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COVID-19 pandemic impact on micro and mini photovoltaic distributed generation in Brazil: selection and analysis of representative indicator

Impacto da pandemia de COVID-19 na micro e minigeração distribuída fotovoltaica no Brasil: seleção e análise de indicador representativo

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ABSTRACT

In the search for sustainability in the energy sector, photovoltaic solar energy (PV) has been highlighted as a solution to promote sustainable development. As PV technology expands, there is a need for studies to assess how the new market behaves in different scenarios with the consequent elaboration of different indicators. Following an interdisciplinary approach, and based on the epistemological paradigm of Design Science, the objective of this study was to analyse, preceded by selection and evaluation, indicators that reflect a possible impact of the COVID-19 pandemic on the Micro and Mini Photovoltaic Distributed Generation (MMDG) market in Brazil in 2020 and 2021. To do so, it was characterized through a systematic literature review - SLR, the state of the art about impact of the COVID-19 pandemic on the photovoltaic market and photovoltaic systems indicators. Subsidized by RSL and supported by the core literature on the subject, the Photovoltaic Systems Monthly Installed Power Capacity indicator was selected. Then, the analysis of this was carried out, by means of feeding the indicator using a query in the open database of the brazilian National Electric Energy Agency - ANEEL. It was identified that with the initial general awareness, caused by the first peak of the COVID-19 pandemic, the photovoltaic market suffered a reduction in the Monthly Installed Power Capacity, however, after this initial moment, the indicator recovered, suggesting a capacity for resilience and adaptation of this market, overcoming the difficulties and new challenges encountered, maintaining the pace of growth observed before the pandemic.

Keywords: photovoltaic systems indicators; photovoltaic market; distributed generation; monthly installed power capacity; design science research.

RESUMO

Na busca pela sustentabilidade no setor energético, a energia solar fotovoltaica (FV) vem-se destacando como solução para promover o desenvolvimento sustentável. À medida que a tecnologia FV se expande, surge a necessidade de estudos para a avaliação de como o novo mercado se comporta diante de diferentes cenários, com a consequente elaboração de indicadores diversos. Seguindo uma abordagem interdisciplinar e baseado no paradigma epistemológico da *Design Science,* o objetivo do presente estudo foi analisar, após seleção e avaliação, indicadores que reflitam um possível impacto da pandemia de COVID-19 no mercado de Micro e Minigeração Distribuída Fotovoltaica no Brasil (MMGD) nos anos de 2020 e 2021. Para tanto, caracterizou-se, por meio de revisão sistemática da literatura (RSL), o estado da arte a respeito do impacto da pandemia de COVID-19 no mercado fotovoltaico e de indicadores aplicados a sistemas fotovoltaicos. Com subsídios da RSL e conforme a literatura de base sobre o assunto, selecionou-se o indicador Potência Mensal Instalada de sistemas fotovoltaicos. Efetuou-se então a análise deste por meio de alimentação do indicador, por meio de consulta em banco de dados abertos da Agência Nacional de Energia Elétrica (ANEEL). Identificou-se que, com a sensibilização geral inicial causada pelo primeiro pico da pandemia de COVID-19, o mercado fotovoltaico sofreu redução na Potência Mensal Instalada; porém, passado esse momento inicial, observou-se a recuperação do indicador, o que sugere capacidade de resiliência e de adaptação desse mercado, superando as dificuldades e novos desafios encontrados e mantendo o ritmo de crescimento observado antes da pandemia.

Palavras-chave: indicadores aplicados a sistemas fotovoltaicos; mercado fotovoltaico; geração distribuída; potência mensal instalada; *design science research*.

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Introduction

The topic of sustainability has become a rising agenda, widely debated in different sectors of society (Fernandes and Vieira, 2014). The growing reflections and interest in it evidenced the need to review existing paradigms, especially the one that natural resources are infinite. Thus, countries and the international community were stimulated to develop joint actions with a view to reconciling the production of goods necessary for the quality of life of societies while preserving natural elements equally responsible for this quality (Philippi Jr. et al., 2013; Fernandes and Vieira, 2014; Erzen et al., 2021).

In the context of the search for sustainable development, the energy issue is one of the main focuses, according to the Ministry of Science and Technology (Brasil, 2010), facing the difficulty of reconciling the maintenance of the supply of energy inputs with the maintenance in short and long-term environmental, social, ethical, cultural, economic, spatial, and political needs of society. The energy issue gains such importance in the context of sustainability that it is mentioned directly in the seventh Sustainable Development Goal (SDG) of the United Nations (UN): "Ensuring reliable, sustainable, modern, and affordable access to energy for all" (UN, 2015, p. 21).

According to Gomes (2013), the global energy policy agenda has been guided by three main pillars:

- economic security: electricity generation at a competitive cost;
- energy security: reliability in energy supply;
- environmental security: restriction of environmental impacts resulting from electricity generation.

In this context, by reinforcing these three pillars, renewable sources of electricity generation emerge as a solution to promote sustainable development in the sector (Connolly et al., 2016; Kuang et al., 2016; Nunes-Villela et al., 2017).

Among these sources, photovoltaic solar energy (PV) has been highlighted thanks to its low environmental impact of deployment and generation (EPE, 2021; REN21, 2021). According to the global think tank Renewable Energy Policy Network for the 21st Century — REN21 (2021), PV technology is expanding as it becomes the most competitive option for generating electricity in an increasing number of locations. Thus, as its penetration level increases, PV generation has a growing effect on electrical systems, increasing the importance of developing indicators and studies to assess how this new market expands and behaves in different scenarios (REN21, 2021).

According to Malheiros et al. (2008), indicators provide diagnoses of topics of interest, supporting the decision-making process. This understanding, therefore, allows the spotting of trends, making it possible to more effectively direct urban policies, energy planning, programs to encourage PV generation, among other actions (Adachi and Rowlands, 2010; Polo and Hass, 2014; Scolari and Urbanetz Jr., 2018).

One of the current scenarios that needs to be evaluated is the identification of how PV generation behaved in the face of the impacts caused by the COVID-19 pandemic. According to Marsillac (2021), the COVID-19 pandemic has had a serious impact on global financial markets, changing consumer and industry behaviors as well as supply chain trends in general, and also affecting the PV market specifically. Wang et al. (2021) consider that solar energy is an important basis for global energy development, and thus it is particularly fundamental to study the effects caused by the COVID-19 pandemic on this market.

This comprehension will increase the understanding of this new technology, assessing its resilience power in the face of the serious social, financial, and cultural impacts caused by the aforementioned pandemic; not only for this, but so that the current and future conjuncture are considered in the country's energy planning studies, evidencing and substantiating its viability and continuity (Scolari, 2019; Eroğlu and Cüce, 2021).

According to Tiepolo (2015), energy sector planning is an essential tool to ensure the continuity of electricity supply and for the formulation of public policies. Along the same lines, according to the Northeast Development Agency (Adene, 2015), policymakers and regulatory agencies are actors with great institutional power, influencing the entire complex national electricity sector through their decisions; however, these decisions, in most cases, are taken in an environment of uncertainty and require systematic decision support processes and adequate indicators. This corroborates the need to assess the influences of COVID-19, a worldwide phenomenon, on the national PV market.

In this context of interdisciplinarity, this article is structured so that such an approach converges to the creation of new knowledge, applicable in different areas. For this, first, the state of the art regarding the impact of the COVID-19 pandemic on the PV market and indicators applied to PV systems will be characterized through a systematic literature review (SLR). Then, the methodology adopted in this study will be detailed, which follows the epistemological paradigm of Design Science, and the strategies of SLR are described. Finally, the results will be reported and discussed, and the conclusions obtained will be presented.

Impact of the covid-19 pandemic on the photovoltaic market

As noted in the SLR, with procedures described in the methodology section, the relationship between the COVID-19 pandemic and PV energy is still poorly addressed in academia. However, even with few studies in this field, it is observed that the approaches are quite varied and conducted under the most different aspects, areas of knowledge, and geographical areas.

Hariharan (2020) and Naderipour et al. (2020), for example, assess the impact of the COVID-19 pandemic on the increase in PV generation. They attest that, since the lockdown caused by the restrictive measures reduced the movement of people and industrial production, there was also a reduction in the emission of greenhouse gases, which intensified the solar radiation on the PV panels and, consequently, increased the generation of electricity of these systems.

In addition, studies focused on the field of Electrical Engineering, more specifically on electrical power systems (Alam and Ali, 2021; Gallo et al., 2021), assess the effects of the change in the profile of electrical consumption caused by the pandemic in electrical distribution networks and the impact of PV generation in this context. In a scenario of electrical system stress, PV generation was seen as an important countermeasure to provide resilience to the electrical power system, which can be defined as the ability to withstand stress events without being compromised, or to adapt to these events to minimize compromise through graceful degradation (Taft, 2017).

Still in the field of Electrical Engineering, studies have evaluated the change in the electrical matrix in Spain and Japan due to the pandemic (Micheli et al., 2021; Tingting Xu et al., 2021). The reduction in industrial production led to a reduction in the load on electrical systems, causing large plants to have their generation reduced. In this context, decentralized PV systems (residential, commercial, and industrial) that are not controlled in the dispatch of energy generated by the electrical system operators continued with their normal generation, which increased the percentage share of this generation source in the electricity matrix of these countries (Micheli et al., 2021; Tingting Xu et al., 2021).

In the area of Economics, studies point to the negative impact of the pandemic on the share prices of companies in the PV sector, scaring investors and making it difficult for these companies to capitalize for new projects (Eroğlu and Cüce, 2021; Wang et al., 2021).

Entering the context of the PV market itself, several authors approach the topic with studies conducted from different perspectives. Marsillac (2021) highlights that the uncertainties and security measures resulting from COVID-19 have led to the interruption of a large part of global industrial production at the same time they have changed consumption patterns, causing a double impact, both on supply and demand. Along the same lines, Eroğlu and Cüce (2021) point out that the solar energy sector has critical points in the production chain, which were negatively affected by the COVID-19 pandemic, a perception also evidenced by Vaka et al. (2020).

Song et al. (2020) report that the influence of the COVID-19 pandemic on the PV market mainly includes production delay, labor shortages, logistical problems, increased production cost, raw material shortages, and uncertain prospects for foreign trade, which are also supported by Vaka et al. (2020).

According to Eroğlu and Cüce (2021), the PV market supply chain is highly dependent on imports of components from China, as already reported by Rabe et al. (2017). The temporary closure of these industries affected the supply to the sector, causing shortages and rising prices (Radu et al., 2020). The studies by Song et al. (2020) and Wang et al. (2021), who report delays in the supply chain of PV modules and other equipment due to the COVID-19 pandemic, support these observations.

Concerning business management aspects, Marsillac (2021) highlights that companies in the PV sector that, even before the pandemic, had been seeking efficient business management were able to react and adapt more quickly than companies that did not adopt such practices.

Turning the analysis to the other extreme of the PV market, Radu et al. (2020) point out that during the initial stages of the pandemic, the greatest concern was related to the production chain, that is, the impact on the supply of components; as soon as industrial production resumed, concern shifted to demand, with the cancellation of construction sites and restrictions on travel and work.

If, at one end, the PV market is fed by the component industries, at the other end it is pulled by the installation, testing, and commissioning workforce (Eroğlu and Cüce, 2021). Therefore, since there is a lack of components in the market and the mobility of professionals is limited during the pandemic, it is not possible to complete stages of the installation process (Das, 2020), which causes delays in projects, idleness of the workforce, and dismissal of employees, with small installers being the most affected (Vaka et al., 2020). Radu et al. (2020) conclude by stating that the impact on the operation of the PV plants already installed, which comprise the final end of the PV market, was minimal, since this operation is largely remote and classified as essential in most countries.

On the other hand, Marsillac (2021) highlights a learning point provided by the pandemic: the interdependencies in the production chain started to be understood in a more concrete way, revealing how problems with critical trading partners can have repercussions throughout the production chain.

In their study evaluating the impact of the pandemic on the Chinese PV market based on modelling, Song et al. (2020) conclude that the pandemic causes an immediate delay effect on the entire chain, ending up causing an increase in the levelized cost of energy (LCOE), an important indicator of the economic return of PV plants. Song et al. (2020) also note that the PV market had a lag in response of approximately three months in relation to the COVID-19 pandemic.

Despite efforts to understand the impact of the pandemic on the PV market, Eroğlu and Cüce (2021) state that the magnitude of the effect is not fully investigated, and that studies along these lines are needed to increase understanding in the area. At the same time, no work was identified that evaluated the impact of the COVID-19 pandemic on the Brazilian PV market based on SLR. Neither was any study found that identified indicators or analyzed them using official databases to quantify this impact. Likewise, no research has evaluated the consequences of the COVID-19 pandemic specifically in the PV market niche, which includes small distributed generation PV plants, considering the databases used in SLR, which will be detailed later.

In this context, considering the advances and gaps revealed by the state of the art on the subject, the aim of this study was to analyze indicators that reflect the possible impact of the COVID-19 pandemic on the micro and mini distributed generation (MMDG) PV market in Brazil in the years 2020 and 2021, through its selection and evaluation.

PV systems of up to 75 kW are called "distributed microgeneration" and PV systems of up to 5 MW are called "distributed mini-generation", installed in the consumer unit itself (residential, commercial, industrial, among others) and supported by Normative Resolution (REN) No. 482, of April 17th, 2012, by ANEEL (2012; 2015). Thus, large PV plants installed centrally were not considered in the scope of this study.

Moving toward achieving the proposed objective, the theme "indicators" will be conceptualized in the next section, with the help of the basic literature on the subject. Next, the state of the art regarding indicators applied to PV systems through SLR will be portrayed. In this way, it is intended to theoretically and conceptually support the selection and evaluation of the indicators used in this study.

Indicators applied to photovoltaic systems

According to Gallopín (1996), different authors define indicators in different ways, including: a measure of the system's behavior in terms of significant and perceptible attributes (Holling, 1978); a measure that summarizes information relevant to a given phenomenon (McQueen and Noak, 1988); a variable hypothetically linked to the studied variable that cannot be observed directly (Chevalier et al., 1992); a parameter that points to information about the state of a phenomenon (OECD, 1993); partial reflections of reality (Meadows, 1998); qualitative, quantitative, statistical and/or graphic information, which seek to present reality in a systematic way (Rauli et al., 2006); a parameter of special relevance to reflect certain conditions of the system under analysis (Silva and Souza-Lima, 2010); tools consisting of one or more variables that, associated in different ways, reveal broader meanings about the phenomena to which they refer (IBGE, 2015).

For Meadows (1998), indicators are tools of change, learning and propaganda, and their presence, absence or prominence affect behavior in relation to the evaluated fact. Also according to Meadows (1998), as indicators are at the center of the decision-making process, when poorly chosen, imprecise, biased or poorly evaluated, they can cause errors in the interpretation of the phenomenon under analysis; decisions based on such indicators may not be effective, leading to misconduct and over- or under-reactions to the phenomenon. Along the same lines, for Malheiros et al. (2008), indicators provide diagnoses of topics of interest, supporting the decision-making process.

According to Tunstall (1992) and Gallopín (1996), the main functions of indicators are:

- assessment of conditions and trends;
- comparison between places and situations;
- assessment of conditions and trends in relation to goals and objectives;
- provision of warning information;
- anticipation of future conditions and trends.

This study considered that the most relevant indicators are those that summarize relevant information about the observed phenomenon, making certain aspects of this it, which are barely perceptible, become apparent to the reader (Gallopín, 1996). Indicators are more meaningful for what they point to than for their absolute value (IBGE, 2015).

Based on the theoretical frameworks presented and on SLR, which will be methodologically described in the next section, it was possible to identify the state of the art in relation to the application of indicators for the evaluation of various aspects of the PV market, with the main findings shown in Chart 1.

It is observed that the theme including indicators applied to the PVS is approached in an interdisciplinary way by the authors of the area, passing through different dimensions of the field of study. Ghenai et al. (2020) and Mei and Chen (2021), for example, categorized PV system indicators into five dimensions: environmental, economic, social, resource, and technological. Following this line, the same categorization was used in this study.

Furthermore, studies in this field move between these different dimensions with greater or lesser intensity, according to the scope or specificity that the author seeks. Although larger studies approach more dimensions of the phenomenon, they do not cover in depth a certain aspect, which is better appreciated in more specific studies.

Chart 1 – Indicators identified by the systematic literature review.

Indicator	Unit	Source
Economic Dimension		
Profitability index — PI	%	Narkwatchara et al. (2021)
Benefit-cost ratio — BCR	%	
Payback period — PB	*Years*	
Net present value — NPV	R$	Liu et al. (2018), Guo et al. (2021), Narkwatchara et al. (2021)
Return on investment — ROI	%	
Internal rate of return — IRR	%	
Levelized cost of energy — LCOE	R$/kWh	Liu et al. (2018), Ghenai et al. (2020), Guo et al. (2021)
Installation unit cost	R$/kW	Liu et al. (2018), Ghenai et al. (2020)
Implementation cost	R$	Mei and Chen (2021)

Continue...

Chart 1 – Continuation.

Indicator	Unit	Source
Resource Dimension		
Solar radiation	kW/m²	Ogbonnaya et al. (2020), Tanu et al. (2021)
Solar irradiation	kW/m²/day	Liu et al. (2018), Guo et al. (2021), Narkwatchara et al. (2021)
Energy payback time — EPBT	Years	Kourkoumpas et al. (2018), Lamnatou et al. (2018)
Delivered energy — DE	kWh	Kourkoumpas et al. (2018)
Energy returned on energy invested — EROEI	Dimensionless	Kourkoumpas et al. (2018), Peiró et al. (2022)
Area intensity	m²/kW	Ghenai et al. (2020)
Material intensity	Kg/kW	
End-of-life recycling input rate — EOLRIR	%	Peiró et al. (2022)
Technology Dimension		
Yield	kWh/kWp	Scolari (2019), Oprea and Bâra (2020), Sakellariou and Axaopoulos (2020), Narkwatchara et al. (2021)
Performance ratio — PR	%	Scolari (2019), Oprea and Bâra (2020)
Capacity factor — CPF	%	Scolari (2019), Ghenai et al. (2020)
Energy efficiency — EFF	%	Ghenai et al. (2020), Ogbonnaya et al. (2020), Erzen et al. (2021), Mei and Chen (2021)
Lifetime	Years	Liu et al. (2018), Ghenai et al. (2020)
Energy production	kWh/month	Narkwatchara et al. (2021)
Occupied area	m²	Scolari et al. (2018), Scolari and Urbanetz Jr. (2018), Scolari (2019)
Average efficiency of PV panels	%	
Centralized x Distributed generation ratio	%	Scolari and Urbanetz Jr. (2018), Scolari (2019)
Environmental Dimension		
Global warming potential — GWP	t CO_2-eq.	Kourkoumpas et al. (2018), Lamnatou et al. (2018), Mei and Chen (2021), Peiró et al. (2022)
Global warming potential per installed capacity	t CO_2-eq./kW	Peiró et al. (2022)
Ecological footprint — carbon dioxide	Pts	Lamnatou et al. (2018)
Ecological footprint — land occupation	Pts	
Climate change	Kg CO_2-eq.	Lamnatou et al. (2018), Garraín et al. (2020)
CO_2 intensity — construction	Kg CO2/kW	Ghenai et al. (2020)
CO_2 intensity — fuel	Kg CO2/kWh	
Sustainability index	Dimensionless	Erzen et al. (2021)
Social Dimension		
Agricultural land occupation	m²	Lamnatou et al. (2018)
Urban land occupation	m²	
Health risk	Dimensionless	Mei and Chen (2021)
Social acceptability	Dimensionless	
Installed power capacity	GW	Liu et al. (2018), Scolari et al. (2018), Scolari and Urbanetz Jr. (2018), Scolari (2019), Urbanetz et al. (2019), EPE (2021), Ghenai et al. (2020), Ogbonnaya et al. (2020), Guo et al. (2021), Narkwatchara et al. (2021), REN21 (2021)
Growth rate	%/ year	Scolari (2019), Urbanetz et al. (2019), Ghenai et al. (2020), REN21 (2021)
Per capita installed power capacity	kW per capita	Scolari (2019)
Per residence installed power capacity	kW/resid.	

In this way, it was evaluated that both types of study are important to build a theoretical framework on the subject.

As described in the "Research Methodology" section, this was not an exhaustive SLR, but rather a saturation one, which does not intend to exhaust all available content on the topic under study, but to sufficiently characterize it for the purposes of the research.

Although no indicator was identified with the specific purpose of representing the influence of the COVID-19 pandemic on the PV market, the large number of indicators collected through SLR opens the way to subsidize the choice of indicators for such representation, object of this study. It was observed, through content analysis, that official energy reports (EPE, 2021), international observatories (IEA 2020a, 2020b, 2021; REN21, 2021), in addition to the literature in the area (Liu et al., 2018; Scolari and Urbanetz Jr., 2018; Scolari et al., 2018; Scolari, 2019; Urbanetz et al., 2019; Ghenai et al., 2020; Ogbonnaya et al., 2020; Guo et al., 2021; Narkwatchara et al., 2021) use the indicator "installed power" to characterize the insertion of a given energy source in the electrical matrix of a given region. Thus, such studies compare and trace trends between different energy sources.

On the other hand, in Brazil, regarding distributed micro and mini-generation, a given plant only has its individual installed power accounted for in the national installed power after it starts operating (ANEEL, 2022). In other words, this plant will be accounted for in the ANEEL database (2022) only after the various stages of the marketing process have been completed: raw material extraction, component manufacture, transport, financing, public policies, design, installation, commissioning, among others (Song et al., 2020).

Thus, any oscillations faced in any of these stages will end up reflecting in the indicator of installed power of PVS in the same period or with delay (Song et al., 2020), which makes this indicator sensitive to market uncertainties, instabilities and variability, thus representing the health of the PV sector as a whole.

It is true that the simple correlation between variables does not mean a causal relationship between them (Vencovsky and Barriga, 1992). However, the causal relationship between the COVID-19 pandemic and its impact on various sectors of the PV market in the years 2020 and 2021 was proved by SLR. Thus, the installed power indicator being sensitive to such impacts, and since no evidence has been identified in the recent literature on the subject that other factors could be impacting the PV market, it is plausibly safe to say that breaks in the growth pattern of the PVS installed power indicator are causally related to the COVID-19 pandemic.

In addition to the practical aspect, theoretical aspects are equally relevant when choosing the indicator to be selected. For this reason, the candidate for the "installed power" indicator was submitted to the sieve of the literature on the subject (Berliner and Brimson, 1988; Tironi et al., 1991; Neely et al., 1997; Meadows, 1998; Callado and Fensterseifer, 2010; Caldeira, 2018), with regard to the characteristics of a good indicator: being selective, clear, representative, sufficient, simple, low-cost, stable, available, and allowing external comparisons. After evaluation, it was judged that the analyzed indicator had all the desirable characteristics mentioned above.

In this way, subsidized by SLR and supported by the analysis of the basic literature on the subject, this study opted to assess the impact of the COVID-19 pandemic on the MMDG PV market in Brazil, the Installed Monthly Power of PVS indicator. For this study, the monthly integration periodicity of the indicator was adopted, since the period of one month has good representation and sensitivity in relation to the phenomenon under study.

Thus, once the selection stage is completed and before carrying out the evaluation of the selected indicator, the methodological lines that guided and epistemologically supported the present study, fundamentally bibliographic and analytical, will be described in the next section.

Research Methodology

From a transdisciplinary perspective, and supported by the model proposed by Gibbons et al. (1994), the present work was intended to produce type 2 knowledge, that is, to use transdisciplinarity to solve problems; unlike type 1 knowledge, which has a purely academic and unidisciplinary bias (Dresch et al., 2015).

Considering that transdisciplinarity has its own theoretical structure and specific research methods, in which traditional sciences may present limitations (Gibbons et al., 1994; Starkey and Madan, 2001; Van Aken, 2004; 2005), adequate epistemological paradigms must be used during the conduct of the study.

In this context, the epistemological paradigm adopted for the elaboration of this research was the Design Science proposed by Simon (1996). Since the objective is not to discover natural or universal laws that explain the behavior of the object of study, Design Science aims to develop solutions to improve existing systems, solve problems or even create artifacts that contribute to better human performance, being suitable for conducting type 2 transdisciplinary research (Gibbons et al., 1994; Dresch et al., 2015).

Once the epistemological paradigm used, which is guided by the strategy for conducting scientific research based on Design Science, proposed by Dresch et al. (2015), it is necessary to substantiate the scientific and the research methods used. According to Dresch et al. (2015), design science research is the research method that underpins and operationalizes research conducted under the Design Science paradigm, oriented toward the solution of specific problems and not necessarily aiming at the optimal solution, but rather a satisfactory solution to the problem.

As it is an important element in conducting design science research, an SLR was performed adapting the method proposed by Dresch et al. (2015), which applies to the needs of the former. For Van Aken (2011), SLR can help to identify solutions for a particular class of problem, in addition to identifying gaps in the existing literature.

Through SLR, we sought to address the state of the art on the relationship between COVID-19 and PV generation, as well as on indicators applied to this form of generation; in addition to verifying if there are studies that address all three major themes simultaneously: COVID-19, PV generation, and indicators.

In this sense, a configurative review was intended to be carried out, in which heterogeneous primary studies are sought, which are explored and interpreted, resulting in a coherent theoretical rendering (Dresch et al., 2015). For this, a saturation search strategy was used, which aims to locate sufficient primary studies for a coherent configuration of the study theme. In this way, the search for new materials extends to the moment when they do not contribute with new concepts to the synthesis process on canvas (Brunton et al., 2012; Dresch et al., 2015).

In the search for minimizing bias in the search strategy, Dresch et al. (2015) emphasize the importance of including synonyms, different spellings and similar expressions in the search, in addition to the main terms. Following this guideline, in addition to the main terms — indicators, PV systems, and COVID-19 — groups of descriptors were searched for each main term, both in Portuguese and in English. The choice of descriptors was performed using the adherence test, which considered several descriptors for each main term.

The query stage was carried out in January 2022 in the following databases:

- Scientific Electronic Library Online (SciELO);
- Digital Library of Theses and Dissertations (*Biblioteca Digital de Teses e Dissertações* – BDTD);
- Scopus (Elsevier);
- Web of Science (Main Collection — Clarivate Analytics).

Among the various databases made available by the portal of the Coordination for the Improvement of Higher Education Personnel (*Coordenação de Aperfeiçoamento de Pessoal de Nível Superior* – CAPES), these were chosen for the large number of peer-reviewed indexed items in each one and for offering a comprehensive overview of the world production in different areas of research. Thus, the research became comprehensive enough to address the issues at hand with the necessary depth and breadth, minimizing any research bias.

In addition to searching for groups of descriptors individually, a combined search for groups of descriptors was carried out, using Boolean logical operators "AND" and "OR", keeping in mind the alignment with the study theme and aiming at both precision and satisfactory recall accuracy. Results were filtered for documents published in the period from 2018 to 2022, in Portuguese and English.

After excluding duplicate materials that were not in line with the research, 21 documents addressing the relationship between COVID-19 and PV generation were selected, as well as 16 documents that deal with indicators applied to PV generation. No relevant results addressing these three themes at the same time were found. Also, no relevant result was found in Portuguese, nor adressing the Brazilian territory.

Dresch et al. (2015) underline the importance of the database search not being exclusive, and the possibility to consult gray literature. Kugley et al. (2017) highlight that, proceedings of congresses, seminars and conferences, documents and reports produced by the government or international bodies, among others, are a good source of gray literature, since more than half of the studies presented are never published. Thus, another six documents were selected to deepen the characterization of the indicators applied to PV generation.

In the next section, the results obtained through the evaluation of the selected indicator, using official open data, will be presented and discussed.

Results and Discussion

Once the Installed Monthly Power indicator of PV systems has been chosen, its analysis will be carried out in this section by means of feeding the indicator, as consulted in an open database.

The Distributed Generation System (*Sistema de Geração Distribuída* – SISGD) is an official open database that contains a list of distributed generation projects (ANEEL, 2022), that is, a list of all MMDG plants supported by REN No. 482/2012 in operation in Brazil (Scolari and Urbanetz Jr., 2018). Thus, as this study intends to only address MMDG systems, the information contained in the SISGD was used to feed the indicator. The database used has, among others, information on the date and installed power of each MMDG plant in Brazil.

Although this information is available for open consultation, it is not compiled in a way that facilitates the analysis, nor does it constitute indicators that can be consulted in a practical way by the agent that demands such information. Thus, firstly, the data contained in the database were exported to an electronic spreadsheet so that the information could be treated with greater flexibility. The database query was performed in February 2022.

Then, only the plants with PV generation were selected, and the time range was made based on PV plants with registration date between January 1st, 2018 and December 31st, 2021. The year considered for the beginning of the time range was 2018 so that it was possible to assess the trend of the indicator before the event to be analyzed: the COVID-19 pandemic, which started in December 2019.

Then, the monthly payment of the PVS power installed in each month was elaborated. The monthly payment period was used because it has a good representation of the trend of the analyzed indicator. Finally, this information was consolidated in the form of graphics, in order to make the analyzed fact more understandable.

Graphic 1 shows the generated SFV power curve of MMDG added per month in Brazil, from January 2018 to December 2021. To assist in the interpretation of the indicator's behavior through the smoothing of the aforementioned curve, the moving average technique is used, one of the most used for this purpose (Latorre and Cardoso, 2001). Thus, the centered moving average of period three was calculated, that is, for each month, the average of the added power values in the previous month, in the current month, and in the following month was calculated; the resulting curve of this process is also represented in Graphic 1.

There is a constant and consistent increase in the monthly power added between January 2018 and March 2020, when the peak of 256 MW added in the month was reached. The months of April and May are marked by a sharp drop in Installed Monthly Power, with 212 MW and 196 MW added in these months, respectively. The month of March 2020 represents the moment when the COVID-19 pandemic began to be felt more intensely in the Brazilian territory. The Installed Monthly Power started to drop the following month, suggesting a correlation between the two facts, but with a delay of approximately one month. Thus, the initial impact of the pandemic on the Installed Monthly Power of PVS was felt from April 2020.

This delay, also observed by Song et al. (2020), can be explained by the dynamics of the PV market. The date of installation of a PVS indicated in the consulted database is the date on which the PVS actually went into operation. Before that, there is a whole process of commercial negotiation with the installing company, in addition to the elaboration and approval of the project by the energy concessionaires, the purchase of equipment, and installation and commissioning of the PVS. Thus, a PVS that went into operation in March, for example, was already contracted and being installed at least a month earlier.

The downward trend in Installed Monthly Power continued until August 2020; in the following months, it followed a growth trend, suggesting the beginning of the recovery and culminating in installed capacity in December 2020 higher than that recorded before the beginning of the pandemic. Thus, the beginning of the recovery in the Installed Monthly Power was observed in the fifth month (August) after the initial impact (April), a recovery that was completed eight months (December) after this initial impact.

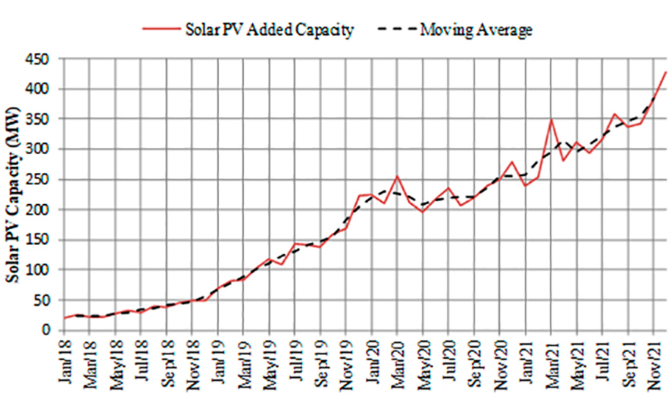
In the first three months of 2021, the increase in Installed Monthly Power was accentuated, with the addition of 350 MW being recorded in March 2021, the highest monthly value ever recorded so far; this shows that, in addition to recovering, the PV market was heated in the first quarter of 2021.

However, the second peak of the pandemic began in March 2021, reaching its peak in April 2021. It is observed that, with the same delay that occurred during the first peak of the pandemic, there was a sharp drop in Installed Monthly Power in the following three months. From July 2021, the monthly installed power growth trend is again observed, which remained until the end of the time frame adopted in this study, December 31, 2021.

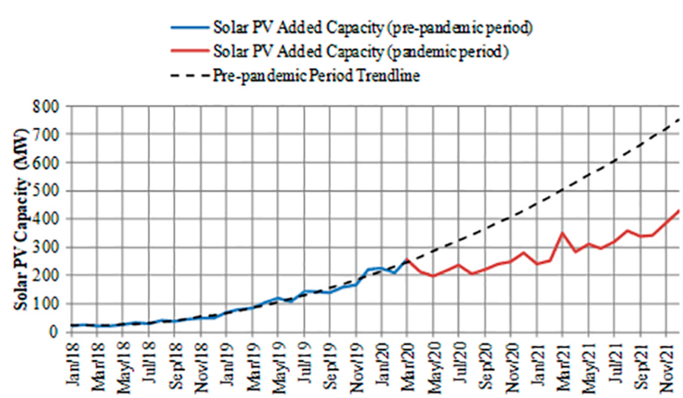
In order to compare the installed monthly power in the pre-pandemic period (until March 2020) and in the pandemic period (after March 2020), a trend line based on polynomial regression was calculated, which consists of an interpolation method capable to determine the relationship between two variables, with the objective of making it possible to predict behaviors of unknown periods based on known periods (Hair et al., 2009; Gomes et al., 2015). Thus, the order-three polynomial trend line, which best fits the data, was calculated for the pre-pandemic period (known period) and extrapolated to the post-pandemic period (unknown period), as can be seen in Graphic 2.

Although the Installed Monthly Power after March 2020 also followed a growth trend, it did not follow the pre-pandemic growth pace, ending 2021 with a real Installed Monthly Power of 428 MW, against the statistical expectation of 750 MW (Graphic 2, trend line) in a non-pandemic scenario. Notwithstanding the impact of the pandemic, records were broken in the years 2020 and 2021 in the Installed Monthly Power of PVS.

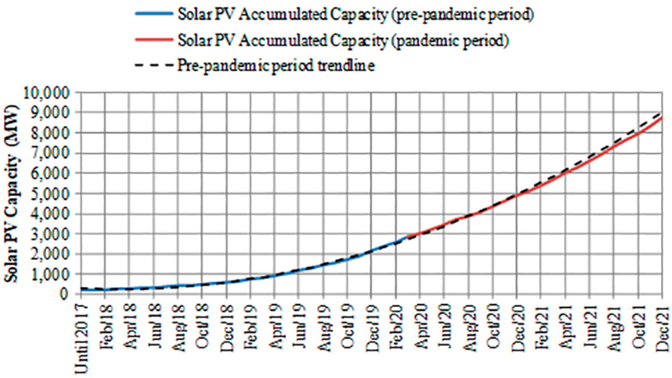
In Graphic 3, the installed power indicator is represented in an accumulated way, and a polynomial trend line of order 2 of the pre-pandemic period is also calculated, this line being extrapolated to the pandemic period. Despite the monthly declines identified, it is observed that the accumulated installed power of the pandemic period followed a growth trend similar to that of the period before the pandemic, resulting in the real accumulated power at the end of 2021 of 8,772 MW, against the statistical expectation of 9,012 MW (Graphic 3, trend line) in a non-pandemic scenario. In addition, in 2020, 78% more PV power was added than in 2019; and in 2021, 153% more PV power was added than in the pre-pandemic year.



Graphic 1 – Power of photovoltaic systems of Micro and Mini Distributed Generation added per month in Brazil.
Source: based on data from ANEEL (2022).



Graphic 2 – Trend line of the power of photovoltaic systems of Micro and Mini Distributed Generation added by month in Brazil.
Source: based on data from ANEEL (2022).



Graphic 3 – Trend line of the power of photovoltaic systems of Micro and Mini Distributed Generation accumulated in Brazil.
Source: based on data from ANEEL (2022).

Thus, it is observed that the PV sector experienced a turbulent first semester both in 2020, during the beginning of the COVID-19 pandemic, and in 2021, during the second peak of the pandemic, a fact that was observed by the sharp drop in the quantity and in the PVS Monthly Power Installed during the two peaks.

The pace of growth lost at the beginning of the pandemic was quickly recovered in the following months, suggesting a high capacity for resilience and adaptation of the PV market in the face of the COVID-19 pandemic.

Interruptions in the supply chain, restrictions on the movement of labor and goods, delays in deliveries, price increases, as well as impediments in the preparation of projects, licensing and construction of plants, allied to the crisis and insecurity felt by a large part of industries and commerce, can be pointed out as the likely responsible for the drop in the evaluated indicator, corroborating the studies by Das (2020), Radu et al. (2020), Song et al. (2020), Vaka et al. (2020), Eroğlu and Cüce (2021), and Marsillac (2021).

On the other hand, the installation of a PVS is an activity carried out practically entirely outdoors, with little social contact between the professionals involved in the installation. In addition, working from home due to the COVID-19 pandemic made people spend more time in their homes, consuming more electricity and raising monthly costs on their electricity bills, which may have led to greater demand of a residential PVS to take advantage of the moment for renovations and various improvements in homes. Thus, these two factors may have contributed to the rapid recovery of the market and are options of possible future studies and evidence.

Conclusions

Based on the research findings and their subsequent discussion, it is possible to infer, firstly, that the study of the impact of the COVID-19 pandemic on the PV market has an interdisciplinary scope, extending to the field of environmental sciences, engineering, economics, administration, international trade, as well as related areas. The same reality is verified for the indicators applied to PV systems, which are related in the following dimensions: economic, resources, technological, environmental, and social.

It was also found that the indicator selected by the present study, the monthly installed power of PVS, was able to reflect the impact of the COVID-19 pandemic on the MMDG PV market in Brazil, considering the years 2020 and 2021, as the results observed in Graphics 1, 2 and 3. As demonstrated in the presentation and discussion of the results, the initial impact of the COVID-19 pandemic on the Installed Monthly Power of MMDG PVS in Brazil was felt from April 2020, and the onset of recovery was observed in the fifth month (August) after the initial impact. However, the observed recovery did not follow the pace of pre-pandemic growth, although records were perceived in the years 2020 and 2021 in the Installed Monthly Power of PVS. It was also observed that the accumulated installed power of the pandemic period followed a growth trend similar to that of the period before the pandemic.

In this way, the history of distributed generation photovoltaic energy in Brazil during the two-year crisis caused by the COVID-19 pandemic was one of resilience and adaptation, overcoming the difficulties and new challenges encountered, in order to maintain the rhythm of growth observed before the pandemic.

It is thus concluded that, with the initial general awareness caused by the first peak of the COVID-19 pandemic, the PV market suffered a reduction in the Installed Monthly Power, however, after this initial moment, there was a recovery of this indicator.

A stratification of this indicator in terms of the class of consumer unit (residential, commercial, industrial and public sector) is suggested as a future work, in order to assess the differences in the behavior and trends of each one of them.

Contribution of authors:

SCOLARI, B. S.: Conceptualization; Data Curation; Formal Analysis; Investigation; Methodology; Writing — Original Draft; Writing — Review & Editing. NASCIMENTO, D. E.: Conceptualization; Methodology; Supervision; Visualization. SOUZA, M.: Conceptualization; Methodology; Supervision; Visualization. STRAUHS, F. R.: Conceptualization; Methodology; Supervision; Visualization; Writing — Review & Editing.

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