Periódico Eletrônico "Fórum Ambiental da Alta Paulista"
Electronic Journal "Environmental Forum of Alta Paulista"

ISSN 1980-0827 – Volume 20, Number 2, Year 2024

Contributions of Photovoltaic Generation in Achieving Sustainable Development Goals

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ABSTRACT
In the search for energy sustainability the photovoltaic solar energy (PV) has stood out as a solution to promote the sustainable development of the sector. As PV technology expands, there is a need for studies that evaluate how this new market affects the search for environmental, social and economic sustainability. Following an interdisciplinary approach, and based on the epistemological paradigm of Design Science, the aim of the present study was to survey the contributions of distributed photovoltaic generation to achieving each of the seventeen Sustainable Development Goals (SDGs). To this end, the state of the art on the topic was characterized through a systematic literature review – SLR. Subsidized by SLR and supported by the basic literature on the subject, a descriptive table was prepared about the contributions of PV generation to achieving each of the SDG. Next, the relevance of the contributions made to achieving each SDG was quantitatively assessed. It was identified that PV generation contributes to the achievement of all SDGs, with this contribution having greater or lesser relevance depending on the SDG considered. PV generation was also found to be intrinsic relevance to achieving SDG 7 – Affordable and Clean Energy, SDG 11 – Sustainable Cities and Communities and SDG 13 – Climate Action. This study presents a step towards a better eco-socio-economic understanding of PV generation in order to contribute to the advancement of this technology and decision-making in the sector.

KEYWORDS: Sustainable Development Goals – SDGs. Photovoltaic Generation. Distributed Generation.

1 INTRODUCTION

Sustainability has been presented as a rising agenda, widely debated in different social sectors (FERNANDES; VIEIRA, 2014). The growing reflections and interest in the topic have made evident the need to review current paradigms, especially that natural resources are infinite, encouraging countries and the international community to develop joint actions aiming to reconcile the need to produce goods necessary for the quality of life of societies and, at the same time, preserve the natural elements equally responsible said quality of life (FERNANDES, VIEIRA, 2014; PHILIPPI JR. et al., 2013).

From an international cooperation perspective, the United Nations Conference on Sustainable Development - UNCSD, known as Rio+20, held in Rio de Janeiro in 2012, encouraged governments to think about a set of goals intended on achieving sustainable development (GRIGGS *et al*., 2013). As a result of this initial discussion, in 2015, the United Nations Summit on Sustainable Development in New York released the 2030 Agenda (UN, 2015), which consists of an official declaration adopted by the members of the United Nations (UN) containing a global action plan with goals to be achieved by 2030 (SALVIA *et al*., 2019). The Agenda has 169 goals and several indicators for monitoring, guided by the 17 Sustainable Developments Goals – SDGs, which are supported by the economic, environmental and social dimensions of sustainability (UN, 2015).

Sachs (2012) stated that grouping priorities into an easily understandable set of goals and establishing measurable, time-bound objectives helps to promote global awareness, political responsibility, the development of improved metrics, the participation of the society and responding to related public pressures.

Thus, following the development of the SDGs, related research began to emerge in an interdisciplinary manner in academia (BEBBINGTON; UNERMAN, 2018). Leal Filho *et al*. (2018), besides emphasizing the interdisciplinary nature of sustainability research, add that the

ISSN 1980-0827 – Volume 20, Number 2, Year 2024

SDGs are an opportunity to stimulate the study of sustainability in academia, since studies on certain eco-socioeconomic aspects and their links with the SDGs are important for adequately understand sustainability from a broader perspective and on a larger scale, with academic research being an important mechanism in this search.

In a context of interdisciplinary study of sustainability, the energy issue takes prominence, from the perspective of the Ministry of Science and Technology – MCT (2010) and Lajara *et al*. (2023), facing the difficulty of reconciling the maintenance of the supply of energy inputs with the preservation - in the short and long term - of the environmental, social, ethical, cultural, economic and political needs of society. Furthermore, the energy situation is important in the context of sustainability, mentioned directly in the seventh SDG, which reads: "Ensure access to affordable, reliable, sustainable and modern energy for all" (UN, 2015, p. 14).

In this context, by reinforcing the seventh SDG, in the view of Connolly, Lund and Mathiesen (2016) and Lajara *et al*. (2023) renewable sources of electrical energy generation emerge as a solution to promote sustainable development in the energy sector.

Among renewable sources, photovoltaic solar energy (PV) stands out both on global and national scenes, due to the low environmental impact of both its implementation and generation (EPE, 2021; REN21, 2020). According to the Think Tank Global Renewable Energy Policy Network for the 21st Century – REN21 (2020), PV technology is expanding as it becomes the most competitive option for distributed generation[1] in a growing number of locations. Thus, as its level of penetration increases, distributed PV generation~~s~~ has a progressively greater effect on electrical systems, increasing the importance of carrying out specific studies of its effects (REN21, 2020).

The contribution of photovoltaic distributed generation to the fulfillment of SDG 7 (Affordable and Clean Energy), it should be noted, is already widely debated in the literature in the area (AMESHO; EDOUN, 2019; CONNOLLY; LUND; MATHIESEN, 2016; KUANG *et al*., 2016; NUNES-VILLELA *et al*., 2017; PEREIRA *et al*., 2017; SCOLARI *et al*., 2022). Furthermore, "the interlinkages and integrated nature of the Sustainable Development Goals are of crucial importance in ensuring that the purpose of the new Agenda is achieved" (UN, 2015, p. 2), thus highlighting the interconnection between the different SDGs and the importance of evaluating the contributions of PV generation on achieving the other SDGs.

According to Brunet *et al*., (2020), although based on natural elements such as the sun, PV generation requires advanced technological systems, whose complexity of eco-socioeconomic interactions cannot be underestimated, requiring in-depth studies.

So, considering the advances and gaps, evidenced by the state of the art on the topic, the aim of this study is to survey the contributions of distributed photovoltaic generation to achieving each of the seventeen Sustainable Development Goals.

To achieve the proposed objective, the next Section will describe the methodological lines that guided and epistemologically supported the present study, fundamentally bibliographic and analytical.

[1] Distributed generation is characterized by "generation of electricity from dispersed, generally small-scale systems that are close to the point of consumption". (REN21, 2020, p. 254).

2 RESEARCH METHODOLOGY

Based on the model proposed by Gibbons *et al*., (1994) and following a transdisciplinary approach, the present study uses this to solve problems and produce knowledge, and it's structured in such a way that this approach converges to the creation of knowledge applicable in different areas of learning (DRESCH *et al*., 2015).

In this context, to prepare the present study, the epistemological paradigm of Design Science, proposed by Simon (1996), was adopted. While 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, not necessarily aiming to optimal solution, but rather a satisfactory solution, therefore being suitable for conducting transdisciplinary research (DRESCH *et al*., 2015; GIBBONS *et al*., 1994).

Thus, guided by the Strategy for Conducting Research on Design Science proposed by Dresch *et al*., (2015), it is worth highlighting that the data collection method used in this study was through bibliographical research, more specifically through a Systematic Literature Review – SLR; while data analysis was carried out using Content Analysis, based on Bardin (2016).

To conduct the SLR the method proposed by Dresch *et a*l., (2015), was adapted which applies to the needs of design science. For Van Aken (2011), the SLR can help identify solutions for a given class or problem, in addition to identifying gaps in existing literature. Through SLR, we sought to address the state of the art in the literature on how renewable sources of distributed energy generation, especially photovoltaics, can contribute to achieving the Sustainable Development Goals.

In this sense, the intention was to carry out a configurative review, in which heterogeneous primary studies are sought, 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 topic. In this way, the search for new materials extends until the moment they do not contribute new concepts to the synthesis process in question (BRUNTON *et al*., 2012; DRESCH *et al*., 2015).

With a view to minimizing the search strategy bias, Dresch *et al*. (2015) highlight the importance of including symbolism, different spellings and similar expressions in addition to the search of mains terms. Following this direction, in addition to the main terms: (i) Sustainable Development Goals, (ii) Photovoltaic Generation, (iii) Renewable Energy Sources and (iv) Distributed Generation, groups of descriptors were searched for each main term, both in Portuguese and English. The choice of descriptors was carried out using an adherence test for these different descriptors for each main term, as shown in Table 1.

The consultation stage was carried out in June 2023 in the following databases; (i) SciELO (Scientific Electronic Library Online), (ii) BDTD (*Biblioteca Digital de Teses e Dissertações* - Digital Library of Theses and Dissertations), (iii) Scopus (Elsevier) and (iv) Web of Science (Main Collection – Clarivate Analytics). Among the various databases made available by the journal portal of the *Coordenação de Aperfeiçoamento de Pessoal de Nível Superior* - CAPES, these were chosen due to the large number of peer-reviewed indexed items in each of them and because they offer a comprehensive overview of world production in different areas of research, thus making the research comprehensive enough to address the topics in question with the necessary depth and breadth and minimizing research biases.

Next, the descriptors were then searched in combination using Boolean logical operators ("AND" and "OR"), keeping in mind the alignment with the study topic and aiming for both satisfactory precision and recall. The terms were searched in the Title field of the documents and the results were filtered for documents published in the period 2019 – 2023, in Portuguese and English.

In order to provide SLR with the reproducibility inherent in scientific research, the search strategy was represented as a single command line, written using syntax elements in such a way that includes all the parameters adopted in the research, so that it can be used by other researchers to reproduce the results found (GUEDES, 2022). However, as each database has a different search syntax, the specific strategy for the Scopus database will be presented, but it can be adapted for the other databases consulted, as shown in Table 1.

Table 1 – Search strategy for the Scops database

TITLE (("Photovoltaic" OR "Solar Energy" OR "Solar Power" OR "Distributed Generation" OR "Renewable Energy" OR "Solar Thermal" OR "Access to Energy") AND ("Sustainable Development Goals")) AND PUBYEAR > 2018 AND PUBYEAR < 2024 AND (LIMIT-TO (LANGUAGE,"English") OR LIMIT-TO (LANGUAGE,"Portuguese"))

Source: Own authorship.

After reading through the results and excluding duplicate material that was not in line with the research, 26 documents were selected that meet the objectives of the SLR. No relevant results were found in Portuguese, nor in Brazil.

Dresch *et al*., (2015) also highlight the importance of not only searching databases, but also consulting grey literature. Kugley *et al*. (2017) point out that the proceedings of congresses, seminars and conferences, among others, are a good source of grey literature, since more than a half of the studies presented are never published. In this way, two more documents were selected to delve deeper into the topic, resulting in 28 documents that make up the dynamic corpus of the research. In addition, another 28 documents were added, used to support the research methodology and to contextualize the theme – the static corpus, so the article corpus consists of 56 documents.

Having completed this stage of the research, the next section will present and discuss the results obtained the systematic literature review.

3 RESULTS AND DISCUSSION

As mentioned in the previous section, the systematic literature review (SLR) resulted in 28 documents relevant to the research, each with a specific emphasis on the contributions of renewable sources of distributed energy generation.

It was noticed that the topic is approached in an interdisciplinary way by authors in the field, cutting across different dimensions of the field of study. On average, in each document consulted, the authors identified 8 SDGs that benefit from renewable and distributed electricity generation, thus moving between environmental, social and economics

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SDGs with greater or lesser intensity, according to the scope or specificity that the author envisages – Table 2.

Table 2 – Documents resulting from the SLR and the respective SDGs cited by the authors

Reference of the document consulted	Number of SDGs cited	Amount of SDGs cited
(ACHEAMPONG *et al*., 2019)	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 13 e 16	12
(ADENLE, 2020)	1, 2, 3, 4, 5, 6, 7, 8, 13, 15 e 16	11
(AMESHO; EDOUN, 2019)	7, 8 e 9	3
(AMIN *et al*., 2022)	4, 7, 8, 9, 12, 13, 14, 15	8
(ANAM *et al*., 2022)	2, 3, 7 e 8	4
(BERTHEAU, 2020)	2, 3, 4, 5, 6, 7, 8, 13 e 15	9
(BISAGA *et al*., 2021)	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13 e 17	14
(BRUNET *et al*., 2020)	1, 2, 3, 4, 5, 7, 8, 9, 11, 13, 14, 15 e 17	13
(BUONOCORE *et al*., 2019)	3, 6, 7, 9, 13, 14 e 15	7
(CALDÉS; SERRANO, 2018)	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 15, 16 e 17	15
(CHEN *et al*., 2022)	7, 8, 9 e 13	4
(CHENG *et al*., 2021)	1, 2, 4, 6, 7, 8, 9, 13, 14, 15 e 17	11
(HANNAN *et al*., 2021)	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16 e 17	17
(LAJARA *et al*., 2023)	1, 2, 7, 8 e 13	5
(LOHANI *et al*., 2022)	1, 2, 3, 4, 5, 7, 8, 9, 13, 15 e 17	11
(MEHMOOD, 2021)	4, 7 e 13	3
(MUDAHERANWA; UDOAKAH; CIPCIGAN, 2019)	7 e 13	2
(OBAIDEEN *et al*., 2021)	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16 e 17	17
(OLABI *et al*., 2022)	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16 e 17	17
(PHILIP; EMIR; UDEMBA, 2022)	7 e 13	2
(SABOORI; MEHRJERDI, 2022)	6, 7 e 13	3
(SALAMEH *et al*., 2022)	6, 7 e 13	3
(SAREEN; NORDHOLM, 2021)	7, 10 e 13	3
(SCHONE; HEINZ, 2023)	7	1
(SCHONE; TIMOFEEVA; HEINZ, 2022)	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 15, 16 e 17	15
(UDEMBA *et al*., 2022)	7, 8, 9 e 13	4
(WEN *et al*., 2023)	7, 8, 10 e 13	4
(ZHOU; LI, 2022)	7, 8, 9 e 13	4

Source: Own authorship.

It was also found that 71% of the documents consulted – 20 articles – cited four or more SDGs, corroboring the idea of interconnection between the various SDGs, a view shared by Bisaga *et al*. (2021), McCollum (2018) and Nerini *et al*. (2018, 2019). Three studies addressing all 17 SDGs were also identified.

At this juncture, several studies have set out to investigate the interconnections between the SDGs (SCHONE; TIMOFEEVA; HEIZ, 2022), such as Le Blanc (2015), who applied network analysis techniques to map the links between the different SDGs, concluding that the thematic areas with the greatest number of interconnections with SDG 7 include inequality, sustainable production and consumption, poverty, hunger and education.

Following the line of the studies mentioned above and using the texts used in the SLR correlated to the SDGs, the correlation and occurrence of the main terms were mapped based on the analysis of the networks formed using VOSviewer software, as shown in Figure 1. This analysis showed that in addition to the themes intrinsic to photovoltaic generation and SDG 7, such as: energy, electricity and solar energy, themes relating to other SDGs were also

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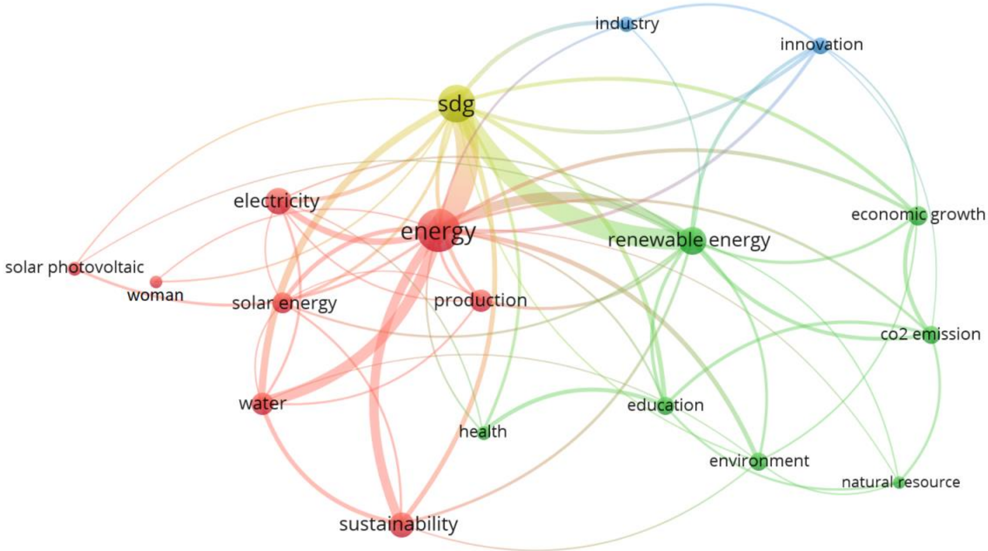
indentified, such as: health (SDG 3), education (SDG 4), women (SDG 5), water (SDG 6), economic growth (SDG 8), industry and innovation (SDG 9) and CO_2 emissions (SDG 13), corroborating the idea of interactions and links among the various SDGs.

Figure 1 – Results of the analysis of the networks formed by the texts used in the SLR



Source: Own authorship, using VOSviewer.

Along these lines, Nilsson, Griggs and Visbeck (2016) developed the idea of synergies and conflicts between the SDGs, contributing with a framework describing different types of interactions between the Goals. Moreover, these authors emphasize the importance of assessing the local context, available technologies and aspects of time and space in this analysis.

Nerini *et a*l. (2018) identified and examined the links between the energy context and the SDGs, concluding that the interdependencies at the level of individual SDG targets are multiple and highly context-specific. Also at this juncture, McCollum *et al*. (2018) assessed, through a literature review, the interactions of SDG 7 with the other SDGs, considering the nature and strength of the interactions identified and the robustness of the evidence from literature, concluding that positive interactions (synergies), outweigh negative interactions (conflicts) both in number and magnitude, among all SDGs.

Although there may be conflicts between the SDGs, Buonocore *et al*. (2019) estimate that the pursuit of clean energy contributes more than detracts from progress towards the other SDGs, since SDG 7 is fundamentally linked to the achievement of more than half of the targets contained in other SDGs. Along these lines, Bisaga *et al*. (2012) state that electricity infrastructure plays an important role in the collective aspirations for greater well-being and health, identifying a bidirectional relationship between SDG 7 and the other SDGs, so that SDG 7 underpins the achievement of all the other SDGs and vice versa.

That said, the various contributions from renewable sources of distributed energy generation cited in the documents collected through the SLR and which are applicable to photovoltaic generation – PV were synthesized, catalogued and compiled, as shown in Table 3.

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Table 3 – Contribution of photovoltaic generation to achieving the Sustainable Development Goals

SDG 1: No poverty • Reduces global electricity costs, freeing up resources for other domestic demands. • Enables energy supply in hard-to-reach places, which increases productive hours, improves income-generating activities and enhances entrepreneurial opportunities in communities. • Generation of employment opportunities in the sector, whether in the manufacture, installation or maintenance of these systems. • Reduces poverty through the achievement of other SDGs (see SDG2, SDG4, SDG8).

(continue)

(Continuation of Table 3)

SDG 2: Zero hunger • Reduces global electricity costs, freeing up resources for food. • The use of photovoltaic Generation to pump water for crop irrigation reduces cultivation costs and increases productivity, which lowers the value of the end product, generates greater food security and consequently minimizes hunger. • The use of low-cost distributed energy sources in Family farming makes cultivation more efficient and more competitive by reducing production costs. • Makes it possible to store and preserve food in places where access to electricity is difficult (see SDG 3).
SDG 3: Good health and well-being • Contributes to the reduction of respiratory diseases, as PV Generation helps to reduce air pollution. • By reducing the effects of climate change (see SDG 13), its repercussions on the population's health are also reduced. • Improves healthcare infrastructure and technology. • Allows vaccines and medicines to be stored in refrigerators in places Where electricity is difficult to access. • Improves access to drinking water through water pumping, purification and desalination systems (see SDG 6). • Enables food storage and preservation in places Where electricity is difficult to access (SDG 2). • Reduces global electricity costs, freeing up resources for health and well-being. • Improves security through public lightning.
SDG 4: Quality education • Improves school learning outcomes by enabling the use of computers, the internet and other electricity-based educational devices, as well as increasing the possible hours of study in the Evening. • Encourages professional training and participation in distance education for children, young people and adults. • Reduces overall electricity costs, freeing up resources for education. • Contributes to the inclusion of environmental education in schools.
SDG 5: Gender equality • The possibility of a quality education (seed SDG 5) allows women to gain economic independence and autonomy as they gain access to more job opportunities, which directly affects their social environment. • Allows access to electronic devices to obtain relevant information on affirmative gender equality policies. • In traditional communities Where the collection of firewood used for cooking, lighting and heating is carried out exclusively by women and children, access to an electricity supply means a reduction in the need for firewood, providing more free time to engage in more productive endeavors, such as education. • Improves security through street lighting, allowing girls and women to carry out activities after dark.
SDG 6: Clean water and sanitation • Improves access to Drinking water through pumping, purification and desalination systems. • PV generation consumes significantly less water than other technologies, including thermoelectric plants.
SDG 7: Affordable and clean energy • Contributes directly to ensuring reliable, sustainable, modern and Affordable access to energy for all, since photovoltaic Generation is a renewable, clean and Affordable source of energy for places with difficult access to electricity supply. • Reduces dependence on fossil fuels and the emissions of harmful gases resulting from combustion such as CO2, SO2 and NOX, since it reduces the use of more polluting generation technologies such as thermoelectric plants.
SDG 8: Decent work and economic growth • The photovoltaic Generation sector (manufacturing, installation, operation and maintenance) increases gross domestic product and creates Jobs. • Improves income-generating activities and business opportunities by bringing electricity to hard-to-reach places. • Enables the creation of small photovoltaic system installation companies. • Encourages an increase in the number of working shifts, since it is possible to extend working hours during the night. • Improves access to education and professional training (see SDG 4).
SDG 9: Industry, innovation and infrastructure

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• Encourages the emergence of new companies and industries as a result f the development of the PV market. • Encourages research and technological development in the sector in order to develop new solutions and make photovoltaic Generation more efficient. • The use of photovoltaic generation in an industry reduces its energy liabilities and increases the energy sustainability of its production processes. • The manufacture, installation, operation and maintenance of photovoltaic systems leads to job creation (see SDG 8) and the emergence of new local companies and industries. • Makes the infrastructure of the electrical distribution and transmission system more resilient and reliable. • Reduces electricity distribution and transmission losses, making the infrastructure more efficient. • Improves the quality of electricity supplied to consumers. • Challenges the power distribution and transmission system, freeing up capacity for industrial use.
• Enables the mechanization of production processes in places where electricity supply is difficult to access. • Reduces overall electricity costs, lowering the cost of industrial production.
SDG 10: Reducing inequalities • Contributes to the eradication of poverty (see SDG 1), the reduction of hunger (see SDG 2) while enabling quality education(see SDG 4), gender equality (see SDG 5) and decent work (see SDG 8), all of which are factors in reducing inequalities.
SDG 11: Sustainable cities and communities • Reduces atmospheric pollution in urban centers, since it reduces dependence on other more polluting Generation Technologies, such as thermoelectric plants. • Reduces the use of fossil fuels When associated with electric urban mobility systems. • Reduces the energy liabilities of urban centers and favors the Search for energy self-sufficiency in cities. • Enables the construction of energy-sustainable homes and buildings, with a positive energy balance and sustainable Building certification labels. • Encourages harmonious integration between electricity generation methods and the urban environment.
SDG 12: Responsible consumption and production • Contributes to Building resilient infrastructure, promoting inclusive and sustainable industrialization and fostering innovation (see SDG 9). • Promotes sustainable production and consumption of electricity (see SDG 7). • The use of photovoltaic generation in an industry reduces its energy liabilities and increases the energy sustainability of its production processes.
SDG 13: Climate action • Reduces dependence on fossil fuels and the emission of greenhouse gases such as CO2 (see SDG 7), combating global climate change by reducing the use of other more polluting Generation Technologies, such as thermoelectric plants.
SDG 14: Life below water • Combating global climate change (see SDG 13) prevents ocean temperatures from rising and preserves aquatic ecosystems. • By reducing the emission of combustion gases such as CO2, SO2 and NOX (see SDG 7), ocean acidification is reduced. • By reducing dependence on fossil fuels, such as oils and natural gas (see SDG 7), the environmental risks arising from their offshore extraction and transportation, which include the risks of leaks and spills of these fuels into oceans, are reduced.
SDG 15: Life on land • By combating global climate change (see SDG 13), changes to the hydrological cycle are avoided, preserving terrestrial ecosystems. • By reducing the emission of combustion gases such as CO2, SO2 and NOX (see SDG 7), soil acidification is reduced. • By reducing dependence on fossil fuels, such as oil and natural gas (see SDG 7), the environmental risks arising from their onshore extraction and transportation, which include the risks of leaks and spill of these fuels on the ground, are reduced.
SDG 16: Peace, justice and strong institutions • Favors the inclusion of the Whole of Society in public policies and access to relevant information for citizens, since it makes it possible to access the electricity supply in hard-to-reach places. • Helps to reduce economic and social disparities within a country and between nations, contributing to the promotion of more harmonious communities. • Reduces conflicts around the world over the ownership and supply of fossil fuels such as oil and natural gas, since photovoltaic generation reduces the need for these fuels.
SDG 17: Partnerships for the Goals • Distributed photovoltaic Generation represents a means of implementing sustainable development in the energy sector (see SDG 7), as well as contributing directly or indirectly to all the Other SDGs.

- It allows for the creation of public-private partnerships between private solar suppliers and public authorities to implement photovoltaic systems.
- It opens up space for non-governmental organizations (NGOs) to work in partnerships with public authorities to provide access to photovoltaic energy in socio-economically vulnerable communities.
- Encourages research and development (see SDG 9), integrating professionals and researchers in the field towards the search for solutions, as well as strengthening the global partnership in the search for sustainable development.

Source: Own authorship, based on the authors cited in Table 2.

It should be noted that, as proposed by Nilsson, Griggs and Visbeck (2016) and Nerini et al. (2018), a broad social and territorial context was considered in this analysis, since PV system can either be installed in an urban area with good infrastructure, or it can be used to supply electricity to a community with difficult access, where another source of generation would be unfeasible; therefore, in these two cases, the contributions in relation to the SDGs of a social, economic and environmental nature of these two characteristics of PV systems are different.

It was observed that distributed photovoltaic generation contributes at some level to all SDGs; either directly, as is the case with SDG 7, SDG 11 and SDG 13, or indirectly, as is the case with SDG 4, SDG 5 and SDG 16, for example. Furthermore, it was observed that these contributions are more or less relevant depending on the SDG considered.

For this reason, in order to quantitatively assess the relevance of photovoltaic generation contributions to each SDG, the methods proposed by Le Blanc (2015) and Schone, Timofeeva and Heiz (2022) were adapted, establishing a five-point ordinal scale ranging from 0 to 4, as shown in Table 4.

Table 4 – Scale of relevance of contributions to the respective SDGs

Degree of Relevance	Type of relevance	Description
4	Intrinsic	Intrinsically linked to the achievement of the respective SDG.
3	Reinforcement	Reinforces the achievement of the respective SDGs
2	Conditional	Creates conditions for the implementation of the respective SDG.
1	Favorable	Helps indirectly.
0	Irrelevant	Makes no contribution.

Source: Own authorship, adapted from Le Blanc (2015) and Schone, Timofeeva and Heiz (2022)

When describing their ranking method, Schone, Timofeeva and Heiz (2022) already cautioned that the five-point ordinal scale does not allow for complete accuracy in ranking the contributions of distributed photovoltaic generation to each of the SDGs; however, it does reflect the limited evidence available in the literature in the area and in research articles. Thus, the aforementioned authors state that the suggested ordering, despite its limitation, is a relatively precise and objective way of shedding light on this topic.

Following the proposed method, the contributions of distributed photovoltaic generation identified through the systematic literature review were assessed according to their relevance in achieving each of the SDGs, as shown in Figure 2.

Figure 2 – Degree of relevance of the contributions of distributed photovoltaic generation to achieving each of the SDGs on a scale of 0 to 4.

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Source: Own authorship

Although distributed photovoltaic generation contributes to all the Sustainable Development Goals, it should be emphasized that it is intrinsically relevant to achieving SDG 7 – Clean and Renewable Energy, SDG 11 – Sustainable Cities and Communities and SDG 13 – Action Against Global Climate Change, which represent the SDGs linked to energy sustainability, sustainable cities and environmental issues.

Secondly, it was observed that distributed photovoltaic generation corroborates the achievement of SDG 8 – Decent work and economic growth, SDG 9 – Industry, innovation and infrastructure and SDG 12 – Responsible consumption and production; these SDGs are related to economic and resource issues of sustainability.

Regarding to SDG 2 – Zero hunger and sustainable agriculture, SDG 3 – Health and well-being, SDG 4 – Quality education, SDG 6 – Drinking water and sanitation, SDG 10 – Reducing inequalities, SDG 14 – Live Below Water and SDG 15 – Terrestrial life, the type of relevance is conditional, i.e distributed photovoltaic generation creates conditions for the implementation of the respective SDG, acting in conjunction with other direct actions relating to these SDGs.

Evaluating the SDGs with a social and institutional bias: SDG 1 – Eradication of poverty, SDG 5 – Gender equality, SDG 16 – Peace, justice and effective institutions and SDG 17 – Partnerships and means of implementation, it was found that distributed photovoltaic generation has a favourable relevance, indirectly helping other actions aimed at promoting these SDGs.

Finally, it should be added that no SDG is insensitive to the possible contributions of PV generation, i.e. even if the contributions is indirect and subtle, it exists and should not be ignored in related studies.

4 CONCLUSION

A systematic review of the literature revealed the contributions of distributed photovoltaic (PV) generation to achieving each of the 17 Sustainable Development Goals

(SDGs). It was found that PV generation contributes to achieving all the SDGs, with this contribution having greater or lesser relevance depending on the SDG considered, as shown.

So, this study is a step towards a better eco-socioeconomic understanding of PV generation in order to contribute to the advancement of this technology and decision-making in the sector, making it possible to more effectively direct urban public policies, energy planning, incentive programs, among others, to make PV generation and, consequently, the photovoltaic market as a whole, increasingly sustainable in its various dimensions.

It is suggested that future, sequential work can be carried out on studies that exemplify in practice the contributions of an existing PV generation system to the achievement of the SDGs, considering different classes of consumer unit (residential, commercial, industrial and public sector) and different spatial cut-outs, in order to assess the differences in behavior and trends of each of them.

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