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Global research trends in building-integrated photovoltaics: a bibliometric analysis (1971-2022)

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ABSTRACT

The number of academic publications in the building-integrated photovoltaics (BIPV) field has rapidly grown. Most published articles focus on a specific topic, such as mathematical model, solar architecture design, photovoltaic effect, solar cell, grid-connected, efficiency, performance assessment, economic analysis, optimization, and others with broader focus areas. This work focuses on BIPV research with bibliometric analysis through documents, cited references, authors, affiliations, countries, funding sponsors, sources, words, and conceptual structure based on the Scopus-indexed database between 1971 and 2022. The result shows that BIPV research constantly grows annually with strong collaboration authorship. China is the most relevant country with the top affiliation and funding sponsor to support the BIPV research. The terms conjugated polymers, photovoltaic properties, and organic polymer are identified as niche themes. On the other hand, the terms of conversion efficiency, perovskite, photovoltaic devices, solar cells, efficiency, and photoelectrochemical cell clusters are emerging themes. In the future, BIPV research will move towards microgrids, energy, performance, energy management systems, and energy efficiency issues. The finding will also provide researchers and organizations with a comprehensive understanding of BIPV research areas and new directions for future research.

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1. INTRODUCTION

Electric energy supply is critical to modern society and is crucial in supporting economic growth, social welfare, and technological innovation. Most aspects of modern life, such as transportation, communication, healthcare, entertainment, and education, rely on a reliable and affordable electricity supply [1]. As today's primary energy source, fossil fuels are limited and have caused several environmental issues [2]. These conventional fuels' immense global exploitation and utilization have accelerated resource insufficiency and caused severe negative environmental impacts and climate problems [3]. The rapid growth of global electric energy consumption will further put carbon emissions at the forefront of global consciousness, e.g., in the United States, China, Pakistan, and many more [4]–[6]. New and renewable energy as an alternative energy source is widely preferred to displace, i.e., hydro, geothermal, biomass, tidal, wind, hydrogen, and sunlight [7]–[9]. These kinds of energies emanate from natural sources that are replenished. The new and renewable energy generation percentage in the energy mix continues to grow worldwide [10].

International Energy Agency (IEA) report in 2021 indicates that the operation of buildings accounted for 27% of total energy sector emissions and 30% of global final energy consumption [11]. A lockdown rule has been implemented to control the spread of coronavirus disease 2019 (COVID-19) worldwide. Total energy consumption tends to decrease compared to the previous year, but most residential and facility buildings have decreased during the lockdown [12]. Using more efficient and renewable energy sources in buildings is accelerating while the power sector decarbonizes [13]–[15]. Nevertheless, the building sector needs a quick change to align with the global net zero emissions scenario.

Solar energy is one of the most popular renewable sources with substantial global potential and prospects [16]. Solar energy is also available as a local renewable resource [17]. It offers the electrical provider advantages to electrifying not only urban areas but also underdeveloped, remote, and outer/frontier areas [18]. Solar photovoltaics (PV) is one promising technology that can convert sunlight into electrical energy. Unlike conventional energy sources, solar PV produces electrical power without depleting natural resources, causing noise pollution, and emitting harmful greenhouse gases [19]. Solar PV is a vital alternative energy that accelerates the clean energy transition and net-zero energy building [20]. Likewise, PV solar panels are visually unobtrusiveness. Most residential users prefer installing PV solar panels on a rooftop and benefiting from unused space in existing buildings. Today, conventional building materials as parts of the building envelope (e.g., skylights, windows, flat/pitched/curved roofs, facades, glazing, shading systems, and curtain/external walls) can be replaced by solar PV innovations known as building-integrated photovoltaics (BIPV) [21]. Another reference from [22] called this system with building attached/applied PV called BAPV indicates that the PV system is added to a building.

BIPV is a technology that integrates solar panels or modules into the building envelope, such as roofs, facades, or windows, to generate electricity from sunlight while also serving as a functional part of the building [23]. BIPV systems can be designed to match the building's architectural style and energy needs and can contribute to reducing energy consumption and greenhouse gas emissions [24]. BIPVs can take different forms, such as PV tiles, shingles, glass modules, or cladding systems. The BIPV modules can be installed in various orientations and angles to optimize solar energy production and minimize shading. The electricity generated by the BIPV system can be used onsite to power the building's electrical loads, or it can be fed into the grid for others to use. Simultaneously functioning as a power generator and building envelope material, this system can reduce electricity bills and provide a modern appearance and aesthetics to the building [25]. BIPV has several advantages over traditional solar PV systems, including reduced installation and maintenance costs, increased energy efficiency of buildings, improved aesthetics, and potential for higher energy production due to the integration of PV modules in areas that would otherwise be unutilized. The applications of BIPV technology are commonly classified into standard in-roof systems, semitransparent systems, cladding systems, solar tiles & shingles, and flexible laminates [26]. However, BIPV also faces challenges, such as higher upfront costs than traditional building materials and the limited availability of skilled installers. Despite these challenges, BIPV is becoming increasingly popular in many countries to promote sustainable building practices and meet renewable energy targets [27].

Advanced innovation and development employment in BIPV materials boosts module efficiency, reduces generation costs, and improves building integration. Therefore, the thin-film BIPV module is flexible and can be quickly seated in any uneven parts of the building envelope. A curtain wall is another alternative that is the fastest-growing market segment. Investigation from [28] study on the BIPV combined with active heat recovery systems called building-integrated photovoltaic-thermal (BIPVT systems). There are two kinds of technology: closed loop based on liquid and open loop with forced air. The results indicate that the BIPVT system has substantial benefits and potential for broad use in buildings in the future. Most studies on BIPV research focus on specific issues, such as mathematical models [29], material [30], [31], solar architecture design [32], the PV effect [33], solar cells [34]–[36], grid-connected [37], efficiency [38], performance assessment [39], economic analysis [40], optimization [41], and others with broader focus areas.

Bibliometric analysis is a quantitative approach to evaluating scientific publications, authors, or research fields [42]–[44]. It involves the application of statistical methods to bibliographic data, such as authorship patterns, publication frequency, citation counts, co-authorship networks, keywords, and research trends. Bibliometric analysis provides insights into the production, impact, and dissemination of scientific knowledge and the structure and dynamics of research communities. It is commonly used by researchers, librarians, funding agencies, and policymakers to assess the scientific output and impact of individuals, researchers, institutions, and countries, to identify emerging trends and research gaps, and to inform decision-making processes in science and technology. The bibliometric analysis employs metadata from Scopus, Clarivate Analytics' Web of Science (WoS), PubMed, Digital Science Dimensions, and Cochrane databases [45]–[49]. According to a logical bibliometric workflow, this tool was developed in R programming language, which is highly extensible. This packages investigation and builds data matrices to review sources, authors, affiliations, countries, documents, clustering, conceptual, intellectual, and social structures analysis [50]. It

delivers a structured analysis of an extensive body of knowledge to infer trends over time, determine shifts and themes in the boundaries of the disciplines, detect most of the prolific scholars and institutions, and show the big picture of extant research. These techniques support the synthesis of past research findings and summarize the amount of scientific shifting to effectively use the existing knowledge base in a transparent, systematic, and reproducible examination process. BIPV represents an innovative solution to the growing demand for sustainable energy sources. Despite its potential, adopting and developing BIPV technologies have faced numerous challenges, including high initial costs, integration issues with building structures, and variability in energy production. Understanding the global research trends in this field is crucial for identifying gaps, guiding future research, and accelerating the adoption of BIPV technologies. Bibliometric analysis is very appropriate when the number of academic publications is rapidly growing, and it is increasingly unfeasible to keep track of the publication [51]. It is a helpful method of defining the impact of publications, researchers, or organizations in the scientific community.

Although extensive scientific research has been published in BIPV fields, the need for systematic analysis concerning global research trends must be sufficiently recognized. This review study can support relevant researchers in understanding the BIPV field's science mapping and knowledge base more rapidly. The review uses a general overview, documents, cited references, authors, affiliations, countries, funding sponsorship, sources, words, and conceptual structure as bibliometric analysis with proper and dynamic graphs to explore BIPV from the Scopus-indexed database, combining the two powerful bibliometric analysis tools (i.e., Bibliohiny R-package and VOSviewer). The review study is structured as follows. The materials and method, including data collection and bibliometric tools, are all explained in section 2. Simulation results include a general overview, documents, annual cited references, authorship, affiliations, countries, funding, sources, keywords, thematic map, and tren topic, all covered in section 3. Section 4 is a result discussion and research outlook, while section 5 is the review's conclusion.

2. METHOD

2.1. Bibliometric analysis and network visualizing

Bibliometrics is a rigorous and popular open-source tool for analyzing and exploring quantitative research. It has enormous volumes in bibliometrics and scientometrics and includes all the main bibliometric analysis methods [52]. This tool provides a web interface method for bibliometric analysis created by the K-Synth team consisting of Massimo Aria, Corrado Cuccurullo, Michaelangelo Misuraca, Mario Spano, Luca D'Aniello, Agostino Gnasso, and Allesandra Belfiore. Moreover, for visualizing bibliometric networks, this study utilizes VOSviewer as a software tool that offers text-mining functionality of essential terms extracted from the scientific literature. It is developed by Nees Jan van Eck and Ludo Waltman from Leiden University's Centre for Science and Technology Studies (CWTS) in the Netherlands [53]. VOSviewer enables users to create and visualize bibliographic networks based on bibliographic data such as co-citation, bibliographic coupling, or co-authorship relationships. The software offers a range of clustering, network analysis, and visualization options to identify research trends and relationships between authors or documents and research communities. One of the critical features of VOSviewer is the ability to create and visualize bibliometric maps, which are graphical representations of bibliographic networks. These maps can provide a visual summary of the key themes and relationships within a research field or set of publications. VOSviewer also offers the option to export maps in various formats, such as image files or interactive web pages, making it easy to share and present bibliometric analyses. VOSviewer is freely available for academic and non-commercial use, and it is widely used by researchers, bibliometricians, and research administrators to analyze and visualize bibliographic data. In this study, the visualization constructed in the researcher's networks was based on co-authorship relations. Density visualizations provide a quick overview of the main areas in a bibliometric network.

2.2. Identification of sources and search criteria

For this study, bibliometric analysis and visualizing methods were applied. Bibliometric analysis provides a systematic approach to evaluating research trends, identifying key contributors, and visualizing collaborative networks. This method is well-suited for our objective of mapping the global research landscape of BIPV. Bibliometric techniques are widely accepted for handling large datasets and producing replicable results. They allow for a comprehensive analysis of publication trends, citation patterns, and research impact. The initial stage in this review was to explore the Scopus database for all published works on BIPV to collect a data set. Scopus is a bibliographic database comprehensively covering scientific, technical, medical, and social science literature. Elsevier is a leading publisher of scientific journals, books, and online resources. Currently, Scopus offers a range of features and tools for searching, filtering, and analyzing the literature, including citation analysis, author and affiliation profiles, keyword tagging, and subject classification. It also provides metrics such as the h-index and source normalized impact per paper to

assess the productivity and impact of researchers and research institutions. Scopus is widely used by researchers, librarians, and research administrators to discover, track, and evaluate scholarly literature and research trends. Scopus indexing integrated a comprehensive, expertly curated citation database and abstract across various subject areas in BIPV fields (i.e., energy, engineering, material science, environmental science, physics, computer science, mathematics, social science, chemical engineering, chemistry, and multidisciplinary). It includes the article, conference paper, review, book chapter, conference review, book, editorial, note, data paper, letter, report, and short survey. The Scopus website provides quick information, i.e., document access, year, identifies experts by author name, subject area, document type, publication stage, source title, keyword, affiliation, funding sponsor, country/territory, source type, language, and access to metrics and simple analytical tools.

Boolean "AND" and "OR" are logical operators in Boolean algebra and computer programming. The "AND" operator returns true if both operands are true or false. The "OR" operator returns true if at least one of the operands is true and false otherwise. These operators are also used in database queries and search engines to combine multiple search criteria or conditions. The search string uses the Boolean operators "AND" and "OR" to query the article titles, abstracts, and keywords from the Scopus database (accessed on 3 March 2023). An initial search for building AND integrated AND photovoltaic OR PV OR BIPV (TITLE-ABS-KEY) resulted in 12,014 documents. Applying the following initial screening criteria reduced the original dataset by 1,120 to 10,894 documents. Filter (i.e., exclude and limit to) is utilized as following criteria: exclude 2023 in the year, limit to article and conference paper in document type, limit to English in language, limit to journal and conference proceeding in source type, and exclude article in press in publication stage (only final). In order to use the metadata from the Scopus database for the bibliometric analysis, the metadata was exported to BibTeX (Bibliometrix) and RIS (VOSviewer) file formats. We used co-occurrence analysis to identify the most frequently occurring keywords, revealing the main research themes. Citation analysis was performed to determine the most influential articles and authors in BIPV. Biliometrix was employed to create visual representations of co-authorship and citation networks, illustrating the collaborative structure of the research community.

3. RESULTS

3.1. Main overview

Bibliometric time refers to the period for which data is collected and analyzed in bibliometric studies. The length of the period can vary depending on the search criteria. The results show that the BIPV research started in 1971 and will continue into 2022. The more extended period provides a comprehensive overview of a particular field or tracks the development of a specific scientific idea or paradigm in BIPV research. The general information about the dataset is shown in Table 1.

Table 1. General information about dataset

Description	Results
Timespan	1971:2022
Sources	2,565
Documents	10,840
Annual growth rate (%)	15.09
Document average age	6.99
Average citations per doc	19.8
Keywords plus	32,717
Author's keywords	18,566
Authors	25,134
Authors of single-authored documents	634
Single-authored documents	746
Co-authors per doc	4.13
International co-authorships (%)	22.09

3.2. Documents and cited references

Research document annual production refers to the number of publications produced by researchers, institutions, or countries in a given year. The documents can refer to journal articles and conference proceedings. Measuring the annual production of research documents is a meaningful way to track the researcher's productivity in the BIPV research. The yearly scientific output in the BIPV research field is shown in Figure 1. The annual growth rate is 15.09%, indicating that the BIPV field is growing and attracting significant research production. However, it is essential to know that the yearly production of research

documents is just one measure of research output and productivity. It should be interpreted with caution, such as the quality and impact of research, the funding, and the collaboration, which can also play essential roles in shaping the research landscape.

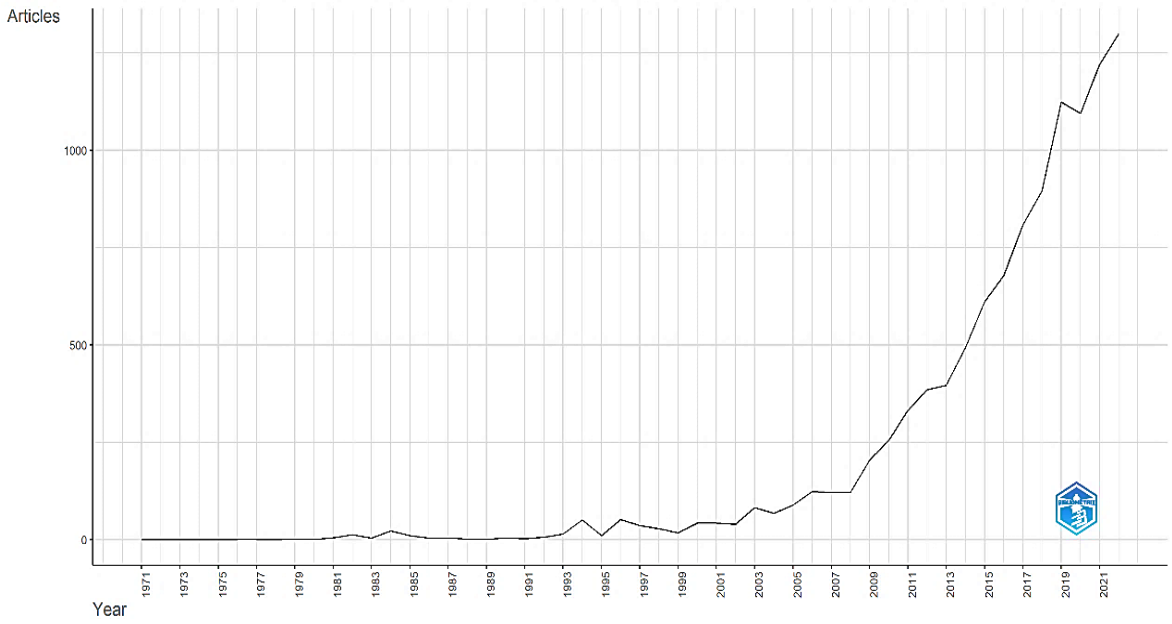

Figure 1. Annual scientific production

Average citation per year refers to the average number of times a research document, such as a journal article or conference proceeding, is cited yearly since its publication. This metric is often used to assess the impact and influence of a research document over time. The total number of citations a document receives is divided by the years from 1971 to 2022 and used to calculate the average citation per year. The average citation per year metric can provide a helpful way to compare the impact of research documents published in different years and disciplines. Figure 2 shows the highest average citation per year in the BIPV research field between 1971 and 1977. The metric is influenced by various factors, such as the research area, the research quality, and the authors' dissemination.

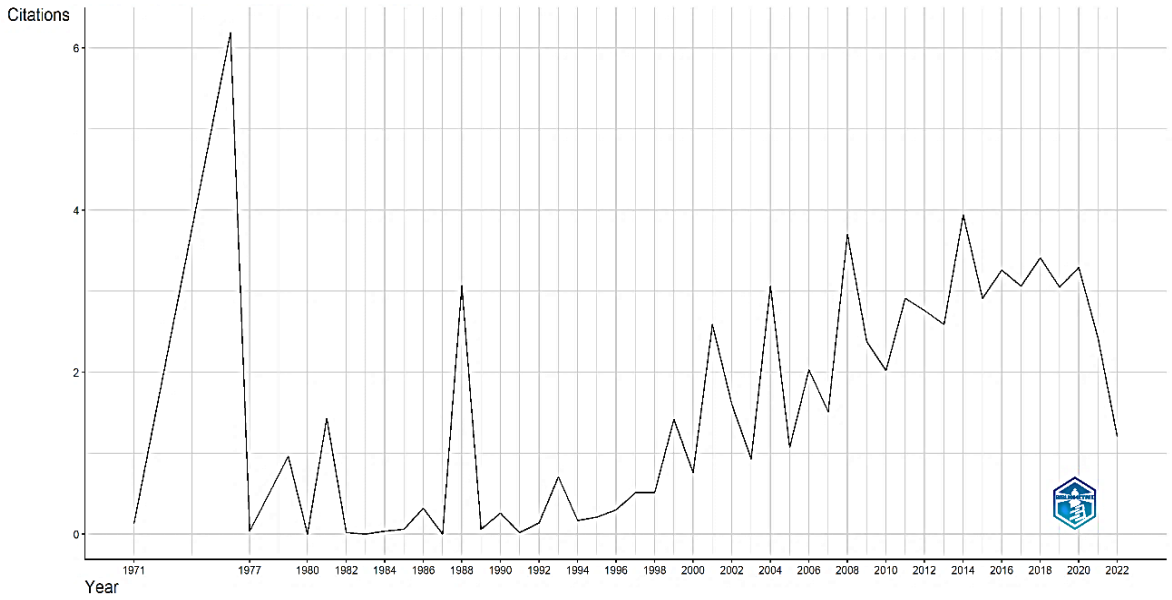

Figure 2. Average citations per year

Documents by subject area refer to research documents, such as journal articles or conference proceedings, that are categorized and indexed according to their research field. Categorizing and indexing research documents by subject area is essential in bibliometrics analysis, as it allows researchers to search and retrieve relevant documents in their field of interest. Subject area classifications can also be used to identify trends and patterns in research output, assess the productivity and impact of researchers and institutions within specific fields, and track scientific fields' evolution over time. The documents by subject area in BIPV research are shown in Table 2. Energy and engineering are the highest subject areas in the BIPV documents.

Table 2. Documents by subject area

Subject area	Results
Energy	5,763
Engineering	5,660
Materials science	2,062
Environmental science	1,780
Computer science	1,365
Mathematics	1,185
Physics and astronomy	1,099
Chemistry	727
Social sciences	612
Chemical engineering	482

3.3. Authors

A research author is a person who has contributed to a research publication, such as a journal article or conference proceeding. The authorship of a research publication typically reflects the intellectual contribution of the individual to the research project. Authorship is essential in research publications, as it can impact individual researchers' and research groups' visibility, impact, and recognition. Mallick from the Environment and Sustainability Institute of Exeter, United Kingdom, is the most relevant author in BIPV research with 53 documents [54]. The top ten pertinent authors in the BIPV research field are shown in Table 3.

Table 3. Author's impact

Authors	Affiliation	Country	Relevant documents	Citation	Co-authors	h-index
Mallick, Tapas Kumar	Environment and Sustainability Institute of Exeter	United Kingdom	53	8,975	400	53
Yang, Hongxing	Hong Kong Polytechnic University	Hong Kong	48	18,574	345	66
Ji, Jie	University of Science and Technology of China	China	46	14,281	331	63
Athienitis, Andreas K	Centre for Zero Energy Building Studies of Montreal	Canada	42	5,624	168	40
Tiwari, Gopal Nath	Rajiv Gandhi Institute of Petroleum Technology of Jais Amethi	India	34	16,184	260	70
Chemisana, Daniel	Universitat de Lleida	Spain	31	3,081	145	35
Rüther, Ricardo	Universidade Federal de Santa Catarina	Brazil	31	2,650	204	31
Pei, Gang	University of Science and Technology of China	China	30	8,614	283	46
Peng, Jinqing	Hunan University	China	30	4,455	267	36
Lu, Lin	Hong Kong Polytechnic University	Hong Kong	29	13,054	239	55

Co-authorship refers to the practice of two or more individuals collaborating on a research project and being listed as authors on a resulting publication, such as a journal article or conference proceeding. Co-authorship is a common practice in academic research and reflects the collaborative nature of much research work. The co-authorship in BIPV research is shown in Figure 3. Co-authorship in BIPV research can also facilitate networking and collaboration among researchers and contribute to developing research communities. Co-authors are expected to give appropriate credit to each other for their contributions to the BIPV research project.

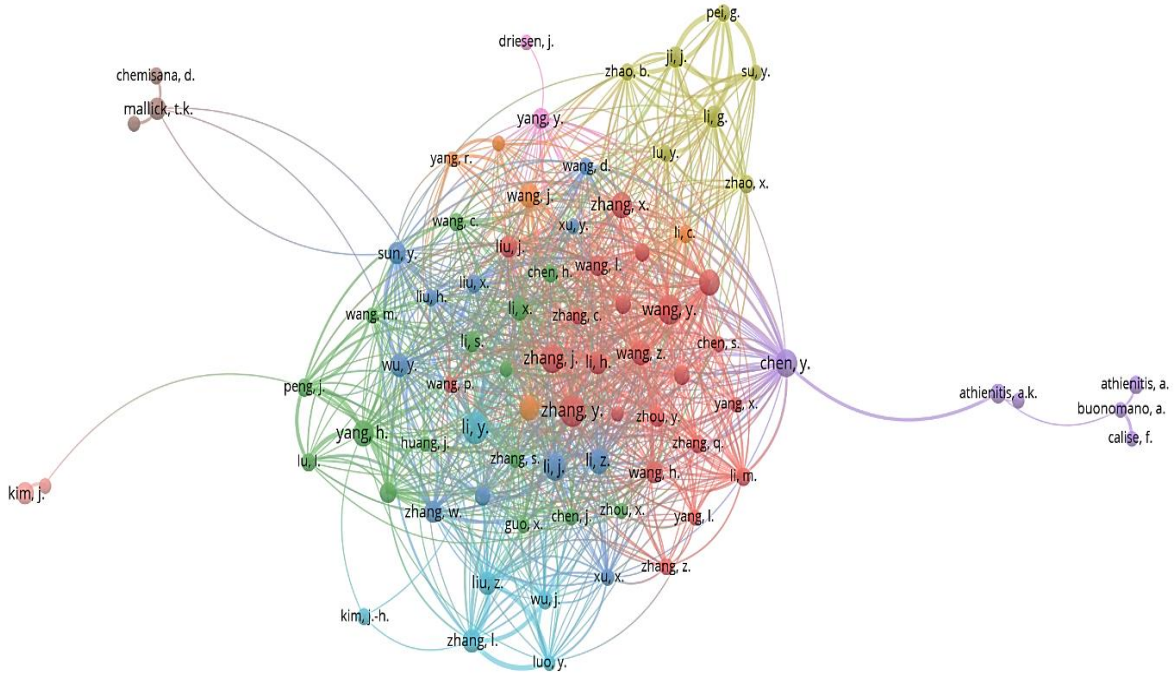

Figure 3. Co-authorship

3.4. Affiliations, countries, and funding sponsorship

In research, an affiliation refers to the organization or institution with which a researcher is associated. Partnerships can include universities, research institutes, corporations, government agencies, non-profit organizations, or other organizations supporting research activities. Affiliation is typically included in academic publications to identify the researcher's institutional affiliation and acknowledge any support or resources provided by the institution, as shown in Table 4.

Table 4. Documents by affiliation

Author's affiliation	Results
Chinese Academy of Sciences	191
Ministry of Education China	167
Concordia University	116
Hong Kong Polytechnic University	113
University of Nottingham	99
Politecnico di Milano	91
National University of Singapore	90
Ecole Polytechnique Fédérale de Lausanne	86

The Chinese Academy of Sciences (CAS) is the most relevant affiliation. CAS is a national academic institution in China that conducts research, provides scientific advice to the government, and promotes innovation and development in science and technology. It is one of the largest research organizations in China and comprises a network of research institutes and affiliated enterprises nationwide. In the second position, the Ministry of Education (MOE) China is also from China and is included among the top two relevant affiliations. MOE of the People's Republic of China is a government agency responsible for overseeing and regulating education in China. The MOE includes schools, universities, and research institutes. It is responsible for formulating policies and regulations, managing educational institutions, and promoting education reform and innovation.

In bibliometrics analysis, the corresponding author's country is where the corresponding author of a research publication is based. This information can be used to analyze trends and patterns in scientific research output across different countries and regions. The documents often provide the authors and affiliations of academic papers. The corresponding author's country is one piece of information that can be used to identify the geographic distribution of research output and collaborations and compare the research output of different countries or regions. Figure 4 shows that China has the highest scientific production in

BIPV research. Figure 5 shows China has more single-country publications (SCP) than multiple-country publications (MCP). These analyses track the growth and impact of scientific research where international collaborations are solid. The corresponding author's country is one factor that can be used to help identify these trends and patterns.

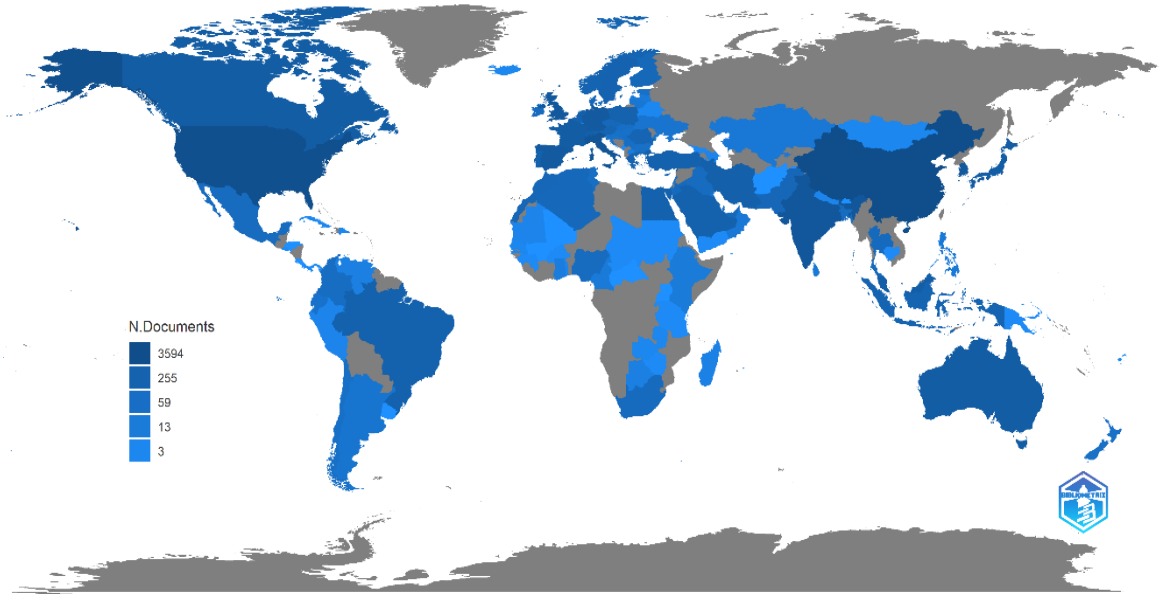

Figure 4. Countries scientific production

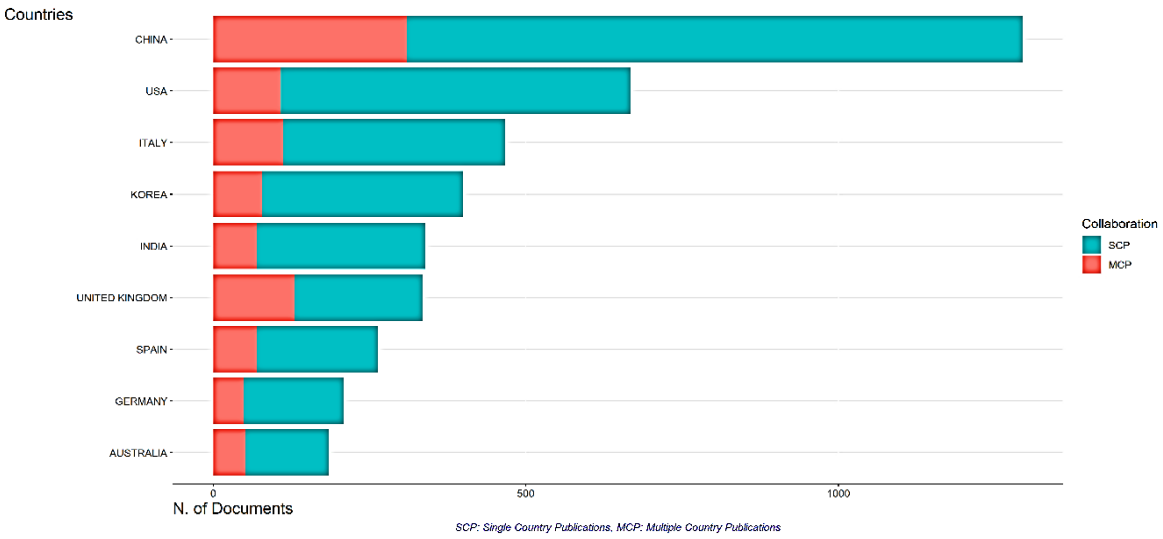

Figure 5. Corresponding author's countries

China is a major producer and user of PV cells and modules and has been rapidly expanding its renewable energy capacity in recent years. BIPV is a vital part of this effort, as it can help reduce the environmental impact of buildings and promote the use of clean energy. In recent years, the Chinese government has introduced a range of policies and initiatives to support the development and deployment of BIPV in the country. These include subsidies and incentives for BIPV projects, regulations, and standards for BIPV products and installations.

A research funding sponsor refers to an organization or entity that provides financial support to a BIPV research project. Research funding can come from various sources, including government agencies,

non-profit organizations, foundations, corporations, and private individuals. Research funding sponsors can play an essential role in shaping the direction and priorities of scientific research, as they may be more likely to fund projects that align with organizational goals. Researchers commonly must acknowledge their funding sponsors in their publications to recognize their support and contribution to the project. This can also be important for demonstrating the credibility and legitimacy of the research, particularly when the findings have implications for policy or decision-making. Table 5 shows that China's National Natural Science Foundation is the most relevant funding sponsor supporting the BIPV development.

Table 5. Documents by funding sponsor

Funding sponsor	Results
National Natural Science Foundation of China	742
European Commission	178
National Research Foundation of Korea	176
European Regional Development Fund	173
Fundamental Research Funds for the Central Universities	154
U.S. Department of Energy	154
National Science Foundation	140
Horizon 2020 Framework Programme	138

3.5. Sources

In bibliometric analysis, the sources refer to the journals and conference proceedings where research articles are published. These sources are often analyzed to gain insights into the productivity and impact of researchers or institutions and to understand the trends and patterns in a particular field of research. The journals and conference proceedings are the most common publication sources for research documents. They are often ranked based on their impact factor, which measures the average number of citations received by articles published in the journal. Figure 6 shows that solar energy is the most relevant source in BIPV research with 417 documents.

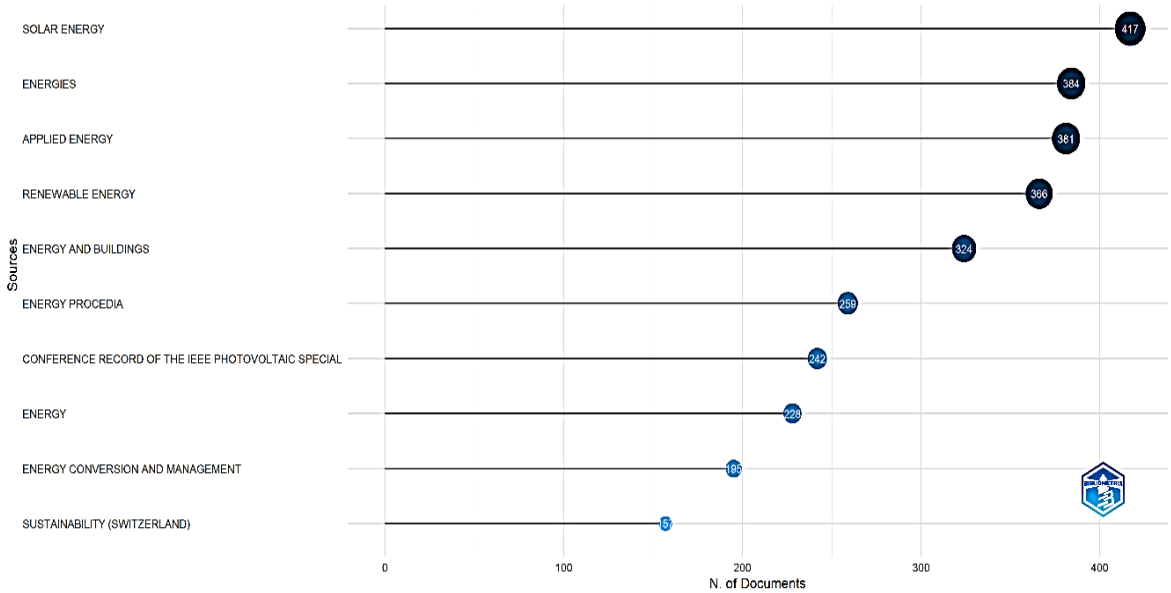

Figure 6. Most relevant sources

The h-index is a metric used to evaluate the productivity and impact of a researcher's publications or sources. It was proposed to measure the "quality and quantity" of a source. The h-index is calculated based on the number of documents and citations each publication has received. Specifically, a source has an h-index if they have published h papers cited at least h times each. Figure 7 shows that the Applied Energy Journal has an h-index of 78, which means 78 documents have each been cited at least 78 times. The h-index is intended to provide a more comprehensive picture of a source's impact than traditional metrics like the number of publications or the total number of citations.

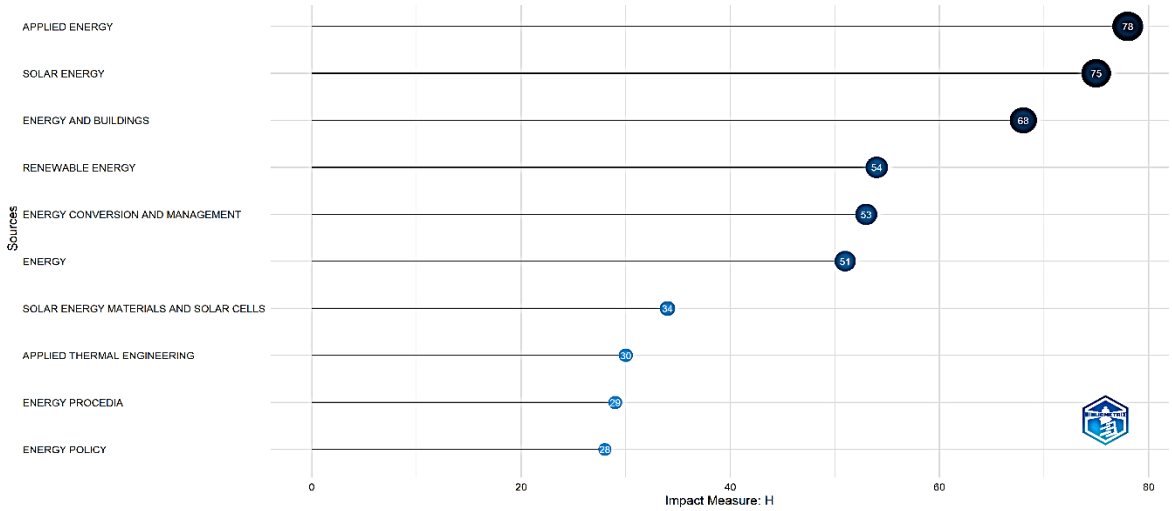

Figure 7. Sources local impact (measure h-index)

Bradford's law is a bibliometric principle first described by Samuel C. Bradford in 1934. The law states that the literature in a particular field can be divided into a core set of journals highly relevant to the BIPV research, as shown in Figure 8. Bradford's law has important implications for bibliometric analysis, particularly for selecting sources to include in a citation database. There are 18 journals in the BIPV research field in core sources. By focusing on the core set of journals in a field, researchers can ensure that they capture a significant proportion of essential research in the BIPV field. Additionally, Bradford's law can be used to identify potential new sources for inclusion in a database by analyzing the distribution of publications across different journals and identifying those that fall within the core set.

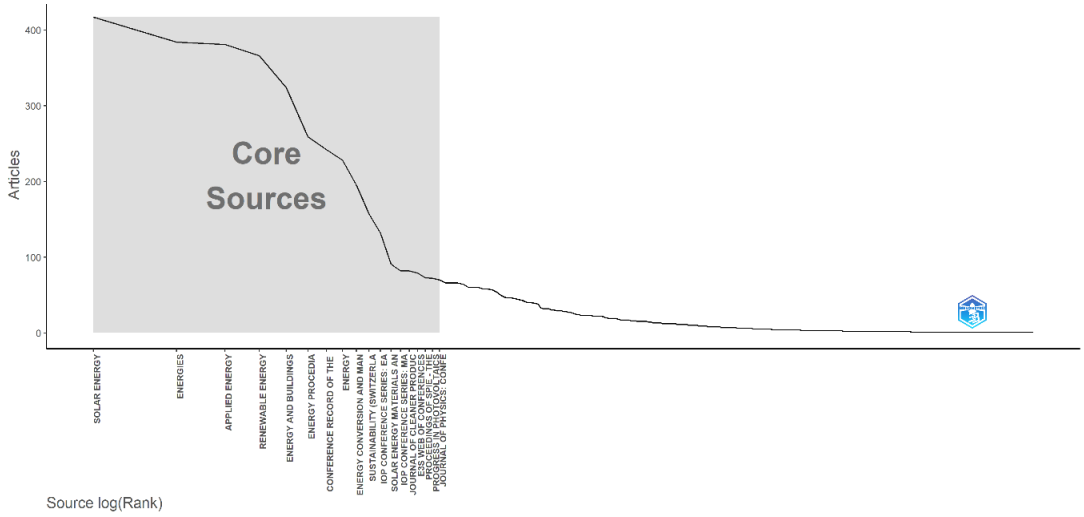

Figure 8. Core sources by Bradford's law

3.6. Words

In bibliometric analysis, the word refers to the keyword most closely associated with a BIPV field of research. The most relevant word can help researchers understand a field's key concepts and themes and identify the most important publications and researchers working in the BIPV research area. Figure 9 shows the PV cells, solar power generation, energy efficiency, energy system, energy utilization, solar cells, buildings, PV system, and PV effects topics and keywords within a set of publications. It can help researchers to focus their analysis on the most critical issues and themes in a field and to identify the most influential publications and researchers working in BIPV research.

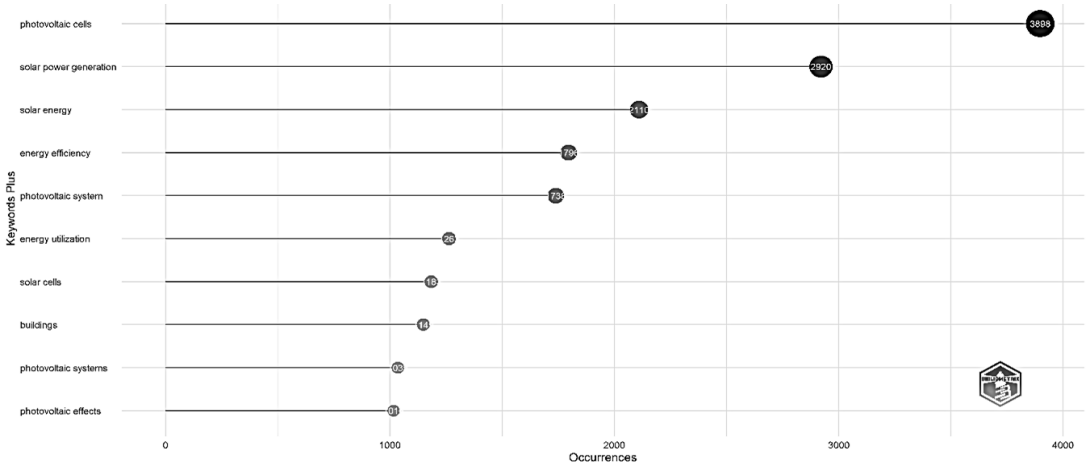

Figure 9. Most relevant words

A co-occurrence network is a type of network analysis in bibliometric analysis that visualizes the co-occurrence of keywords within a set of research documents—the metadata export from the Scopus database with RIS files format. The network is based on the co-occurrence frequency of these entities and represents the relationships between them in a graphical form. The co-occurrence matrix is then used to construct a network, where each node means a keyword, and the edges represent the frequency of co-occurrence between them. Figure 10 identifies key topics or research areas within a BIPV research field by identifying three clusters (red, green, and blue) of closely related keywords. The influential keywords within the network are the red cluster with PV cells, the green cluster with solar power generation, and the blue cluster with a PV system. Additionally, it can track the evolution of research trends over time by analyzing changes in the co-occurrence patterns over the years.

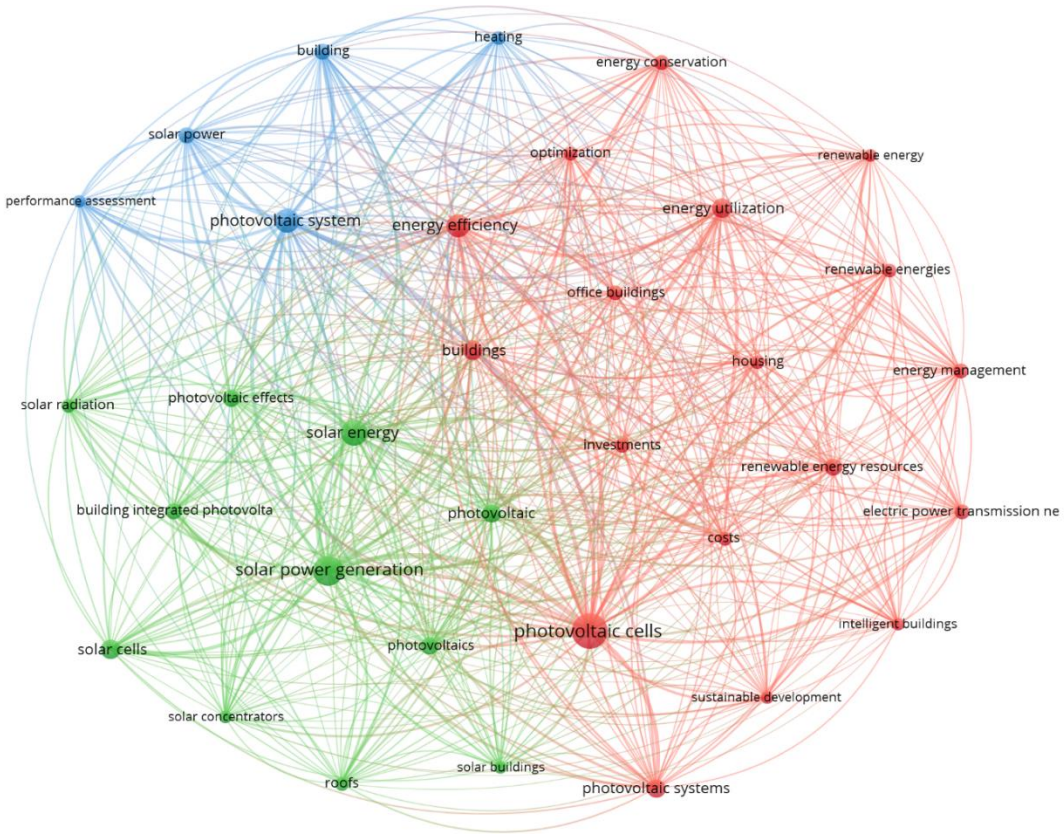

Figure 10. Co-occurrence network

3.7. Conceptual structure

In conceptual structure, a thematic map visually represents the relationships between different topics or themes within the BIPV research. The map is generated using data from co-occurrence or co-citation analysis and is designed to show the strength and direction of the relationships between different themes. Thematic maps can help identify the most critical topics by highlighting the clusters of the three most closely related keywords. They can also identify basic, motor, emerging or declining, and niche themes by identifying relevance and development degrees. Relevance refers to the degree to which a particular theme is central to the domain in question. Themes that are more central or foundational are considered more relevant, while themes that are more peripheral or specialized are considered less relevant. Development refers to the degree to which a particular theme has been explored or elaborated within the domain. Themes that have been extensively studied and developed are considered more advanced, while themes that have received less attention are considered less advanced.

Figure 11 shows the terms of solar power generation, PV effect, and PVs cluster as the basic themes. This means this cluster has high relevance and low development degrees. By organizing basic themes based on their relevance and development, researchers can better understand the structure and dynamics of a particular domain of BIPV research. The motor themes in the thematic map are the cluster of PV cells, solar energy, and PV systems and the group of energy utilization, renewable energy resources, and office buildings. This means that both sets have high degrees of relevance and development. Motor themes are essential because they help provide a framework for organizing and synthesizing much information in BIPV research. By identifying the motor themes most closely associated with the field, researchers can better understand the overall structure and dynamics of the area. They can use this knowledge to guide further research and exploration.

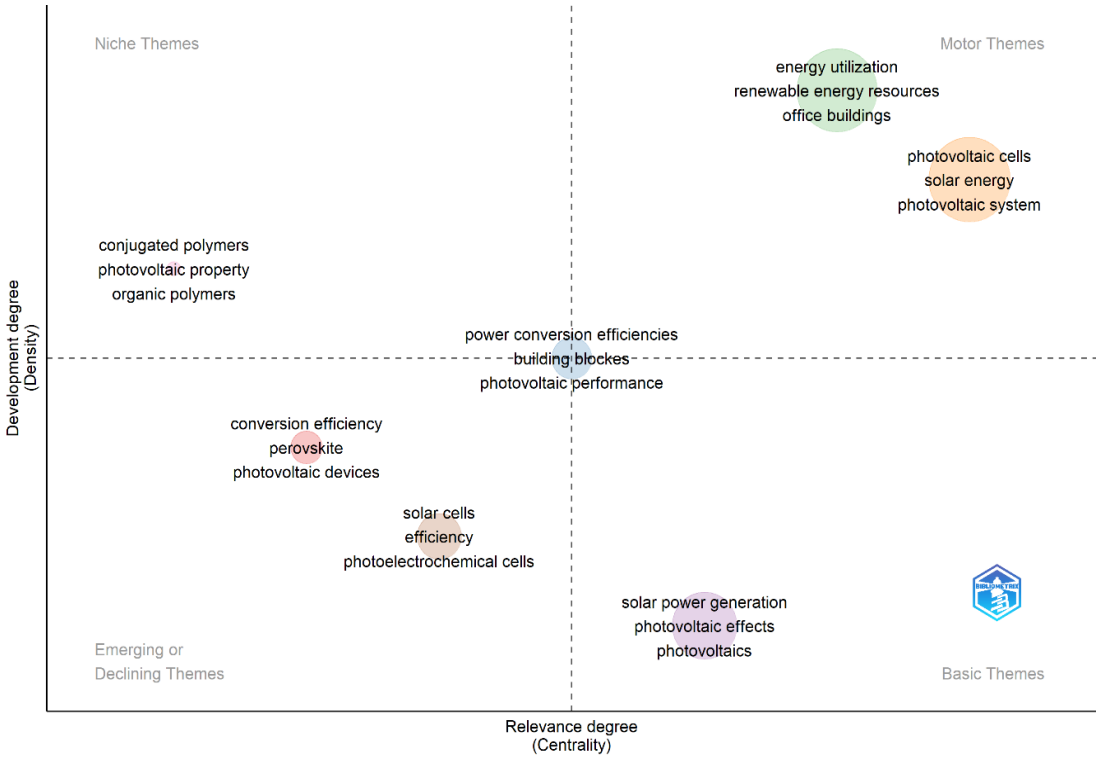

Figure 11. Thematic map

The opposite of basic themes is niche themes. It has a low degree of relevance but a high degree of development. The terms conjugated polymers, PV property, and organic polymers are identified in one cluster of niche themes. Niche themes are essential because they represent areas of research that are often overlooked or underrepresented in the BIPV field. By identifying these themes, researchers can gain a more comprehensive understanding of the overall structure and dynamics of the field. They can use this knowledge to explore new research areas and develop new perspectives and insights. The thematic map identified the

cluster of conversion efficiency, perovskite, and PV devices, and the group of solar cells, efficiency, and photoelectrochemical cells are the emerging themes. This means both clusters have low relevance and development degrees. Emerging themes are essential because they represent areas of research that are gaining importance and relevance within the field and may signal new directions or trends in research. By identifying these emerging themes, researchers can gain insights into the current state of the area and can use this knowledge to guide their research and exploration. Figure 11 shows the unique cluster of power conversion efficiencies, building blocks, and PV performance terms in central development and relevance degree. This means this cluster has a medium degree of development and relevance.

Furthermore, trend topics refer to the concepts and issues currently experiencing a significant increase in research interest and attention within a particular field of study. These topics are identified by the frequency of publications in the BIPV area over time, as shown in Figure 12. Trend topics can provide insights into the current state of BIPV research and may signal new directions of interest. In the early 1971 period, the issue was in PV cell applications. However, in the last five years, starting in 2022, the research has been related to microgrids, energy, performance, energy management systems, and energy efficiency. By exploring these trend topics, researchers can better understand the developments and stay up-to-date with the latest trends to ensure that their research remains relevant and impactful and contributes to the ongoing advancement of knowledge.

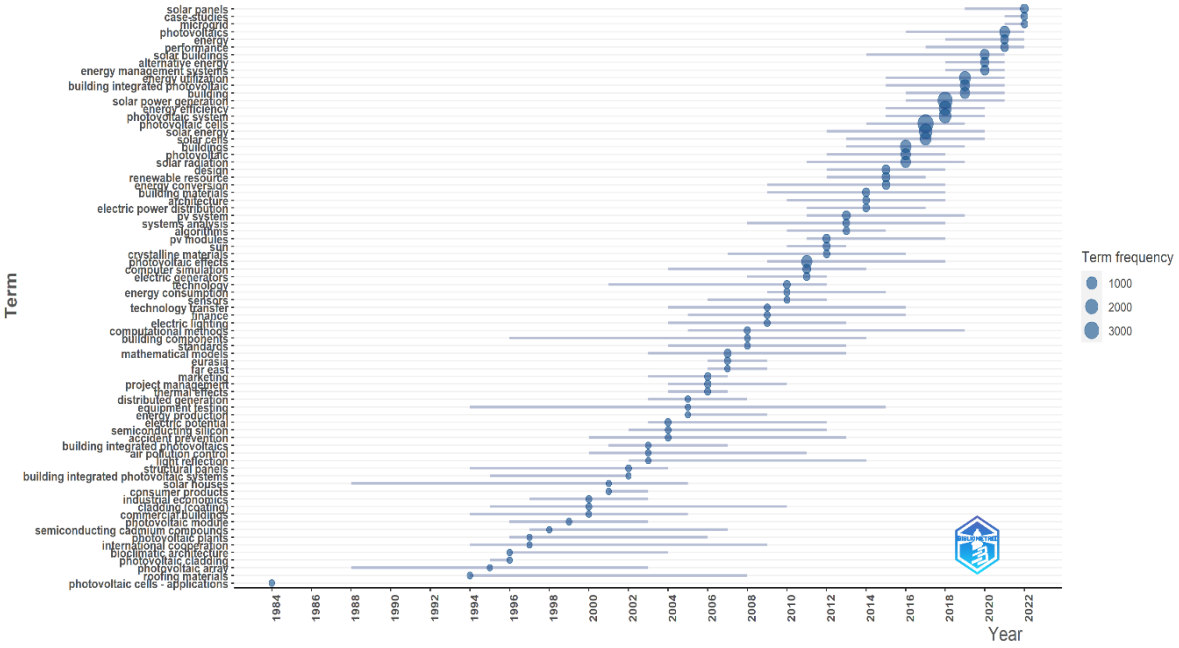

Figure 12. Trend topics

4. Discussion

BIPV is a technology that integrates solar panels into building materials, such as roofs, facades, and windows, to generate electricity and contribute to the building's energy needs. Our findings highlight emerging research areas, such as advanced integration techniques and novel PV materials, which are critical for the future development of BIPV. In China, BIPV has been recognized as essential for promoting sustainable development and reducing the country's carbon footprint [24]. China is a major innovative producer and user of PV cells and modules and has rapidly expanded its renewable energy capacity [55]. BIPV is seen as a vital part of this effort, as it can help to reduce the environmental impact of buildings and promote the use of clean energy [56].

We have shown that BIPV research has experienced significant growth, with notable contributions from interdisciplinary collaborations. In recent years, the Chinese government has introduced a range of policies and initiatives to support the development and deployment of BIPV in the country [57]. From the simulation result, China is the most relevant country with the top affiliation and funding sponsor to support the BIPV research. China's funding, such as the Chinese Academy of Sciences and Ministry of Education China, is the top affiliation in the BIPV research area. China is the country with the highest scientific

production and has more single-country publications in BIPV research. The National Natural Science Foundation of China also shows seriousness as the top funding sponsor from China.

The Chinese government gives subsidies and incentives for feed-in tariffs [58] and regulations and standards for BIPV products and installations. As a result of these efforts, BIPV has been increasingly used in China's construction industry, with projects ranging from small-scale residential buildings to large commercial and industrial complexes. The Shanghai Tower, which features a BIPV façade that generates electrical power for the building's energy needs [59], and the National Stadium (also known as the Bird's Nest) in Beijing, which features a BIPV that covers the roof [60]. Overall, BIPV is an essential technology for promoting sustainable development and reducing the environmental impact of buildings in China and is expected to play an increasingly important role in the country's energy transition in the coming years [61].

Future research trends can be discovered from niche and emerging themes. The terms conjugated polymers, PV property, and organic polymers are niche themes. Moreover, the thematic map identified the cluster of conversion efficiency, perovskite, and PV devices, and the cluster of solar cells, efficiency, and photoelectrochemical cells are the emerging themes. Both themes can potentially have a higher degree of relevance in future research. In the recent study, the issues related to microgrids, energy, performance, energy management systems, energy efficiency, and other relevant topic. By exploring these trend directions, researchers can better understand BIPV knowledge structure and stay up-to-date with the latest trends to ensure that their research remains relevant and impactful and contributes to the ongoing advancement of knowledge.

5. CONCLUSION

BIPV is a technology that integrates solar panels or PV modules into building materials, such as roofs, facades, and windows, to generate electricity and contribute to the building's energy needs. This technology matches the building's architectural style, generates electrical power to reduce energy consumption, and is one of the alternative ways of achieving carbon neutrality and contributing to green and sustainable global development. The number of publications in the BIPV research field has significantly grown with broader focus areas. This study utilizes bibliometric analysis through documents, cited references, authors, affiliations, countries, funding sponsors, sources, words, and conceptual structure based on the Scopus-indexed database between 1971 and 2022. The result shows that the annual publication in the BIPV research field has a yearly growth rate of 15.09%, indicating that the BIPV field is still growing and developing—the highest average citation per year founded between 1971 and 1977. Tapas Kumar Mallick from the Environment and Sustainability Institute of Exeter, United Kingdom, is the most relevant author in BIPV research with 53 documents. China has more single-country publications than multiple-country publications, where the Chinese Academy of Sciences is the most pertinent affiliation in the BIPV research, and the National Natural Science Foundation of China is the most relevant funding sponsor. The Solar Energy Journal is the most pertinent source, with 417 documents, but the Applied Energy Journal has the highest impact, with a 78 h-index. Based on Bradford's law, both journals are in the core sources, with 16 other journals in the BIPV research field. PV cells, solar power generation, and energy efficiency are the top three keywords in BIPV research.

The recent study in BIPV research is related to microgrids, energy, performance, energy management systems, and energy efficiency issues. The future trend can be identified from niche themes: conjugated polymers, PV properties, and organic polymer issues, and emerging themes: conversion efficiency, perovskite, PV devices, solar cells, efficiency, and photoelectrochemical cells problems. This finding will also provide researchers and organizations with a comprehensive understanding of BIPV research areas and new directions for future research. We suggest that future research should address the identified gaps, such as cost reduction and regulatory standardization, to enhance the adoption of BIPV technologies.

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