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Article

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Photovoltaic Projects for Multidimensional Poverty Alleviation: Bibliometric Analysis and State of the Art

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ABSTRACT

Motivated by initiatives such as the UN Sustainable Development Goals (SDG), particularly SDG 1 - Poverty Eradication and SDG 7 - Clean and Accessible Energy, the search for solutions aiming to mitigate poverty has been recurrent in several studies. This paper main objective is to evaluate the dynamics of global research on the use of photovoltaic projects for poverty alleviation (PVPA) from 2003 to 2022. We use a bibliometric analysis to identify publication patterns and consequently list research trends and gaps of the area. A total of 336 publications from Scopus database are identified and complemented by a state-of-the-art study, where the articles are investigated and classified according to: Business model and financing and evaluation of PVPA results. The results show that PA is often associated with PV power and its application in rural areas. "Biomass" and "application in developing countries" have become a trend. Urban areas application, aiming to reduce poverty, and the need for a synergetic integration of energy and urban planning, to mitigate the risks associated with energy flow and efficiency, are the most relevant gaps identified. Most of the publications focus on macropolicies effects involving PV technology; papers on projects construction and ex-post are not identified.

Keywords: Bibliometric Analysis, Photovoltaic Projects, Multidimensional Poverty Alleviation
JEL Classifications: Q20

1. INTRODUCTION

Up to 132 million people may fall into poverty in the world by 2030 (World Bank, 2020). The United Nations (UN) 2030 Agenda recognizes the eradication of poverty in all its forms and dimensions, including extreme poverty, as the greatest challenge faced by mankind, an indispensable requirement for a sustainable development. The 17 Sustainable Development Goals (SDGs) are integrated and indivisible, aiming to achieve and maintain a balance among environmental, economic, and social sustainable development dimensions (ONU, 2022). "SDG 1 - Poverty Eradication" and "SDG 7 - Clean and Accessible Energy" are significantly correlated, since energy consumption is often used as an indicator of the well-being level of modern societies. Therefore, energy poverty (EP) can be used to identify and characterize poverty; failing in providing energy may impact economic development potential between 1 and 2%, causing effective losses (Molyneaux et al., 2012; Mulugetta and Urban, 2010).

In such context, solar energy use to reduce EP has been addressed since 1985 (Gregson, 1995). In recent years, researches have focused on the use of photovoltaic (PV) power to address poverty alleviation (Piai et al., 2020). Such studies investigate very particular aspects: rural electrification (RE) and EP reduction (Diouf and Miezan, 2021; Obeng et al., 2008; Yang, 2003); household use of solar energy (Liu et al., 2018); relationship between EP and economic development (Acharya and Sadath, 2019); EP metrics, scales, perspectives, and limits (Sareen et al., 2020). Many studies develop support policies for EP reduction using PV plants and assess passive solar heating potential, among other applications (Z. Liu et al., 2019; D. Zhang et al., 2019). Other researches, aiming the development of projects to determine the optimal size and location (Zhang et al., 2019) emphasize the importance of focusing on regions where poverty predominates, while not considering only low-income families. Most studies on this topic are focused on rural areas or applied concomitantly with other projects, such as heating and social housing purposes (Geall et al., 2018).

Considering applications in semiarid regions, significant attention has been given to water scarcity (Nobre et al., 2019). Most studies aiming to validate the results of such projects are related to financial impacts and environmental indicators (Han et al., 2020; Wang et al., 2020) or assessment of the user satisfaction with renewable energy technologies (Ding et al., 2021, 2022; Mirza, 2015). Another research field associates the use of renewable technologies, especially PV, with the reduction of carbon dioxide (CO_2), emissions and air quality improvement (Acosta-Pazmiño et al., 2021; Brunet et al., 2021; Papadopoulou et al., 2019).

Hence, PV projects for poverty alleviation (PVPA), have been applied in several countries at different scales. Aiming to characterize such initiatives, we analyze publication patterns and research trends through a bibliometric analysis using VOSviewer. The investigations associated with PVPA are classified considering business and financing models and project assessment; sequentially, the results are discussed and recommendations for future trends are suggested. Our contribution is innovative, since no previous bibliometric analysis on PVPA was identified. Considering the aforementioned objectives, our paper is structured as follows: After the introduction, section 2 presents the adopted methodology; section 3 brings the bibliometric analysis; section 4 discusses the state of the art on PVPA; section 5 shows the results and discussions and section 6 brings our main conclusions.

2. METHODOLOGY

To investigate the extent and trends of the research topic, we use Scopus database (Scopus, n.d.); VOSviewer software (VOSviewer, n.d.) and StArt (State of the Art through Systematic Review) software (Zamboni et al., 2010). Scopus is one of the best-known and classic scientific databases, aggregating information from other bases such as Science Direct, thus comprising a larger indexed content (Mongeon and Paul-Hus, 2016). The flowchart used in the investigation is shown in Figure 1.

The study first step consists of performing searches using Scopus database, with the following strings: (TITLE-ABS-KEY (photovoltaic AND energy AND for AND poverty AND alleviation) OR TITLE-ABS- KEY (distributed AND generation AND for AND poverty AND alleviation) OR TITLE-ABS- KEY (solar AND energy AND for AND poverty AND alleviation) OR TITLE-ABS-KEY (solar AND pv AND for AND poverty AND alleviation) OR TITLE-ABS-KEY (solar AND electrification AND for AND poverty AND alleviation) OR TITLE-ABS -KEY (photovoltaic AND energy AND anti-poverty)). As result, a total of 336 documents come from this investigation phase.

In the second stage, StArt is used to perform the systematic literature review (SLR) based on the protocols previously defined by the researcher (Zamboni et al., 2010).

The database selected using Scopus undergoes an initial analysis and the following questions are defined: (1) What are the main business/financing models used by PVPA?; (2) What are the main methodologies for evaluating results and indicators implemented in the scientific literature? These questions aim to identify trends and perspectives for regional or local applications, as well as their impacts on multidimensional poverty.

Publications related to meteorology, agricultural applications, decarbonization, greenhouse effect, climate changes and technical impacts are excluded from the SLR, resulting in 123 documents. Sequentially, VOSviewer is used to build and visualize bibliometric maps, considering its characteristic for displaying large bibliometric maps in an easy-to-interpret manner (van Eck and Waltman, 2010); the database selected using Scopus is used as VOSviewer input. The bibliometric parameters used to analyze publications on PVPA in the last 20 years are: Type and language; total number of publications, number of authors, average number of authors per publication; author performance and publication patterns (number of publications, publication patterns for countries); journal metrics; collaboration and co-analysis citation using Scopus records; author and Scopus keywords.

3. BIBLIOMETRIC ANALYSIS

Bibliometrics is a way of systematizing the analysis of academic literature in a given area of knowledge, using mathematical and statistical methods in the compilation of such contributions (Ellegaard and Wallin, 2015). The methodology has been intensively applied in different sectors (Andreo-Martínez et al., 2020; Kandeal et al., 2021; Muhtar et al., 2021; Proskuryakova and Ermolenko, 2019); basically, three types of indicators can be used in the bibliometric analysis: Relative productivity of different agents involved in a specific theme; quality indicator, regarding the relevance of publications, including the commitment record; structural indicator, focusing on the links between different agents (Aznar-Sánchez et al., 2019).

3.1. Document Types and Languages

We analyze a total of 336 documents, identified with the selection criteria established for the present bibliometric review. These publications are classified into five types: Articles (230 works – 68.5%), conference papers (57 works – 17.0%), book chapters (24 works – 7.1%), reviews (20 works – 6.0%), conference reviews and notes (2 works each one – 1.1%), and books (1 – 0.3%); no duplicate publications are identified. Journal articles and conference papers are selected for further analysis since Scopus database offers the broadest download option based on bibliometric parameters. Regarding the language of publication, a total of 327 documents are written in English, whereas 9 are in Chinese and 1 in Spanish.

3.2. Output Characteristics

The total number of publications per year on PVPA, as well as related variations, is shown in Figure 2, indicating an increase

Figure 1: Flowchart of the proposed state-of-the-art and bibliometric analysis

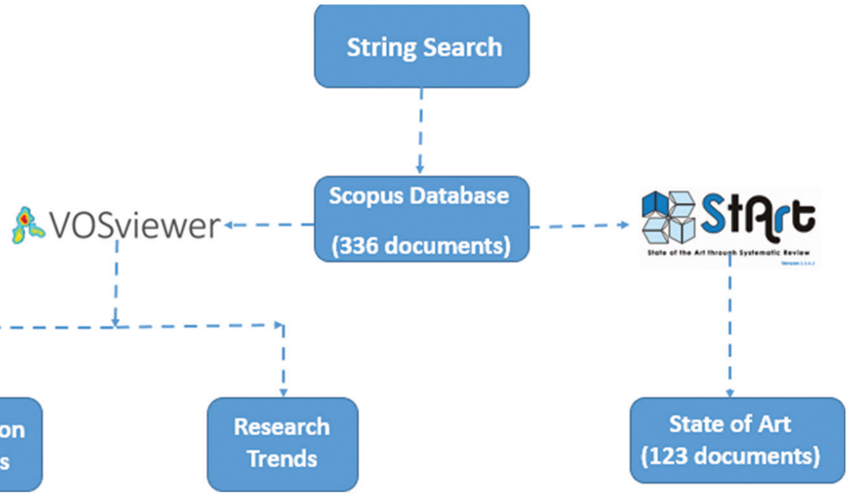
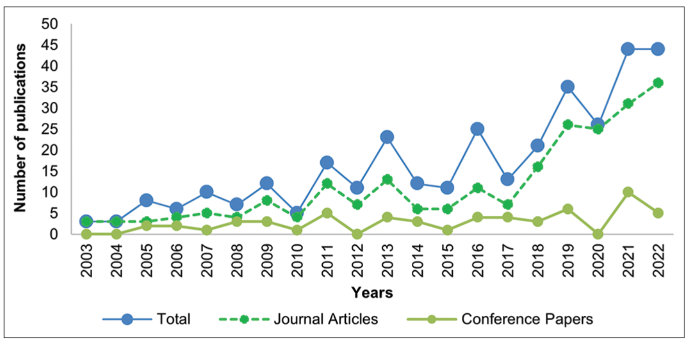
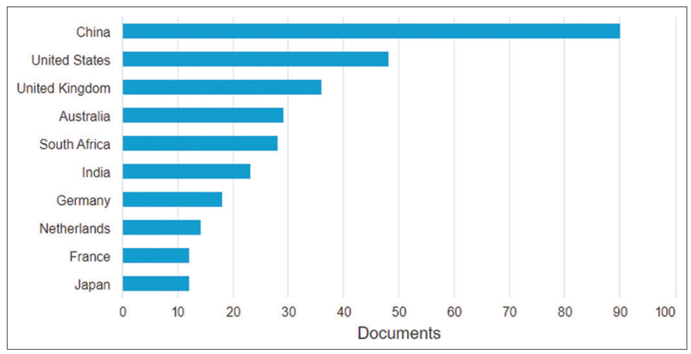


Figure 2: Number of publications per year on PVPA



Source: Author's elaboration based on (Scopus, n.d.)

Figure 3: Number of publications per country



Source: (Scopus, n.d.)

in publications in the period: Only 3 publications in 2003, 44 contributions in 2022. Emphasis has been given to journal articles: The number of publications increased from 3 in 2003 to 36 in 2022. A high correlation is observed involving the number of articles accumulated per year ($R^2 = 0.6904$), characterizing a strong linear relationship between the variables.

3.3. Countries of Origin

The number of publications per country are presented in Figure 3: China shows a strong presence, with 90 publications; the United States of America (USA) holds the second position with 48 publications.

3.4. Journal Publishing Standards and Scopus Subject Category

For a frequency of at least 5 published documents, a total of 202 different sources are identified: *Energy Policy* has the largest number of publications in the period (26 papers); *Energy For Sustainable Development* comprises 14 documents, followed by *Sustainability Switzeland* with 11 contributions and *Energy* and *Renewable Energy*, each one with 9 documents; most sources have only 1 article on the subject.

The position of the aforementioned journals according to the category and level metrics is shown in Table 1, referring to 2022 and collected directly from Scopus.

Three journals are among the top 25 in their category; that is the case of *Energy Policy*, which holds the 11th place among 379 journals.

Publications characteristics in terms of the total number of publications (TP), number of authors (NA), and NA/TP ratio are analyzed: TP increases significantly in 2011 (17 publications and 43 associated authors) and between 2016 and 2022, when the publications represent 61.9% of the amount of the total period; also between 2016 and 2022, an expressive NA increase is observed: from 65 in 2016 to 125 in 2022.

The increase of NA and TP denotes an intensive collaboration among experts on the topic.

3.5. Co-authorship

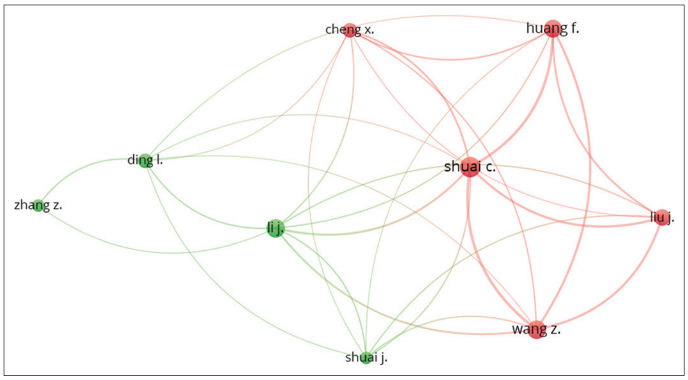
The grouping of the top authors on PVPA based on co-authorship relationships is shown in Figure 4, indicating 12 collaborations among the authors; the networks present frequencies greater than or equal to 4. The circle size represents the number of articles on the subject, while the colors denote possible groupings based on the number of collaborations among distinct authors. The thickness of the connecting line between two circles corresponds to the link's strength.

The relationships among countries is shown in Figure 5, highlighting the leadership of China and USA in terms of the number of publications. Considering the number of citations of a document from a given country, United Kingdom (UK) stands out with a total of 2353, followed by China with 1326 citations; the networks present frequencies greater than or equal to 10.

3.6. Index and Author Keywords

Indexing is defined as "a content analysis technique that condenses the significant information of a document, through the attribution of terms", one of the basic processes of information retrieval (Vieira, 1988). Hence, author keywords and indexed keywords are analyzed to identify the most relevant search trends. Index keywords for frequencies greater than or equal to 20 are ranked and a group of keywords is listed in Figure 6; a total of 25 indexed keywords is identified. The most representative keyword is "poverty alleviation" (79 occurrences), followed by "rural areas" (57 occurrences).

Figure 4: Collaboration network among authors



Source: (VOSviewer, n.d.)

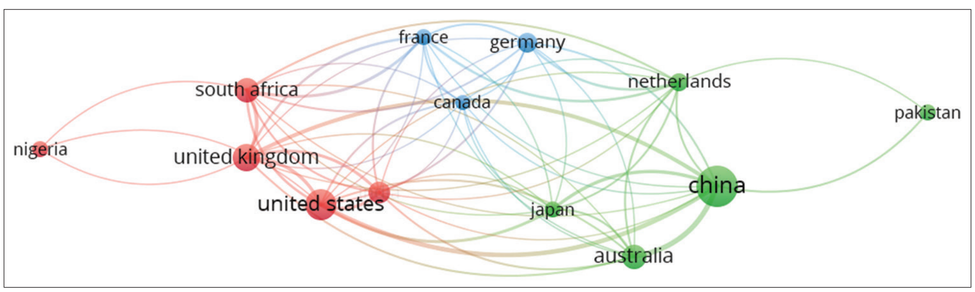
Considering author keywords, frequencies greater than or equal to 5 are considered. According to Figure 7, the most representative keyword is "renewable energy" (47 occurrences), followed by "poverty alleviation" (46 occurrences) and "energy poverty" (23 occurrences). Keyword variations such as "solar energy", "PV", "solar PV" and "solar home system(s)" are identified; other trends such as "rural electrification", "energy poverty", and "energy access" are also found. China (11 occurrences), Africa (9 occurrences), Bangladesh, and Sub-Saharan Africa (5 occurrences each) appear as author keywords, as well as biomass as a second relevant renewable energy source. Keywords frequency evidences the main fields of the search and denotes possible lines for future investigations. Some words appear both in the indexed and author keywords: "sustainable development", "climate change", and "rural electrification", highlighting the research trend.

4. PVPA: STATE-OF-THE-ART ANALYSIS

EP concept emerged in 1991 in Boardman's Book (Moore, 2012), understood as the situation experienced by some families in a wide variety of countries, whose well-being is affected by low energy consumption due to financial factors and environmental reasons, both at home and in their socio-political environment.

EP is also defined as the impossibility of choosing energy services in terms of reliability, quality, safety, and environmental protection

Figure 5: Collaboration network among countries



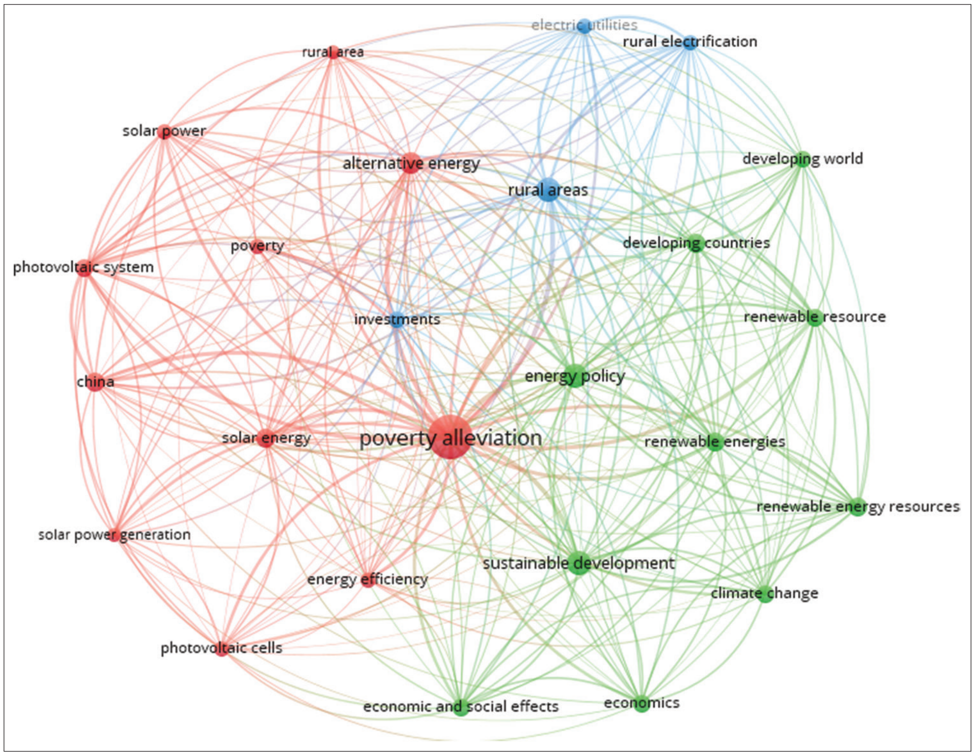
Source: (VOSviewer, n.d.)

Table 1: Level metrics of international journals

Source title	Rank	Categories	Cite score	Highest percentile	SNIP	SJR
Energy policy	11/379	Management, Monitoring, Policy and Law	12.4	97%	2.034	2.126
Energy for sustainable development	38/125	Renewable Energy, Sustainability and the Environment	9.8	82%	1.802	1.44
Sustainability	58/215	Renewable Energy, Sustainability and the Environment	5	58%	1.310	0.664
Energy	22/215	Renewable Energy, Sustainability and the Environment	13.4	90%	2.038	2.041
Renewable energy	21/215	Renewable Energy, Sustainability and the Environment	13.6	90%	2.108	1.877

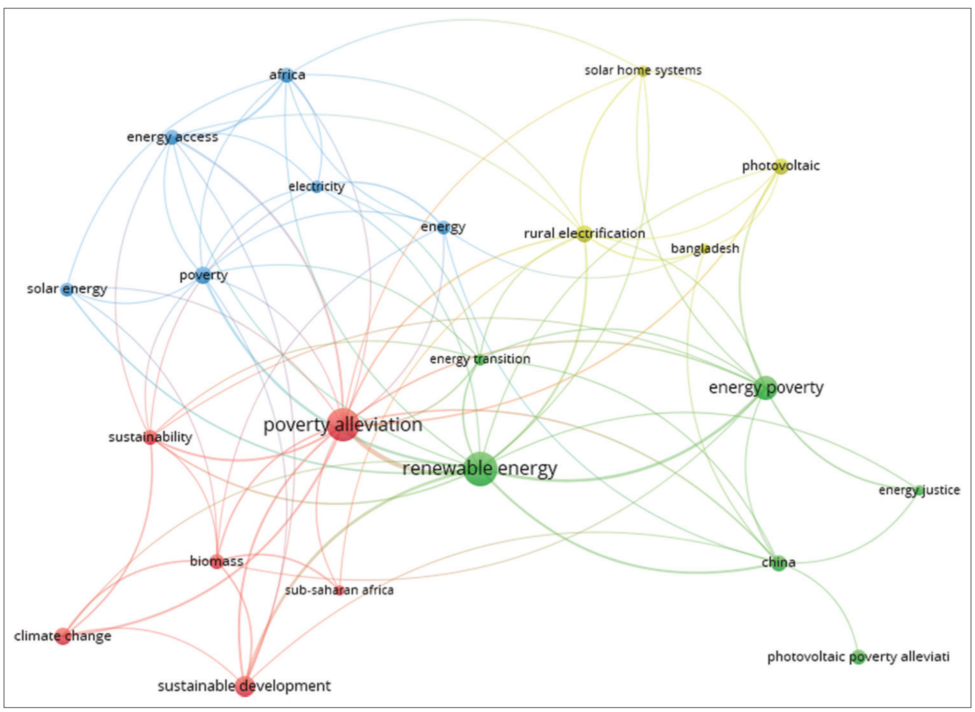
Source: Author's elaboration based on (Scopus, n.d.)

Figure 6: Index keywords



Source: (VOSviewer, n.d.)

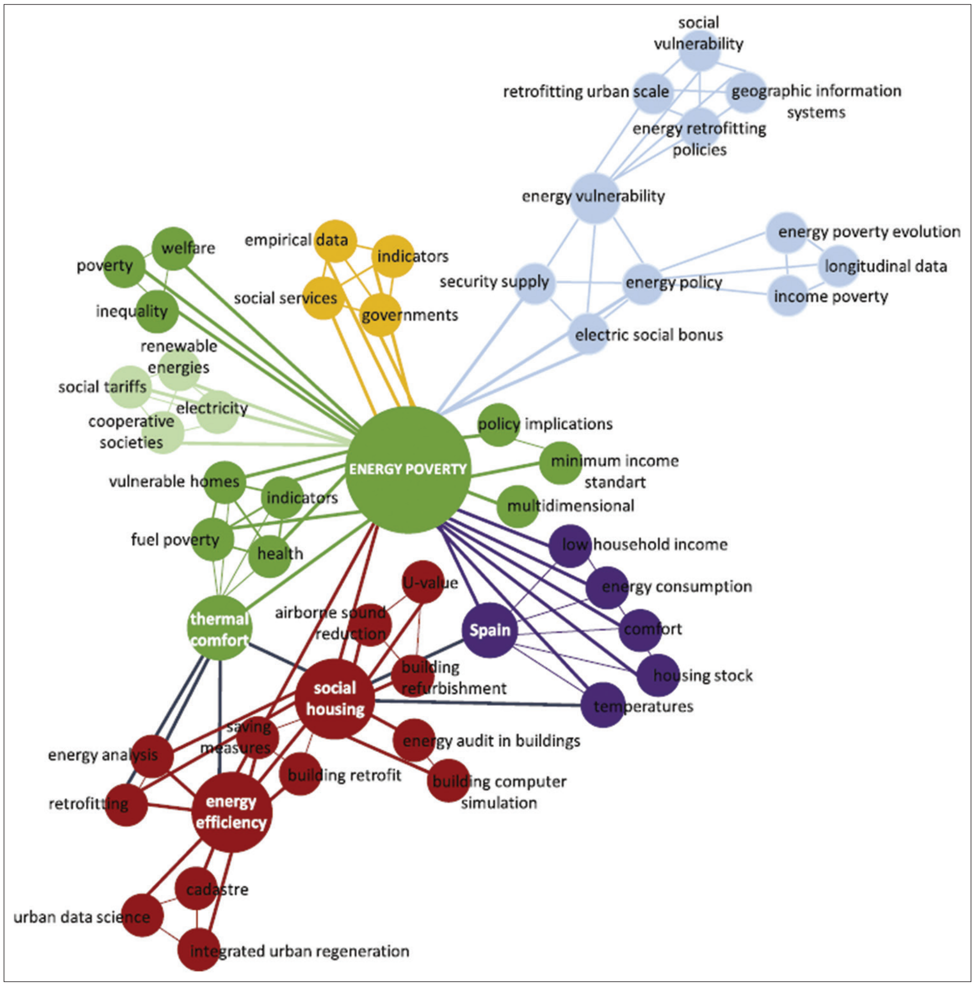
Figure 7: Author keywords



Source: (VOSviewer, n.d.)

under economic conditions that support the economic and social development of families and individuals (González-Eguino, 2015). Complementarily, the human development index (HDI) is compared with the per capita energy demand in and new EP-related concepts are associated with three areas in Spain (Uche-Soria and Rodríguez-Monroy, 2020). EP-related concepts are shown in Figure 8: green circles represent EP, which is directly associated with poverty in general, minimum income and health issues; red circles are associated with subsidized social housing and energy efficiency in buildings; blue circles are associated with energy vulnerability, focusing on ensuring access to energy at economic and health levels, and considering issues that are interconnected

Figure 8: Concepts associated with EP



Source: (Uche-Soria and Rodríguez-Monroy, 2020).

and depend on public policies; circles that are difficult to frame are in yellow, for example representing the focus on governance role.

Issues related to health, women's empowerment and educational training are relevant aspects associated with renewable energy use, especially PV (Gray et al., 2019; Maclachlan et al., 2017). However, other energy sources have also been evaluated in the context of poverty relief projects (Galvão et al., 2020; Yadoo and Cruickshank, 2012). As an example, the biomass development policy and the foreign investment policy are used in Nepal for the development of renewable energy solutions applied to rural projects. Biomass (biogas and improved stoves), solar technologies (PV, solar stoves, water heaters and dryers), and micro-hydro (MH) stand out, aiming to help rural development and poverty reduction (Ojha, 2003).

The influence of solar home-system-related subsidies on rural poverty reduction is analyzed in (Bhattarai et al., 2018). In Northeast England, an assessment of the life cycle sustainability of grid-connected PV power is proposed, focusing on technical-economic, environmental and social issues (Li et al., 2018). The connections between PV and poverty reduction are investigated, along with income, social acceptance of technology and accessibility, in Bangladesh (Meah and Ali, 2019). Factors that affect households' choice of energy sources are analyzed in (Aziz & Chowdhury, 2021).

The high costs of traditional energy services determine the willingness of poor households in sub-Saharan Africa to pay for different types of electricity access, including low-cost grids and off-grid technologies (Sievert and Steinbuks, 2020). Also in Africa, a research in rural areas of Sierra Leone measures the perception of local beneficiaries of two mini solar grid-connected projects regarding the potential for exploring renewable energy, community engagement and poverty reduction (Liu and Bah, 2021). A framework is proposed in India through a government subsidy to support the installation of solar domestic systems in households below the poverty line, incorporating a subsidy disbursement mechanism to improve efficiency (Yadav et al., 2018). The contribution of solar energy to alleviate EP is analyzed in, identifying users socioeconomic characteristics (Akter and Bagchi, 2021). A case study is carried out in Spain in 2018 aiming to assess the benefits of exploring the PV potential of roofs to cover part of the district's electricity consumption, reducing energy bills, and using surplus electricity to supply energy to heat pumps (Romero Rodríguez et al., 2018). Also in Spain, PV and thermal mass storage in low-income homes are combined in (Romero

Rodríguez et al., 2018), as a way to mitigate EP and improve thermal comfort. The effectiveness of the government's sustainable energy policy in providing PV systems to low-income families living in publicly rented apartments in Seoul's metropolitan region is investigated in (Lee and Shepley, 2020). Small-scale solar kits (100–400 Wp) are proposed for non-electrified regions in Guatemala and Puerto Rico as a strategy to reduce energy poverty (Sperry et al., 2023).

Considering the Brazilian context, many projects in the semiarid region aim to guarantee access to drinking water, make its availability more efficient or reduce the impact on climate change (Padilha Campos Lopes et al., 2020; Reges et al., 2021). The feasibility analysis associated with such projects typically considers five major issues: Accessibility, effectiveness costs, financial aspects, environmental impacts, and poverty alleviation (Baurzhan and Jenkins, 2016). Accessibility is associated to the on-grid or off-grid condition of installed systems, which directly impacts the effectiveness costs related to the implementation, operation and maintenance; such aspect is also of great relevance in determining the levelized cost of electricity (LCOE). The feasibility analysis of PV systems primarily considers the solar radiation level, but technical aspects related to the system typology, whether on grid or off grid, influence analyzes about the distance to roads and access to electrical grids (Maleki et al., 2017).

4.1. Case Studies of Photovoltaic Systems for Water Pumping (PVWP)

Photovoltaic Systems for Water Pumping (PVWP) was the theme of Dominique Campana's thesis in 1973. However, the first practical application of such systems was only reported in 1977 in Mali, called Mali Aqua Viva (Fedrizzi, 2003); the project reduced the impacts of drought and motivated the implementation of similar plants in European countries. As a consequence, the first commercial project was implemented in Corsica, France, in 1978. Between 1979 and 1981, PVWP were installed with the support of the United Nations Development Program for Sudan (UNDP), World Bank (WB) and Intermediate Participation Technological Development Group (ITDG), aiming to assess the performance of plants between 100 and 300 Wp for irrigation in rural areas of Mali, Philippines and Sudan. From this pilot project, important issues were identified: the great potential for application in rural areas and the need to improve the equipment reliability and reduce the associated cost.After such pioneer projects, a cooperation program started in 1990 involving the *Deutsche Gesellschaft für Technische Zusammenarbeit* (GTZ) and seven countries (Argentina, Brazil, Indonesia, Jordan, Philippines, Tunisia and Zimbabwe), aiming to assess the real cost and systems maturity (Fedrizzi, 2003).

In Brazil, the state of Ceará (semi-arid region) was selected for the project implementation, envolving 15 small rural communities. To reduce difficulties related to maintenance and data acquisition, all sites were chosen within a 150-km radius from Fortaleza, Ceará's capital. Additionally, the following conditions were also mandatory: Wells should offer a flow rate of at least 1.2 m^3/h; electrical grid should be no more than 6 km far from the sites; local community should have a school and/or health station; water should serve a community and not a specific farmer; community should show will to join the project. The systems were equipped with multistage centrifugal pumps of three different sizes to match the required head and flow of each site; the pumps were coupled to asynchronous motors connected to inverters (Aragão et al., 1994). The PV plants rated power were: 700 Wp (a total of 11 units), 800 Wp (3 units), 1050 Wp and 1200 Wp; each PV module had an output of 50 Wp. A total of 5 plants were equipped with dataloggers for measuring dc current and voltage, solar irradiation, pump flow rate, dynamic water level and water requirements; the following quantities were calculated from such variables: PV power, delivery head, hydraulic power, PV efficiency and overall system efficiency.

The results showed that most pumps were slightly oversized, working within a low operating range (Aragão et al., 1994. The system efficiency ranged between 1.5 and 3.5%; PV efficiency was around 11.59% and no degradation was observed. In some sites, water consumption was much lower than estimated due to the low acceptance of water from deep wells, which tastes different from shallow water from lakes or rivers due to its mineral content. In the social field, the underestimation of local culture in some sites was a weakness of the project. After identifying such problems, a group of sociologists developed activities aiming to integrate the project and community. Hence, by observing the culture and habits while identifying opinion makers in the communities, the acceptance level of the systems coulde be changed. As a consequence of the developed activities, related to health, hygiene and food, a reduction of the number of children with intestinal problems was observed, due to the use of adequate water and hygiene actions. A training booklet was used in the community's schools aiming to seek acceptance through children, since part of the adult population was illiterate.

A cost-effectiveness analysis was carried out to evaluate the rural project in Ceará, comparing solar pumps, wind, diesel and conventional electric pumps, considering the following conditions: Time window of 15 years; yearly interest rate of 12%; no salvage value and evaluation of costs associated with the installation of PVWP based on the national market. According to the results, PVWP are characterized by a low operational cost and a high investment, representing an economical option if the closest grid connection is just 7 km away from the site. Some variables also influence the performance: Operation without human intervention; environmental conservation; population acceptance and other service-related costs, such as improvement of health and life conditions (Aragão et al., 1994). Almost three decades after the conclusion of the GTZ program, the advantages and disadvantages of community involvement in PVWP outcomes are still under study. Another point to be considered is the support required by the community after the implementation of these projects as a way to keep the system operational (Short and Oldach, 2003).

4.2. Business Models and Financing Associated with PVPA

PV power as a distributed resource has directly associated risks, which are inherent in the lack of a clear definition of property rights of roofs, risks of PV power policies and of access to distribution grids and uncertainties of profitability (Luo et al., 2016; Vermeylen, 2010). The use of political, economic, social, and technological –

strengths, weaknesses, opportunities, and threats (PEST-SWOT) strategic analysis enables identifying the internalities (strengths and weaknesses) and externalities (opportunities and threats) of PV power, including politics, economy, society, and technology (Hou et al., 2019). Hence, considering that PVPA are mainly directed to the poor population, the need for resources for initial investments associated with the long return on investment makes the financing conditions a great challenge and/or barrier. For this reason, the first step is to determine how much each family can invest and how long they can maintain the investment, in addition to knowing if they are willing to do so. The second step is to decide whether the data collected previously is viable for investors (Nduka, 2021); the answers to these questions may constrain PVPA implementation. Various PVPA funding models have been tested over the years: Microcredit, village bank and public-private partnership (PPP) models are examples, which are shown in Table 2 with their advantages and disadvantages. A comparative study was carried out using dynamic game models for the following funding modalities: (1) government contributing with all capital expenses, (2) poverty alleviation funds plus loans for poor households, and (3) poverty alleviation funds plus investments from PV companies. The third type of investment brought the best results in terms of income and poverty reduction (Zhang et al., 2018); hence, to motivate the participation of PV companies in PVPA, three strategies are proposed: (1) granting quotas for PV projects for the construction of commercial plants; (2) use of PPP or build-operate-transfer (BOT) strategies; (3) permission for PV companies to issue bonds or use fiat investments; (4) providing technical support to PV companies to reduce the involved costs. Another strategy that allows rural PV units to generate independent revenue is to create a price-based demand-response trading pattern for rural properties to improve sales revenue and local consumption (Tu et al., 2020).

Governments play an important role in the PVPA formulation since they are often the primary sources of initial investment and incentive policies (subsidies and reduction of taxes, among others). For instance, the locations to install PVPA in China were determined based on the regional classification according to solar

Table 2: PVPA business models

References	Aim (country/continent)	Business model	Advantages	Disadvantages
(Biswas et al., 2004)	Evaluation of a sustainable rural development and poverty alleviation model with PV systems (Bangladesh)	Micro-credit	Management is carried out by an implementing company; The project can be individual or cooperative; The payback period is eight times shorter than that of rural electrification.	Need to extend the credit limit; Funding limits for cooperatives may not be sufficient to meet the project's objective.
(Li et al., 2018)	Comparison between business models to provide a reference for PVPA projects (China)	Power Purchase Agreement (PPA)	None or upfront costs; Fundraising for homeowners who cannot obtain self-financing; Profit is ensured by fixed electricity rates; Homeowners take ownership of the system with the buy-out option at the end of the contract.	Homeowners need a good amount of credit; There are long-term commitment policies that involve penalties for breach of contract; It does not include the energy supply to the community itself.
		Financial Leasing	Fundraising for homeowners who cannot obtain self-financing; Lease payments are fixed for the investors; It provides a production guarantee for the homeowner.	Rent is overdue during the operation stage; The funds cannot be used for a specific purpose due to the lack of regulation.
		Crowdfunding	It raises funds from the public and integrates dispersed funds; the investors can quit the project after the lockup period; Fund costs are lower than other financing methods.	Crowdfunding involves the question of legality; The default risks are high, without the existence of relevant laws and insurance.
		Special Purpose Vehicle (SPV)	It is usually applied to large-scale roof-based PV stations; It involves multiple investors, including financial institutes and individual investors; Debt financing is provided by policy banks at a lower rate of interest.	The borrower owns a share of 15% - 30% of the PV project; The loan is entirely repaid by the electricity bills, so a production guarantee is required.
(Li et al., 2020a)	Introduction of the third model for funding and analysis of potential reputational benefits (China)	Policies for third-party financing, considering social reputation like a return.	It works like crowdfunding, with the same advantages, disadvantages, and benefits associated with promoting the investor's reputation.	Positive cash flow only after the 12th year; Funding PVPA projects is more beneficial for companies with better fund operating skills.

Source: Author's elaboration based on (Li *et al*., 2018) irradiation levels. The provincial PV plant benchmarking power tariff varied according to resource area categories from 0.1 USD[1] to 0.13 USD. Considering the hours of sunlight and installed capacity to estimate revenue generation, state subsidies of 0.07 USD amounted to around 50% of earnings from electricity sales (Zhang et al., 2021). Although subsidized tariffs are a common incentive, their impacts need to be characterized. One of the methodologies for reducing subsidies considers the value-added tax tax (VAT) (Tax Foundation, 2022); hence, one can state that the preferential VAT policy used as a regulatory practice would improve the PVPA profitability. Another relevant aspect is that PVPA subsidy should not rely on "one size fits all approaches" in all regions of application (H. Zhang et al., 2021).

The need for clear incentive policies, as well as a plan for their reduction over time, are issues that directly impact PVPA investments. Additionally, the instability of public policies and lack of continuity in the government change are aggravating factors for the expansion scenario of such projects. Complementarily, the LCOE has been applied to evaluate PV projects; since such cost is conceptually defined as the ratio between the invested capital costs (Capex) plus operating costs (Opex) and the energy that is estimated to be produced during the plant operation, it acts as a comparative indicator of production costs involving different technologies, contributing to the definition of financial budget (Fathi Nassar and Yassin Alsadi, 2019). The LCOE has also been used to assess PVPA's dependence on policies and economic sustainability and as a basis for the development of the level net present value electricity (LNPVE) model, which explores long-term economic benefits, as well as the influencing factors of the PV power project; an additional contribution is the impact assessment involving subsidy policies (Chang et al., 2020). However, LCOE use alone may not cover all the variables and impacts related to funding rates, taxes and subsidy reduction, for instance.

Despite the number of PVPA financing models, the business model envisaged in most cases seeks to make energy accessible not only from a technical point of view but also from an economic perspective. The energy apportionment model, or the benefits arising from PVPA use for the community, is similar to that of renewable energy communities (RECs). However, this concept has differents objectives: In Europe, a REC is a legal entity aiming to provide benefits to shareholders, associates or locations in terms of environmental, economic and social gains rather than profit (Directive (EU) 2018/2001, 2018); REC is not used in Brazil, but the term "shared generation" is defined in (Congresso Nacional, 2022) as the modality characterized by the association of consumers through a consortium, cooperative, voluntary civil condominium, building, or any other form instituted for the same purpose. The objective is to share the use of energy from renewable sources and/or benefit from the energy compensation system, while injecting the surplus into the grid; in the USA, the term "community renewables" has been replaced with the term "shared renewable energy" or "shared renewable energies". This change aims to emphasize the capacity of several consumers to share the benefits of a single generating facility (*IREC 2013 UpdatEs and TREnds REpoRt A n n Ual*, 2013). The lack of a universal concept about RECs and related objectives brings complexity to comparative studies involving continents, countries, or even states.

4.3. PVPA Assessment

From the perspective of reducing poverty in its various dimensions, some metrics and tools are necessary for assessing PVPA results (Li et al., 2020b). These metrics and assessment tools can provide useful information on the baseline conditions, such as areas with the best solar irradiation conditions and social impact, also considering the interaction between tool indicators and identifying gaps that need to be filled with finite resources (Linkov et al., 2013; Sharifi and Murayama, 2013). During the literature review, three research lines were identified related to PVPA indicators/results:

1. Sustainability, dealing with indicators and results formulated in the social, environmental and economic contexts;
2. Technical performance, evaluating PVPA performance efficiency based on indicators like generator and installed capacity, labor, operating cost, number of modules and solar irradiation (Wu et al., 2018; Yi et al., 2019);
3. Impact of investments, considering the total amount released for micro-financing (credit loan specially designed for poor families with less than 7.84 USD, per loan, with financing periods shorter than 3 years, no mortgage, low interest rates and financial discount) (Wang, et al., 2020; Wang, et al., 2020).

A summary of studies associated with sustainability is listed in Table 3; several methodologies used in the definition of indicators and/or results are identified: Theory of change (ToC), social networks for financing purposes, life cycle assessment (LCA), net energy analysis (NEA), principal component analysis (PCA), data envelope analysis (DEA) and gray ratio analysis (GRA) and sustainable urban livelihoods approach (SULA). In addition to these, some financial indicators such as: energy payback time (EPBT), energy return on investment (EROIPE-eq), greenhouse gas emission rate (GHGe-R) and carbon payback time (CPBT), are also mentioned.

Despite the significant number of benefits related to PVPA use, it is important to know the values and priorities of end users, as these issues favor engagement with projects (Chen et al., 2021; Huang et al., 2020); such criterion is reinforced in (Huang et al., 2021; Peters et al., 2018), stating that the limited knowledge of the local population is a major challenge for PVPA. Usually the local population has no access to information about PVPA policies, operation and system maintenance; additionally, inefficient market mechanisms, low operational efficiency, lack of public agencies and high abandonment rates are other highlighted challenges.

5. RESULTS AND DISCUSSION

From the developed biliometric analysis we identify that China is the country with the largest number of publications; such aspect is related to the fact that in 2014 the Chinese National Energy Administration (CNEA) and the Council for Poverty Alleviation

1 The values presented in RMB were converted to US Dollars based on the website https://pt.exchange-rates.org/converter accessed on 03/14/2022. Quote 1 US dollar = 6,3709RMB.

Table 3: Indicators and benefits of PVPA projects

	Indicator	PV use				Land use	Reduction of deforestation and/or environmental impact	Return Taxes			
	Benefits	GHG reduction	Replacement of fossil fuels	Improvement of indoor air quality	Grid connection rate			EPBT	EROIPE-eq	GHGe-R	CPBT
Aim (country/ continent)	Type of analysis										
PVPA evaluation (China) (Liu et al., 2019)	Empirical studies (LCA, NEA)							✓	✓	✓	✓
PVPA performance (China) (Li et al., 2020a)	Empirical studies (PCA, DEA, GRA)			✓							
Development of social indicators (Africa) (Wlokas, 2011)	SULA application	✓	✓	✓			✓				
Analysis of SHS benefits (Côte d'Ivoire) (Diallo and Moussa, 2020)	Empirical studies	✓	✓				✓				
Evaluation of SHS to reduce poverty (Africa) (Hakiri et al., 2016)	Empirical studies (ToC)		✓	✓							
Analysis of PVPA social impacts (China) (Chen et al., 2021)	Case study				✓	✓	✓				
Evaluation of PVPA benefits (China) (Li et al., 2019)	Theoretical model										

(Contd...)

Table 3: ***(Continued)***

	Indicator	Investors results		Assets		Financial capital		Gender Capital				
	Benefits	**Self-consumed electricity or profit from sale**	**Reputational promotion**	**Access to new technologies**	**Increased material wealth**	**Financial support to maintenance**	**Cost-effectiveness**	**Reduced expenditure**	**Increased income**	**Income security**	**Government support (subsidies and similar policies)**	**Livelihood level increase**
Aim (country/continent)	Type of analysis											
PVPA evaluation (China) (Liu et al., 2019)	Empirical studies (LCA, NEA)											
PVPA performance (China) (Li et al., 2020a)	Empirical studies (PCA, DEA, GRA)											
Development of social indicators (Africa) (Wlokas, 2011)	SULA application					✓	✓	✓	✓	✓	✓	✓
Analysis of SHS benefits (Côte d'Ivoire) (Diallo and Moussa, 2020)	Empirical studies			✓	✓				✓			
Evaluation of SHS to reduce poverty (Africa) (Hakiri et al., 2016)	Empirical studies (ToC)							✓				
Analysis of PVPA social impacts (China) (Chen et al., 2021)	Case study								✓		✓	✓
Evaluation of PVPA benefits (China) (Li et al., 2019)	Theoretical model	✓	✓									

(Contd...)

Table 3: *(Continued)*

	Indicator	Participation in PVPA									
	Benefits	**Regional economy**	**Improvement of social welfare**	**Training**	**Employment**	**Time saving, increase of hours of opportunity**	**Physical and mental health improvement**	**Education**	**Security improvement**	**Increased business**	**Access to information**
Aim (country/ continent)	Type of analysis										
PVPA evaluation (China) (Liu et al., 2019)	Empirical studies (LCA, NEA)										
PVPA performance (China) (Li et al., 2020a)	Empirical studies (PCA, DEA, GRA)		✓	✓	✓	✓	✓	✓		✓	✓
Development of social indicators (Africa) (Wlokas, 2011)	SULA application		✓	✓	✓	✓	✓	✓			✓
Analysis of SHS benefits (Côte d'Ivoire) (Diallo and Moussa, 2020)	Empirical studies						✓	✓		✓	
Evaluation of SHS to reduce poverty (Africa) (Hakiri et al., 2016)	Empirical studies (ToC)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Analysis of PVPA social impacts (China) (Chen et al., 2021)	Case study	✓		✓	✓	✓					
Evaluation of PVPA benefits (China) (Li et al., 2019)	Theoretical model										

Source: Author's elaboration based on (Wlokas, 2011) and Development (CPAD) Lead Group Office issued joint policies aiming to start the Solar Energy for Poverty Alleviation Program (SEPAP) (Geall and Shen, 2017). Considering the USA context, the publications address distinct subjects: From solar electrification and associated social impact (Jacobson, 2007) to assessment of low-cost, low-carbon energy in rural areas (Casillas and Kammen, 2011). Among the publications per country, a significant portion is related to scientific studies applied to other countries (Boller et al., 2017; Gray et al., 2019; Weaver and Wickramasinghe, 2006).

Author's keywords with the highest occurrences are "poverty alleviation" (79 occurrences) and "rural areas" (57 occurrences), confirming PVPA focus on applications in rural areas. China (11 occurrences), Africa (9 occurrences), Bangladesh and Sub-Saharan Africa (5 occurrences each) appear also as author's keywords, as well as biomass as a second relevant renewable energy source. In the case of indexed keywords, the most representative are "renewable energy" (47 occurrences), followed by "poverty alleviation" (46 occurrences) and "energy poverty" (23 occurrences). Variations of keywords such as "solar energy", "PV", "solar PV" and "home solar system(s)" are identified; other trends, such as "rural electrification", "energy poverty" and "access to energy", are also found. Some words appear in both indexed and author's keywords: "sustainable development", "climate change" and "rural electrification", highlighting the search trend; such aspects denote possible lines for future investigations.

BA has some important limitations that must be observed, such as the ones related to the chosen database, the formatting of the search strings with the use of Boolean markers, the definition of the frequency of occurrence associated with items used in VOSviewer, among other issues. As an example, other energy sources such as wind and dendro occurred in this search, but these were only identified within the state-of-the-art study carried out from the same database used in VOSviewer for the BA. In addition, as identified in the SLR, one of the major problems related to the implementation of PVPA is the issue of financing for low-income residents. In the BA, what comes closest to the theme is the indexed word investment.

From the SLR we identify applications in a large number of continents/countries, predominating projects to reduce EP. Despite the terms seem to be synonymous, there are differences between projects for EP reduction, focused on access to energy, and projects for poverty reduction, considering its multiple dimensions; access to energy does not ensure local poverty reduction, despite being a coincidental relationship (Sadath and Acharya, 2017). Multidimensional deprivations are due to the lack of access or lack of quality of the accessed energy. Education, health, and jobs creation should be considered in an integrative approach, and not only monetary issues (Marchand et al., 2019). Furthermore, most articles focus on the effects of the implementation of macro policies on photovoltaic technology in the socioeconomic environment. Therefore, the need for literature on PVPAs with a focus on construction, operation and ex-post results, which can intuitively reveal their contributions to eradicating poverty, is identified.

The importance of priority projects in rural areas is emphasized, considering that urban areas usually already have a better access to water and energy; however, according to (Ravallion et al., 2007), although rural poverty is on the decline, urban poverty is on the rise. Hence, such criterion needs to be reassessed, including the growth of informal urban settlements; risks of flooding, earthquakes and guaranteed access to the sun's flow are also aspects that should be considered in the feasibility analysis. Furthermore, focus should be given on regions where poverty predominates, without considering only low-income families.

PV systems use has directly associated risks, inherent to the lack of a clear definition of property rights for coverage and access to energy flow, risk of energy policies, access to distribution grids and profitability uncertainties (Luo et al., 2016; Vermeylen, 2010). Considering that PVPA mainly aim poor populations, the need for resources for initial investments and the long return on investment make financing conditions a major challenge and/or barrier. A business model viable for investors (Li et al., 2018) and public policies to encourage investments are still a challenge.

6. CONCLUSION

As an innovative contribution, we present a bibliometric study on PVPA complemented by an in-depth state-of-the-art analysis. Our main motivation is that, over the past 20 years, global research and PV applications to promote poverty alleviation have increased significantly. Considering the analyzed period from 2003 to 2022, a total of 336 publications are found using Scopus database. "Poverty alleviation" is a common term both in indexed and author keywords, corresponding to 7.68% and 5.08%, respectively. Considering the energy resource, the highlight is the solar source, namely "photovoltaic", with some variations such as "PV" and "photovoltaic system". Regarding the indexed keywords, it is important to highlight the presence of terms like "rural area", "rural electrification", and "electric power transmission grids"; such aspect denotes the objective of ensuring the energy supply while enabling the reduction of rural energy poverty. According to our study, most research on PVPA focuses on the association between poverty alleviation and PV use in rural areas. Hence, we identify a gap in the application of PV projects in urban areas of developing countries, aiming to reduce multidimensional poverty, as well as a synergistic integration of energy and urban planning to mitigate risks associated with direct use of roofs and access to solar flow. China dominates this field in terms of publications and projects implemented, and therefore the country's experience should be observed.

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