changing needs (Carvalho *et al.*, 2016). The understanding of the development and feasibility of products with green technology can influence business management and purchasing behavior (Silva *et al.*, 2017). Some authors that study this type of subject are Lobaccaro et al. (2016), Winther et al., (2018), Elshurafa et al., (2019). From this more detailed analysis, the contribution of this study becomes evident since the better understanding on the subject can make it possible to reduce the knowledge gaps about it as well as support the implementation of solar systems in certain locations.

Besides the introduction, this paper is divided in four major sections: in the first one the methods used to design the study are presented, in the next one the results are shown then a discussion is made about the findings; the fourth section the conclusions about the research are delineated. Finally, the references used in this study are presented.

Methods

Studies that place articles and their authors as research subjects allow the identification of researches' intellectual distribution and other actors involved as well as their productivity and their

connections with institutions (Dias, 2018; Rodrigues *et al.*, 2019; Silva *et al.*, 2019; Cochrane & Mello, 2020). This article is a literature review regarding scientific studies related to the topic of solar energy and economic feasibility. The sample was selected from publications indexed in two different bases: Web of Science and Science Direct. To improve the structure of the corpus of analysis, the search followed the described steps bellow:

- 1- Selection of the databases that the publications would be searched (*Web of Science e Science Direct*)
- 2- Selection of terms to be searched according to the subject of study and the best way to combine them:
 - a. “*Economic Viability*”.
 - b. “*Solar Energy*”.
 - c. “*Photovoltaic*”.
 - d. “*Photovoltaic Solar Energy*”
- 3- Extraction of scientific studies to a platform that allows better analysis and presentation of results (Mendeley).
- 4- Choice of eligibility parameters, to refine the publications found in the search.
- 5- Analysis of the results.
- 6- Conclusions about the results obtained.

The terms used in the search were selected from an analysis of the results obtained by searching for the keywords with the greatest relation to the subject of the study. This procedure can be seen in Table 1, where it is possible to identify the number of publications generated through each term / combination of terms in the selected databases. In this research, no filters were selected to refine it, generating only the results for the requested terms.

Table 1 - Search results in the selected databases – Without using filters

General Search (without using filters)		
Terms	Publications	
	Web of Science	Science Direct
Economic Viability	9.294	187.343
Solar Energy	148.743	390.666
Photovoltaic	101.689	116.041
Photovoltaic solar energy	30.301	85.746
Economic Viability and Solar Energy	555	26.801
Economic Viability and Photovoltaic	334	10.442
Economic Viability and Photovoltaic solar energy	211	9.618

Another important point observed was the relevance of obtaining more up-to-date publications, as they give greater credibility to the study because they relate to what is new, both in the academic sphere and the daily observations that are fundamental for research. In this way, the search in the chosen terms was carried out again, but now, restricting the results to the publications of the last 5 years. Table 2 presents this result, in which, despite many studies found, the most current studies (2015 to 2019) represent about 46% in the WEB of SCIENCE database and about 37% in the Science Direct database.

Table 1 - Search results in the selected databases – publications in the period between 2015 - 2019

Filter: publications in the period between 2015 - 2019		
Publications		
Terms	Web of Science	Science Direct
Economic Viability	4.082	62.759
Solar Energy	65.521	137.721
Photovoltaic	48.309	49.016
Photovoltaic solar energy	16.270	37.959
Economic Viability and Solar Energy	319	11.807
Economic Viability and Photovoltaic	213	5.123
Economic Viability and Photovoltaic solar energy	134	4.718

Also, given the large number of results generated, the present study developed another search using another parameter applied to that database: selection of the “Research articles” filter in the Science Direct database and the “Article” filter in the Web of Science database. This restriction means that the search results will only present research articles, excluding book chapters, conference abstracts, errata, mini reviews, among other types of texts that were not included in the corpus of this article.

In addition, another filter applied to the search was the generation of results only in files open for reading, therefore publications of magazines or periodicals that requested registration and/or payment of some value for subscription were excluded due to make it easier to analyze the papers found in the search. Thus, Table 3 shows the variation of the results in the databases after these restrictions, in which a decrease of about 88% is observed in the publications found, showing that, the selected filters helped for a greater direction of the research.

Table 3- Publications in the period between 2015-2019 and only research articles open for viewing

Filter: publications in the period between 2015 – 2019 and only research articles open for viewing		
Publications		
Terms	Web of Science	Science Direct
Economic Viability	1.052	7.532
Solar Energy	10.941	12.530
Photovoltaic	6.543	4.513
Photovoltaic solar energy	2.300	3.768
Economic Viability and Solar Energy	41	1.090
Economic Viability and Photovoltaic	30	510
Economic Viability and Photovoltaic solar energy	20	459

Figure 1 shows a scheme designed to systematize the use of relevant terms to the work when searching for publications indexed in the chosen databases. The most generic terms are at the top of the figure, representing the major subjects that assist in the literature review with a general understanding of each issue represented by these terms. In the second line, there is the association between the more general terms, giving a greater direction to the subject of economic feasibility Study applied to solar and photovoltaic energy, thus bringing more specific publications in which these two aspects are presented together. Finally, in the third line, there are the junctions of terms used to search for the final product of the researches to be exported from the databases for analysis.

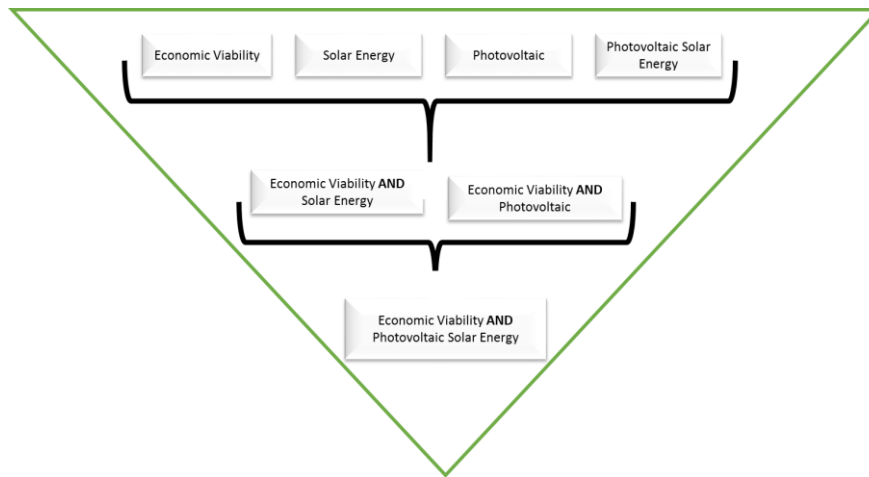


Figure 1- Search term selection scheme

After choosing the terms and criteria used in the search for journals, a total of 479 articles were found, in both databases chosen. For better visualization of these studies, the Mendeley software was used, it is a program that helps in the management and sharing of data and research documents. Through Mendeley a database was generated with 479 works for a deeper analysis.

The analysis of the 479 studies indexed to the databases began with the identification of texts that did not present subjects related to any of the relevant general terms, such as Economic Feasibility, Solar Energy, Solar Photovoltaic Energy, Solar Modules, among other similar terms. In addition, studies that had as main subject the analysis of hybrid energy modules, in other words, the generation of energy is made by solar energy in conjunction with other types (wind, coal, biogas, among others.). This identification happened from the observation of the title, abstract and keywords of the selected papers.

Among the 479 papers extracted for Mendeley, after the first observation, a total of 78 publications were left for a second more detailed analysis. After this refinement, through the eligibility study, 17 publications that most meet the proposed criteria were selected to compose the corpus. Figure 2 shows the scheme with the developed steps, from the choice of the term to be searched to the eligibility study that generated the 17 analyzed papers, also going through the criteria adopted for this final selection.

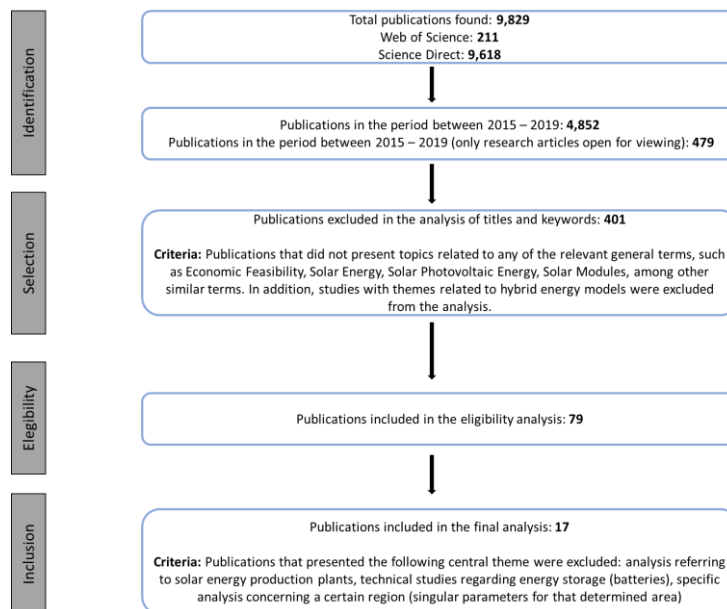


Figure 2 – Scheme for choosing publications for analysis

Results

The analysis of the 17 selected articles made it possible to identify some characteristics among them. Chart 1 shows the distribution over the years of these publications.

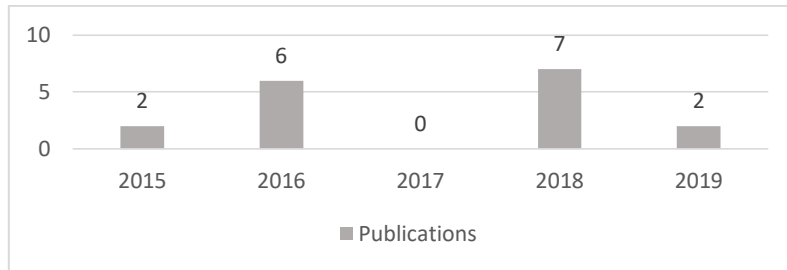


Chart 1 - Annual distribution of selected publications

Table 4 shows the journals that these studies were published, bringing *Applied Energy* as the one that generated the most publications for the study. It is also worth mentioning that the Brazilian journal *Brazilian Archives of Biology and Technology* also had an important contribution to the research, as well as the *Procedia* journal, which appears among the publications selected with studies in its area of Engineering (*Procedia Engineering*), of energy (*Energy Procedia*), Computer Science (*Procedia Computer Science*) and with *Procedia Earth and Planetary Science*.

Table 2 - Distribution of publications in each journal

Journal	Publications
Applied Energy	3
Brazilian Archives of Biology and Technology	2
Procedia Engineering	1
Energy Procedia	1
Energies	1
Energy for Sustainable Development	1
Energy Reports	1
Environmental Innovation and Societal Transitions	1
Journal of Building Engineering	1
NAVUS - Revista de Gestão e Tecnologia	1
Perspectives in Science	1
Procedia Computer Science	1
Procedia Earth and Planetary Science	1
Sustainability	1

Besides that, the publications found were analyzed according to their countries. Table 5 shows the distribution of the countries where the chosen articles came. A wide variety of countries are observed in this selection, including some articles that had contributions from authors from different places. The country with most articles is India, followed by Brazil and Norway.

Table 5 - Distribution of publications in each country

Country	Publications
India	4
Brazil	3
Norway	2
Netherlands / Belgium	1
Netherlands	1
Switzerland / Germany	1
Spain	1
Greece / Poland	1
Saudi Arabia	1
Lebanon	1
Italy	1

Discussions

Currently, the number of individuals that also requires electricity, instead of just consuming, is increasing. A new term used in Brazil to define these users is “Prosumer” (in Portuguese: “Prosumidor”), it comes from the combination of the “producer” and “consumer”. In this sense, a fundamental feature of “prosumers” is an ability to be able to generate energy, which solar production appears as one of the modes in increasing popularity, especially in European countries (Winther, Westkog, & Saele, 2018), given their relative feasibility of implantation in residences or residential buildings, through projects that allow the integration of photovoltaic panels into buildings, preserving their architectural design (Lobaccaro, Chatzichristos, & Leon, 2016) and due to the increasing concern about the negative effects of energy production through fossil fuels and their effects on the climate (Ahsan, Javed, Rana, & Zeeshan, 2016).

In convergence with the ideas presented related to the various possibilities of integrating photovoltaic panels into buildings and homes, Salem & Kinab (2015) brought some options for the installation of these panels, such as mounting on roofs, replacing glass in windows and also as can be seen in the simulation of Figure 3, in the replacement of projections used for shading the areas.



Figure 3 – Simulation of panel integration in buildings

Source: (Salem & Kinab, 2015)

The feasibility analysis of the implementation of a photovoltaic system involves the study regarding the capacity that the model must generate savings (or even profits) over the years, which is, the relationship between the cost of installation, maintenance and operation of the system that will generate energy with the costs that the user pays for the use of energy that is generated by others. The feasibility of the transition to the generation of photovoltaic solar energy must also take into account the infrastructure of each location, since it is possible that, although the financial return is good over the years, the area is not accessible for the implementation of the photovoltaic panels,

bringing problems to the system as a whole and, consequently, to the local energy supply (Elshurafa, Alsubaie, Alabduljabbar, & Al-Hsaien, 2019).

From the study of these characteristics, it is possible to see that the profitability of photovoltaic plants with or without battery systems depends a lot on the self-consumption variable, that is the user's consumption dynamics influences not only the installation dimensions, but also the profitability achieved with the project (Cucchiella, D'Adamo, Gastaldi, & Stornelli, 2018).

As an example of this analysis Ahsan, Javed, Rana, & Zeeshan (2016), through a study on the implementation of photovoltaic panels in mosques in Saudi Arabia, concludes that this installation would reduce light costs by approximately 50 percent in these mosques, without considering net metering, that is the possibility of earning energy credits from surplus production. When considering the use of these credits, energy costs fall to almost 0, since the demand for energy in mosques equates with surplus production. However, although the feasibility analysis shows the advantages of the system, the infrastructure of the mosques prevents the use of the full potential of solar incidence on the roofs, considering that its construction was not designed for this type of resource, as can be seen in Figure 4 due the presence of ventilation ducts and air conditioning in the place.

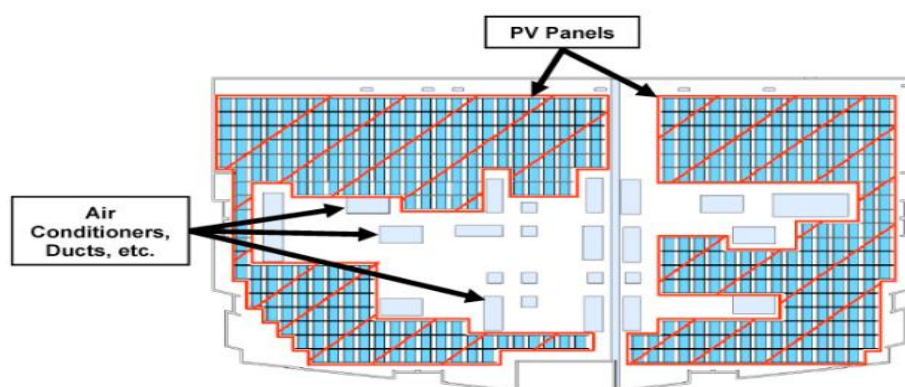


Figure 4 – Roof configuration in the studied mosques

Source: (Ahsan, Javed, Rana, & Zeeshan, 2016)

Another study that corroborates the importance of analyzing the economic feasibility of solar systems was carried out by Ghilardi Júnior, Madruga, & Alvarenga (2019) in military organizations of the Brazilian army in Santa Maria (RS), which some of the techniques that can be used are demonstrated in this type of analysis. Therefore, with tools such as Simple Payback, Discounted Payback, Internal Rate of Return (IRR) and Net Present Value (NPV), it was possible to see the financial benefits of implementing the system in military organizations considering the time of return on capital invested with the savings in the electricity bill.

Other aspects related to attempts to study the feasibility of implementing solar photovoltaic energy in each location are the characteristics that this system will present in relation to several factors, such as: storage, capacity, network usage, among others. When relating to some of these factors Quoilin, Kavvadias, Mercier, Pappone, & Zucker (2016) report a certain difficulty in identifying a consumption projection curve suitable for places that use photovoltaic systems as an energy source, in addition, there is a possibility of matrix optimization if batteries are used in these systems.

Just as Quoilin, Kavvadias, Mercier, Pappone, & Zucker (2016), Schopfer, Tiefenbeck, & Staake (2018) evidenced in their study that this difficulty in the search for an optimal configuration of the system is due to the great variability between the dynamic production/consumption of each user, even in cases where the main characteristics of the users are similar. Other point in common between the authors is the finding that this type of device, the photovoltaic systems that use

batteries, would only be profitable through the reduction of prices in batteries, given that the gains related to the optimization of the system would not be overlap with the high cost of installing the batteries.

Chart 2 presents a graph comparing the costs of photovoltaic solar energy systems in conjunction with diesel, other one that uses batteries and, finally, the on-grid system, that is using only the transmission network. The NPC (net present cost), total cost of installation and operation during the entire life of the project, of systems that use only the network is still lower than with the use of batteries (Sarasa-Maestro, Dufo-López, & Bernal-Agustín, 2016)

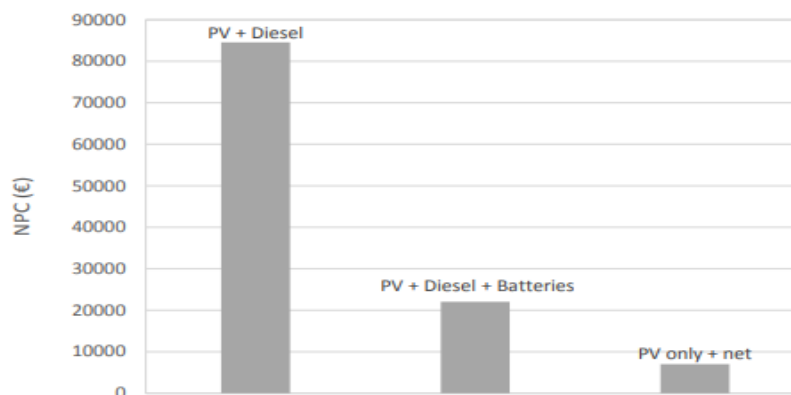


Chart 2 – Comparison between costs (NPC) of different solar photovoltaic systems

Source: (Sarasa-Maestro, Dufo-López, & Bernal-Agustín, 2016)

Still in this sense, another important factor associated with batteries is their peak shaving potential (term that refers to the installation of complementary sources of energy in a system to meet peak demand). To realize this potential, a study about these peaks must be developed, relating them to the size of the batteries to be used, something that influences the cost of the system (Schram, Lampropoulos, & Sark, 2018).

When bringing the discussion to the national level, it is evident that solar energy in Brazil has a high potential to bring great economic and environmental benefits to the Brazilian energy matrix (Silveira, Moreira, Moreira, & Junior, 2018). However, this type of renewable energy still needs greater incentive and engagement, because, despite the good opportunity for return in the medium/long term and the significant decrease in costs over the last decades, a very high initial investment is still necessary. Even in places where the incidence of sunlight is abundant, making the potential for generating this type of energy greater, the effect of the market and its prices have a high impact on the financial viability of the project (Khatri, 2016).

In addition to the high associated costs, Nikas et al. (2018) bring some more barriers associated with the transition to more renewable production, among them: effects of the economic crisis in several regions, public acceptance still limited regarding renewable energies, instabilities in regulatory frameworks. The practices that regulate the solar energy sector, appears as an important factor when analyzing economically the installation of a solar system, the way the region treats self-production. This influence in the economic sphere occurs through the possibility of sharing the network, allowing the export of surplus energy produced, to compensate with energy imports the periods when the production of the system is not sufficient (Kumar, 2015).

For this reason, policies that encourage this type of power generation could also help to increase the production of photovoltaic modules (today the vast majority are imported from other countries) and, consequently, decreasing installation costs, as well as generating return for Brazilian economy. Loan and financing programs in banks such as Caixa Econômica Federal (Caixa), The Brazilian Development Bank (BNDES) and Santander are found in Brazil today, although they do

not have wide dissemination and solid projects for large-scale implementation of solar energy (Garcia, Nogueira, & Betini, 2018).

Another type of actions in the political sphere that can be taken to promote the production of renewable energies, especially solar energy, is to use it as a source of energy in state properties, such as public buildings, electric cars, among others. Kumar, Singh, & Reddy (2016) make an interesting contribution in this regard by presenting a study on the implementation of small solar panels on the streetlights used in public lighting in the city of Fugar, Nigeria, where small batteries would be used to maintain the system in operation during the entire demand period, as can be seen in Figure 5.

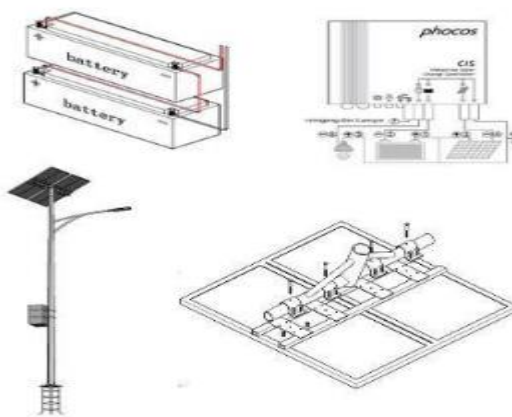


Figure 5 – Configuration of public lighting poles powered by photovoltaic solar energy in the city of Fulgar, Nigeria

Source: (Kumar, Singh, & Reddy, 2016)

An important point that can have a positive impact on the expansion of this type of energy is the fact that its costs have been decreasing considerably over the years in the world. Between 2010 and 2016 there was a decrease of 69% in this cost and, furthermore, the projection is for a drop in half of the cost by 2020, based on the costs data collected in 2017. It should be noted that Brazil contributed with this number as a decrease of about 30% in the costs of installing residential photovoltaic systems (Irena, 2018).

Final Considerations

The studies analyzed in this review can be described as having a wide variety of subjects related to the topic of economic feasibility associated to the production of photovoltaic solar energy. In this way, several characteristics about the literature on this matter were evidenced, from the popular and scientific perception about this type of energy, to the different ways of developing an energy producing system, including the initiatives that would help in the expansion of this type of energy production.

Additionally, it was possible to notice many publications related to the issue, something that emphasizes the need to establish considerably specific filters to acquire several publications that would allow a more detailed analysis. Regarding what was analyzed in the selected articles, it is evident that the authors have sought to identify characteristics, in addition to the economic and environmental benefits, attributed to photovoltaic panels that assists in their popularization as a source of energy for homes and/or buildings, commercial or not.

Another common point discussed by the researchers is the study on the best photovoltaic system to be used for each user, that is, whether batteries are the best option as a storage source, or whether the connection of the system to the network is the guarantee best suited to meet demand. It

is worth mentioning that the economic and environmental aspects is guiding factors in these discussions.

Finally, the literature shows that strategic initiatives, especially government policies, are key to the expansion of photovoltaic solar energy. The characteristics of the regulatory framework and the policy aimed at this type of energy proved to be points that, essentially, should be studied and measured in the development of an economic feasibility study, given that they positively or negatively influence the installation and operation of photovoltaic systems and they are different in each part of the world, either by the characteristics of the political development plans, or by the characteristics of infrastructure and solar resources of each location.

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DECLARATION OF CONTRIBUTIONS TO THE ARTICLE - CRediT

ROLE	COFConcolato	MRCunha	HCAGAfonso
Conceptualization – Ideas; formulation or evolution of overarching research goals and aims.	X		
Data curation – Management activities to annotate (produce metadata), scrub data and maintain research data (including software code, where it is necessary for interpreting the data itself) for initial use and later re-use.	X		
Formal analysis – Application of statistical, mathematical, computational, or other formal techniques to analyze or synthesize study data.	X	X	
Funding acquisition - Acquisition of the financial support for the project leading to this publication.			
Investigation – Conducting a research and investigation process, specifically performing the experiments, or data/evidence collection.	X	X	
Methodology – Development or design of methodology; creation of models.	X		
Project administration – Management and coordination responsibility for the research activity planning and execution.	X		
Resources – Provision of study materials, reagents, materials, patients, laboratory samples, animals, instrumentation, computing resources, or other analysis tools.			
Software – Programming, software development; designing computer programs; implementation of the computer code and supporting algorithms; testing of existing code components.	X	X	
Supervision – Oversight and leadership responsibility for the research activity planning and execution, including mentorship external to the core team.	X		X
Validation – Verification, whether as a part of the activity or separate, of the overall replication/reproducibility of results/experiments and other research outputs.	X	X	X
Visualization – Preparation, creation and/or presentation of the published work, specifically visualization/data presentation.	X	X	X
Writing – original draft – Preparation, creation and/or presentation of the published work, specifically writing the initial draft (including substantive translation).	X	X	X
Writing – review & editing – Preparation, creation and/or presentation of the published work by those from the original research group, specifically critical review, commentary or revision – including pre- or post-publication stages.	X	X	X