

Integration of solar PV systems in residential buildings: a bibliometric review (2010–2026)

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Abstract:

Solar photovoltaic (PV) systems play an increasingly important role in decarbonising housing, yet studies on their integration in residential buildings are widely spread across many disciplines. This paper presents a bibliometric review of 1485 Scopus-indexed publications (2010–July 2026) on PV systems in residential buildings. Bibliometrix/Biblioshiny, VOSviewer, and Excel are used to analyse publication and citation trends, the most active journals, authors, institutions and countries; and to map keyword co-occurrence and collaboration networks. The results show a rapidly growing and strongly interdisciplinary field, which is dominated by energy and engineering perspectives. It is also concentrated in a relatively small group of sources and research groups, mainly in North America, Europe, Australia and parts of Asia. Keywords show strong attention to PV technology, energy efficiency, system performance and nearly zero-energy housing, while architectural and urban design themes and social or behavioural aspects are less represented. The review identifies three main gaps: design-oriented work, social and behavioural studies, and research on specific housing types and regions. It also points to future research directions that can support PV-ready residential architecture and neighbourhood planning.

Keywords:

solar photovoltaics; residential buildings; PV integration; bibliometric analysis; energy-efficient architecture

1. Introduction

Climate change, local air pollution and the depletion of fossil fuels have made reducing greenhouse gas emissions one of the main global tasks [1,2]. Because the energy sector accounts for a large share of these emissions, changing how we produce and use energy is crucial to achieving climate goals [2]. The built environment is especially important in this context. Buildings use a large share of the world's energy and are responsible for a large part of global CO₂ emissions [3]. Housing is especially important because there are many homes, people live in them every day, and their number continues to grow as populations increase and cities expand [4]. For this reason, decarbonising residential buildings is now one of the main tools for building sustainable and climate-resilient cities [5].

To deal with this challenge, policies and research now focus on two main directions. First, they reduce energy use through efficiency, then they use renewable energy to cover the remaining demand [3]. For single houses and residential areas, solar photovoltaic (PV) is now the most common and technologically advanced way to produce electricity directly where it is used [6]. Solar energy is abundant, available in most places, and can be collected directly on buildings without requiring much extra land [7]. PV systems can be installed on existing roofs and facades or fully integrated into the building envelope. Because they are modular, they can be adapted to

a wide range of housing types [8]. As PV has become cheaper, easier to buy and better supported by policy, it has moved to the centre of low-energy, nearly zero-energy and net-zero housing concepts. This makes it an important means of decarbonising the residential sector [9].

In this context, PV integration in housing moved from something unusual to a standard issue for designers and planners [10]. Houses offer large areas of roof and facade surfaces for PV. Yet how much solar energy can actually be used depends on the building's form and orientation, the roof angle, shading from nearby buildings, and how technical rooms and services are arranged [11,12]. At the same time, architects and urban designers must consider facade composition, proportions, and how streets and courtyards look. When PV modules are added to roofs and facades, they must still keep clear views and visual harmony [12–14]. Together, these demands have led to more interest in “solar-ready” or “PV-ready” housing. In this approach, designers plan for PV from the start of the architectural and urban design process, instead of adding it afterwards to a building whose form and structure are already decided [11,15].

Research on PV in housing has therefore grown rapidly and now spans many disciplines [16,17]. Energy and engineering studies examine how PV systems perform, how much energy they produce, how to optimise them, and how they help achieve low- and nearly zero-energy homes [18,19]. In studies on low-energy and nearly zero-energy buildings, this usually means combining

a well-performing envelope, efficient technical systems, and renewable energy sources into a coordinated design [20]. In architecture and urban design, researchers study how different roof types, facade designs, building block layouts, and street networks shape solar access [21]. They also examine how these features affect opportunities to integrate PV. Other studies examine policy frameworks, economic viability, business models, user acceptance of PV, and social equity across different regions and climates [22–24]. Recent studies by Abu Qadourah and Alnusairat have also examined architectural integration, aesthetic perception and user acceptance of residential PV systems, especially in apartment housing and facade applications [25,26]. However, because the studies cover many different topics, scales and methods, it is not easy to form a clear overall picture [27]. We do not fully know how the literature on PV-integrated housing is organised or which viewpoints are strongest. It is also hard to see where the key gaps are, especially at the intersection of technical optimisation and architectural and urban design.

Bibliometric analysis and science mapping are useful tools for dealing with this challenge. They systematically analyse large bodies of literature, citation links, collaboration networks and keyword patterns [28,29]. Previous reviews and bibliometric studies on PV and buildings usually focused on specific technologies, particularly building-integrated PV, as shown in works by Waseef et al. [16], Tambunan et al. [17], Narpuro et al. [27], Zárate-Pérez et al. [30], and Shu et al. [31]. Past studies also looked at broad building categories, or at residents' adoption and policy instruments, as presented in works by Abidin et al. [32] and Lyu et al. [33]. Much of this work is strongly technical or focuses on behavioural aspects, while architectural and urban design perspectives on residential PV integration are less visible. An earlier Russian-language study by the authors presented a preliminary bibliometric and practice-oriented analysis of photovoltaic integration in residential architecture [34]. There is still a need for a focused review that looks only at PV systems in housing. It should show how this field has developed over time and explain how technical, architectural and social questions are connected.

This study aims to fill this gap by examining research on PV systems in housing during 2010–July 2026 using bibliometric and science-mapping tools. It shows how publications on this topic have changed over time, identifies the main journals,

authors, institutions and countries, and highlights the main thematic clusters in the field. The analysis pays special attention to how technical and design-oriented perspectives are balanced. The study also looks at how energy-efficient and nearly zero-energy housing is treated. In addition, it considers underrepresented housing types, regions and social aspects. On this basis, the paper highlights the main gaps in current research. It also outlines future research directions. These directions can support more systematic, PV-ready approaches in residential architecture and neighbourhood planning.

This paper is structured as follows. This section presents the introduction and objectives of the study on the integration of PV systems in residential buildings. Section 2 describes the data collection and bibliometric methods used to build and analyse the dataset. Section 3 presents the main results of the performance analysis and science mapping, including trends, leading contributors and thematic structures. Section 4 discusses these findings in relation to architectural and urban design questions, identifies research gaps and formulates future research directions. Finally, Section 5 summarises the main conclusions.

2. Materials and methods

This study uses a statistical bibliometric method to analyse the evolution and structure of research on solar photovoltaic (PV) systems in residential buildings. Bibliometric reviews are increasingly used in sustainability research to assemble large and fragmented groups of literature in a way that is easy to understand (for example, Wu et al., 2025 [35], the recent bibliometric study on residential rooftop solar panel adoption) [36]. The analysis is based on publications indexed in the Scopus database. This source offers broad coverage of journals in energy, engineering, environmental sciences and the built environment. Figure 1 presents the research methodology. The search was performed on 20 July 2026. Only publications written in English, marked as final, and classified as articles or review articles were included. The search strategy included terms related to solar photovoltaic systems, residential buildings, architectural integration, BIPV, aesthetics, and user perception. As a result, 1485 documents were found and used in the analysis. All publications were exported from Scopus in CSV format with complete bibliographic information and cited references.

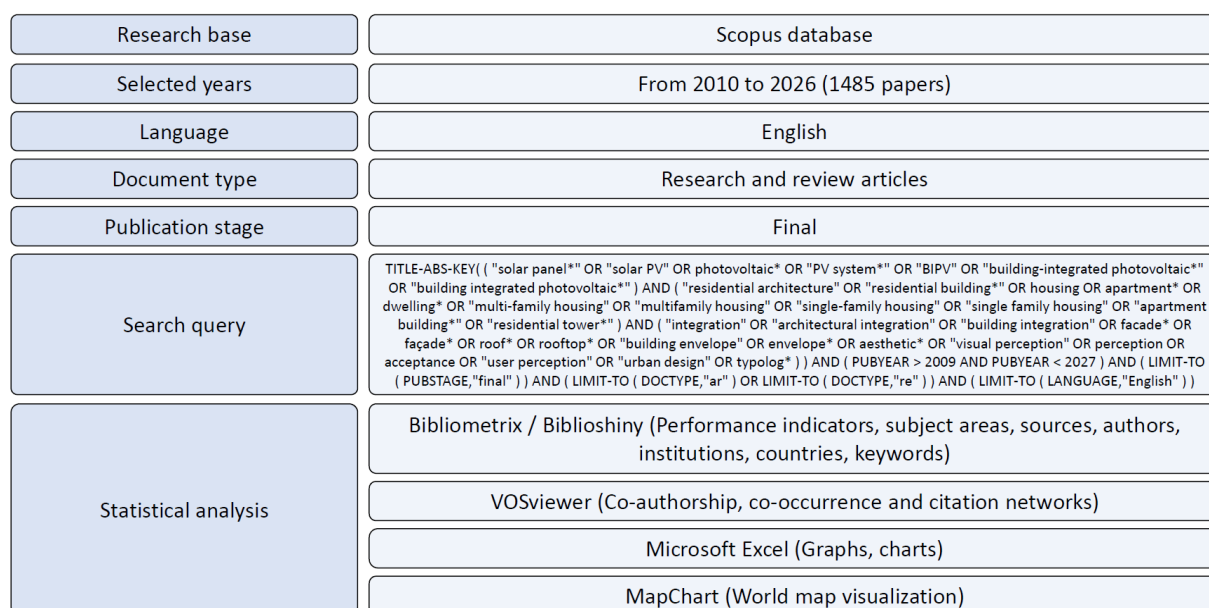


Fig. 1. Methodology flowchart for the research. Source: own study

This research work combines statistical analysis with science mapping techniques. Using science mapping helps to visualise how the field is organised, to highlight key authors and institutions, to show links between topics, and to make it easier to identify gaps and blind spots in the literature [37]. This method was chosen because it is one of the most practical and systematic ways to write a bibliometric review. In this approach, figures and tables play a central role. They turn complex indicators and networks into formats that are easy to read and compare. Each figure and table is briefly explained in the Results section. In the Discussion, the maps and charts are analysed in greater detail, with attention to what they mean for future research and design practice.

The information was analysed using the Bibliometrix R package and its web interface Biblioshiny. These software applications provide useful tools for science mapping [28]. The parameters cover how many papers and citations appear each year, where the papers are published, which journals and authors are most active and most cited, how authors' output changes over time, and which papers receive the most citations. Overview statistics are presented as tables, bar charts, and pie charts, prepared in Microsoft Excel based on Biblioshiny results. The graphs, word cloud, and treemap were generated in Biblioshiny.

VOSviewer was used as another tool for science mapping and network visualisation. The extracted CSV file was imported into VOSviewer, a specialised program for constructing and visualising bibliometric maps [38]. Its clustering algorithm was used to identify major thematic groups (for example, energy efficiency, photovoltaic systems, residential buildings, and architectural integration), collaboration groups between authors and institutions, and main patterns of international cooperation. The number of publications per country was additionally visualised using a colour-shaded world map prepared with the online tool MapChart.

3. Results

3.1. General overview of the dataset

The final dataset contains 1485 documents on the integration of solar photovoltaic systems into residential buildings, published from 2010 to July 2026. The starting year 2010 was chosen because research on this specific topic is relatively recent and became more visible around that time [16]. As shown in Fig. 2, the number of publications was quite low in the early 2010s and then rapidly increased in the second half of the period. The number of publications began to rise more sharply after the mid-2010s, especially after 2020, indicating growing interest in residential PV, nearly zero-energy buildings, and sustainable housing. In 2026, productivity seems to fall. This is mainly because the search was performed in July, when the year was not complete, and not all 2026 publications were indexed at that time. At the same time, although only half of the year had passed, the number of publications in 2026 was already almost as high as in the whole of 2025.

The subject-area distribution illustrated in Fig. 3 reveals that studies on PV integration in residential architecture come from many different fields. The largest shares of publications belong to Energy and Engineering. However, a noticeable portion of the literature is also classified under Environmental Science and Social Sciences. This shows that the topic is not limited to technology, but also includes sustainability and social issues. Smaller shares in Mathematics, Computer Science and Materials Science reflect the use of modelling, optimisation and materials research to support PV integration in buildings. There are several other subject areas that contain publications on the theme, but their shares are very small. For clarity, these minor fields are not shown in the chart. Together, these subject areas demonstrate the field's strongly interdisciplinary nature.

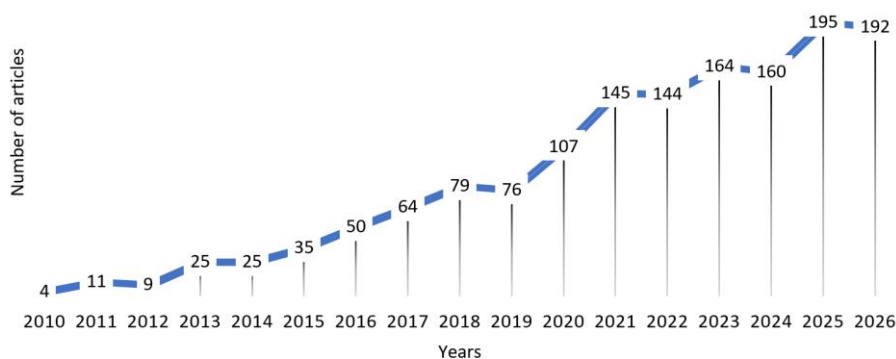


Fig. 2. Annual publication trend in the field of solar PV integration in residential architecture. Source: own study

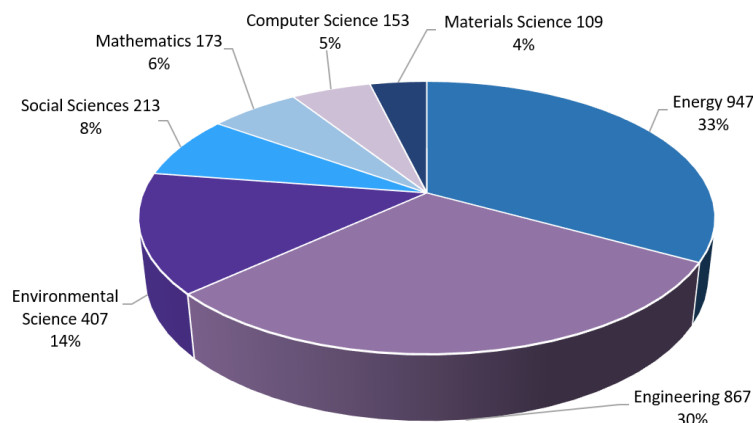


Fig. 3. Top subject areas on solar PV integration in residential architecture. Source: own study

3.2. Main journals and sources

The 1485 publications appear in 160 journals, although a limited number of specialised journals account for a substantial share of the output. Figure 4 illustrates the ten most productive journals in the field of PV integration in residential architecture. The highest numbers of papers are published in Energy and Buildings (102 documents), Energies (101 documents) and Applied Energy (93 documents). Renewable Energy and Sustainability (Switzerland) follow with 62 and 58 papers, respectively. The remaining five journals – Solar Energy, Energy, Buildings, Energy Conversion and Management, and Journal of Building Engineering – contribute between 30 and 54 publications.

3.3. Analysis of authors

From 2010 to July 2026, authors from 97 countries have published 1485 articles on the integration of PV systems into residential architecture. As shown in Fig. 5, the ten most active authors are highlighted. Li Y. is the most productive, with 15 publications. Zhang Y. and Krarti M. follow with 13 and 12 publications respectively. They are followed by Wang Z. (11 papers), Asif M. (10), and Zhang X. (9). Chen X., Chen Y., Li H. and Li J. (8 papers each) close the list. Figure 6 illustrates these authors' production over time. Interestingly, many leading authors show a noticeable increase in productivity after 2020, suggesting that sustained research programmes on residential PV and energy-efficient housing have developed primarily in recent years.

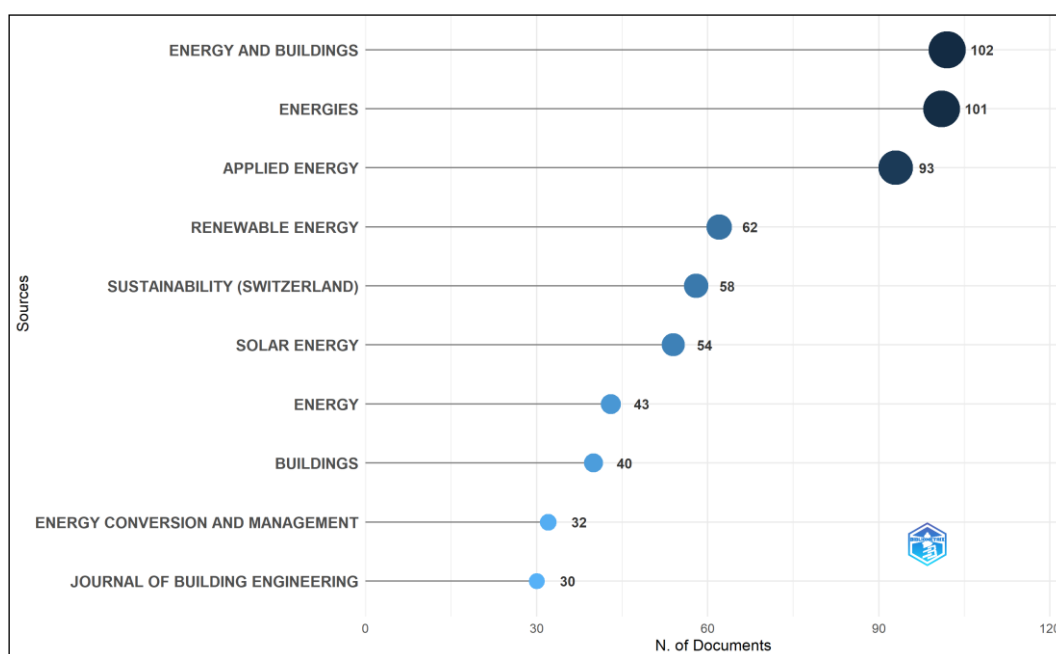


Fig. 4. Most relevant journals. Source: own study

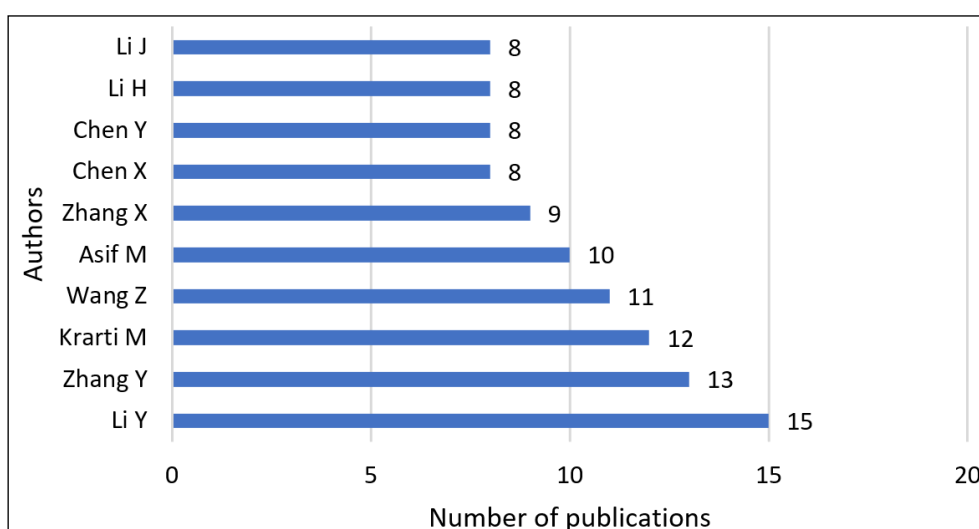


Fig. 5. Top authors on solar PV integration in residential architecture. Source: own study

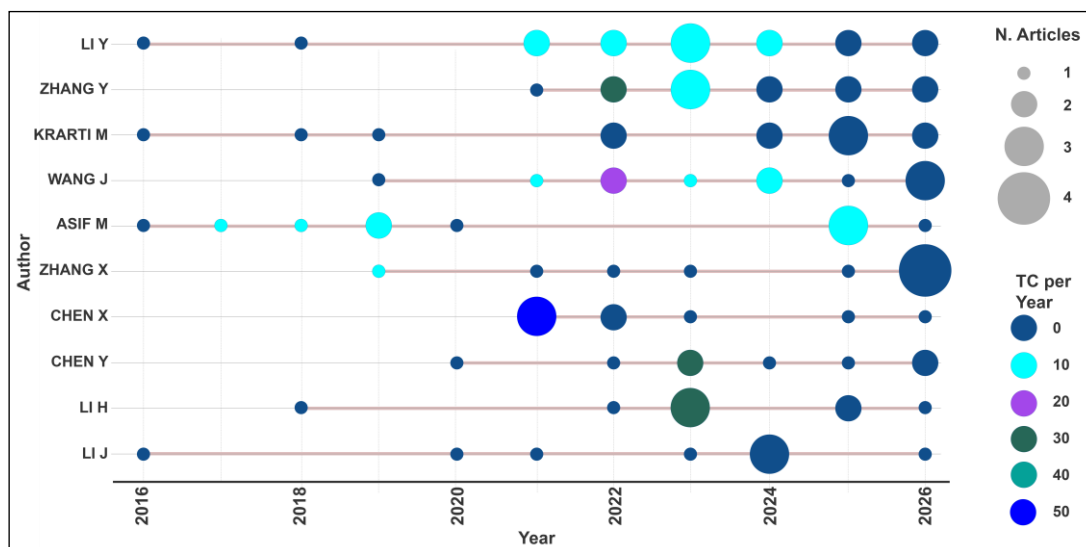


Fig. 6. Authors' production over time. Source: own study, adapted from Biblioshiny output for readability; underlying data unchanged

3.4. Institutional collaboration

Overall, approximately 1500 research institutions published related publications. Figure 7 presents a simplified visualisation of selected institutional co-authorship links identified in the dataset. The figure focuses on the principal confirmed collaborations rather than displaying the complete institutional network. The most interconnected part comprises Asian institutions, particularly Hong Kong Polytechnic University, Hunan University, National University of Singapore, Nanyang Technological University, and Tongji University. Another

visible group links King Fahd University of Petroleum and Minerals with the University of Colorado Boulder and other institutions from the Middle East and North America. The University of Texas at Austin forms a smaller collaboration cluster with national laboratories and applied research institutes. European participation is represented by the University of Naples Federico II and its connections with institutions in Canada, Cyprus and Asia. Overall, the network demonstrates geographically dispersed cooperation across Asia, North America, Europe, the Middle East and Australia.

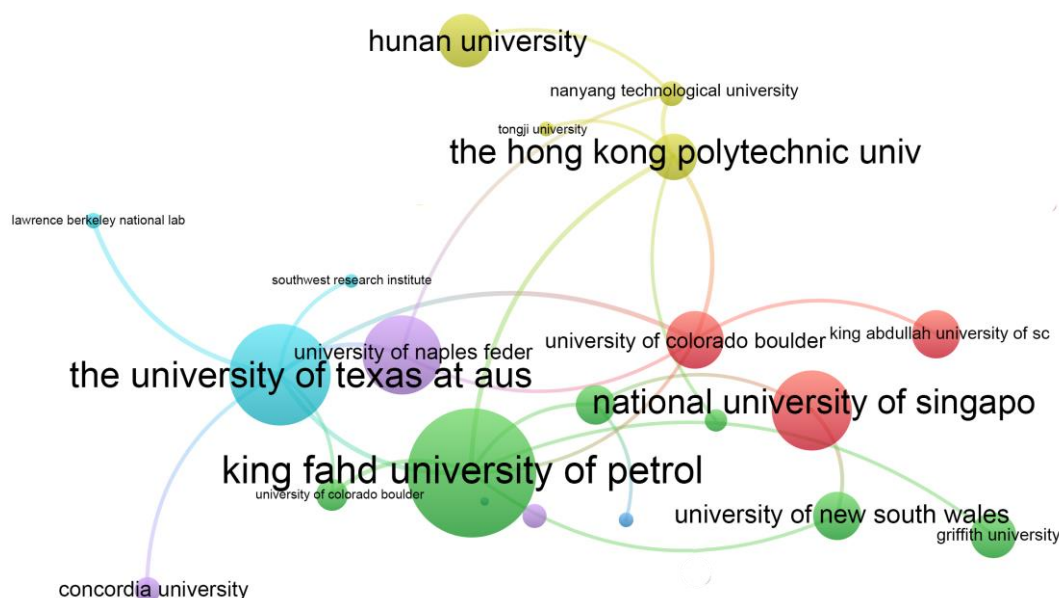


Fig. 7. Simplified visualisation of selected institutional co-authorship links in research on solar PV integration in residential architecture. Source: own study

The 10 most productive institutions are listed in Table 1. Affiliation-name variants referring to the same parent institution were manually harmonised before calculating institutional publication output. Five out of ten of these institutions are based in Asia, while the remaining five are located in North America, Europe and Australia. King Fahd University of Petroleum and Minerals holds the first position, with 40 publications (20% of the total output of the top 10). It is followed by the University of

Texas at Austin (23 papers, 12%) and the University of New South Wales (22 papers, 11%). National University of Singapore and Hong Kong Polytechnic University share the next position, with 18 publications each (9%). Concordia University, University of Naples Federico II, Griffith University, Hunan University and Zhejiang University complete the list, with 15-16 publications each (8%).

Table 1. Top 10 institutions publishing research on solar PV integration in residential architecture. Source: own study (Note: Affiliation-name variants referring to the same parent institution were manually harmonised, and each institution was counted once per publication. Percentages represent shares within the combined output of the top 10 institutions)

Rank	Institution	Count (%)
1	King Fahd University of Petroleum and Minerals, Saudi Arabia	40 (20%)
2	The University of Texas at Austin, United States	23 (12%)
3	University of New South Wales, Australia	22 (11%)
4	National University of Singapore, Singapore	18 (9%)
5	The Hong Kong Polytechnic University, Hong Kong	18 (9%)
6	Concordia University, Canada	16 (8%)
7	University of Naples Federico II, Italy	16 (8%)
8	Griffith University, Australia	15 (8%)
9	Hunan University, China	15 (8%)
10	Zhejiang University, China	15 (8%)

3.5. Countries and international cooperation

In total, 97 countries have published research on the integration of PV systems into residential architecture from 2010 to July 2026. [Figure 8](#) highlights the ten most productive countries, each with a minimum of 71 publications. The United States clearly dominates with 199 articles (about 13.4% of all documents), followed by China with 156 papers (10.5%). Italy

and Australia also play a leading role, with 123 and 122 publications respectively (around 8% each). A second group of active countries consists of the United Kingdom (89 papers), India (83), Spain (74), Canada (74), Saudi Arabia (72), and Germany (71), each contributing between 4.8% and 6.0% of the total output. Overall, the map highlights that research on PV-integrated housing is mainly driven by countries in North America, Europe, Australia, and Asia.

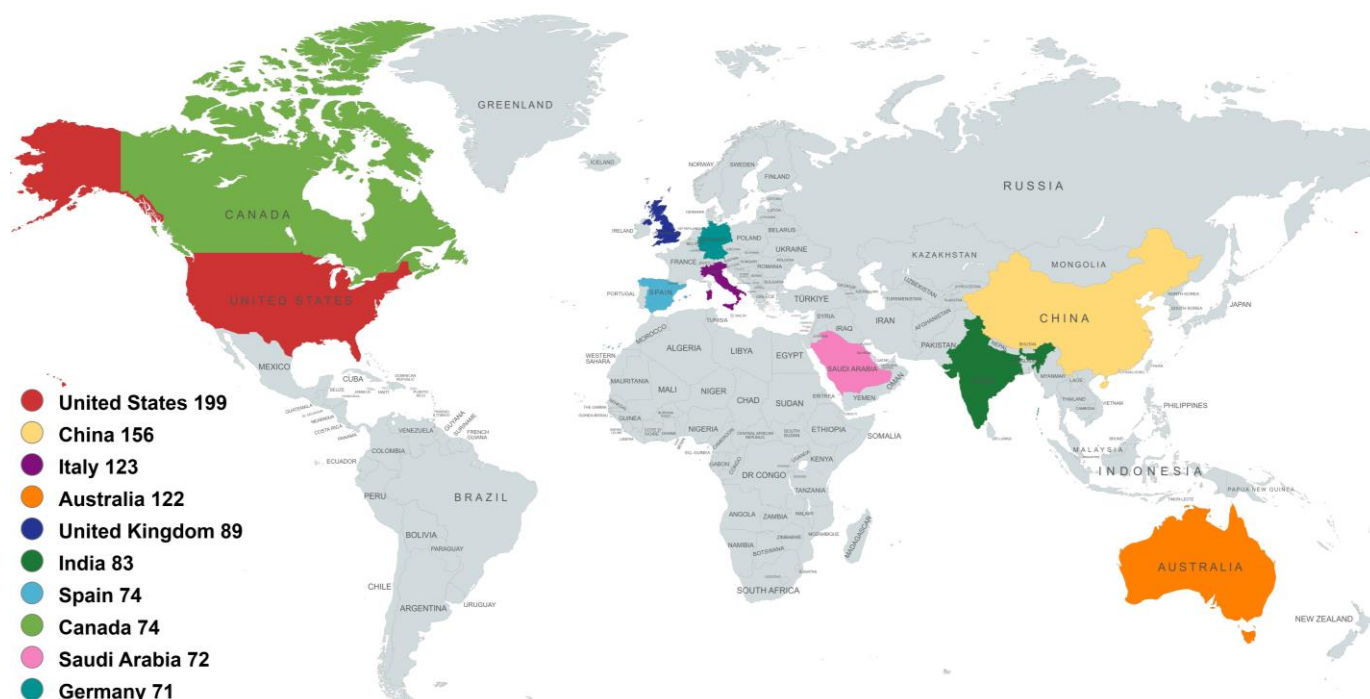


Fig. 8. Leading publishing countries. Source: own study

For the analysis of international cooperation, a country co-authorship network was generated in VOSviewer ([Fig. 9](#)). Of the 97 countries identified in the dataset, 62 met the minimum threshold of five publications per country and were included in the map. Nodes represent countries, while links indicate co-authored publications. Node size reflects publication output, link thickness represents collaboration strength, and colours indicate collaboration clusters. The network shows a main cluster of collaboration centred on the United States, which has strong

collaborative links with China, Italy, the United Kingdom, Australia, Germany, Saudi Arabia, Iran and several other countries. China, Italy and Australia appear as additional major clusters, connecting a wide range of Asian and European partners. The United Kingdom, Australia, Germany, Spain and Saudi Arabia also act as important regional bridges. Overall, the map indicates that international cooperation is an important feature of PV-integrated housing research.

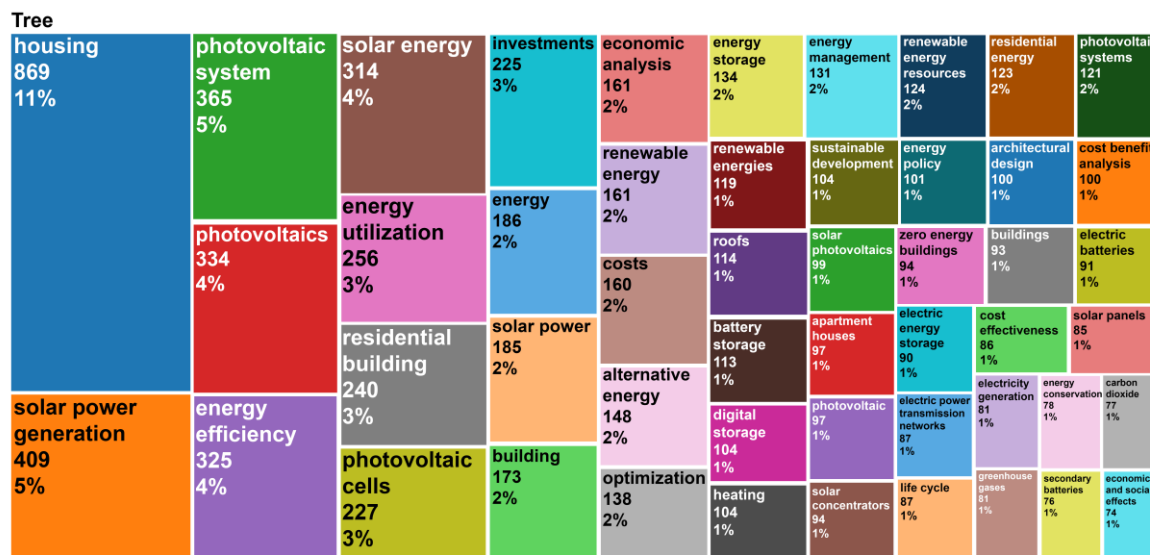


Fig. 11. Keyword treemap. Source: own study, adapted from Biblioshiny output for readability; underlying data unchanged

4. Discussion

The strong growth in publications over the last decade shows that integrating PV systems into residential buildings has become a central topic in energy and building research. After a slow start, the field began to grow quickly as PV technology became cheaper, energy rules became stricter and interest in nearly zero-energy housing increased. This shows that research follows actual changes in policy and the energy market [39-41]. PV on homes is now seen as one of the main tools for decarbonising the residential sector [42]. At the same time, the publications curve is still rising, so methods, technologies and design ideas are still changing, and there is space for further development.

The mix of subject areas and journals shows that the field is interdisciplinary, but technical studies still dominate. Most work is published in energy and engineering journals, while architecture, urban planning and housing studies are less visible. This imbalance can have practical consequences. When results remain primarily within technical communities, they rarely become simple design rules or standard details. As a result, architects and urban designers do not get clear planning guidelines they can use. In practice, this often means that PV is added late in the project and simply adjusted to whatever roof or facade is available. It then has to compete with other elements on the building envelope. As a result, many buildings are not “PV-ready” even when they have good solar potential [43].

The patterns of authors, institutions and countries also show a high level of concentration. A relatively small group of researchers, universities, and countries generates a large share of publications. On the one hand, this helps to create strong research hubs with stable cooperation networks and continuous development of tools and models. On the other hand, it means that much of the knowledge is produced in a limited set of climatic, economic and regulatory contexts. Many regions with high solar potential and rapid housing growth – including parts of Africa, Central Asia and Latin America [44] – remain underrepresented. As a result, many design solutions fit temperate or coastal climates but do not work as well in hot, dry, very cold or highly compact cities [45]. This situation can delay the wider adoption of PV-oriented design in these places [46].

The keyword structure shows that the field mainly focuses on energy efficiency and PV technology. Most studies focus on system performance, how much energy they produce, how they

can be optimised and how they help achieve low- or nearly zero-energy houses (for example, papers by Zhang et al. (2018) [47] and Maghrabie et al. (2021) [48]). This technical base is important, but it leaves several important aspects in the background. Keywords related to architectural design, roofs, buildings and residential buildings appear, yet they are not as dominant as the energy and system keywords. Topics such as urban form, facade design, typology of multi-storey housing, open-space structure and street layout are even less visible.

At the same time, an architectural and user-oriented line of research is clearly emerging. Recent studies have examined aesthetic perception, architectural integration and user acceptance of residential PV systems, particularly in apartment housing and façade applications [25,26]. Recent evidence also indicates that the aesthetic acceptance of BIPV in apartment housing may vary across demographic and socioeconomic groups. This highlights the importance of considering user characteristics in architectural design and solar-energy policy [49]. Nevertheless, these themes remain less prominent in the overall field structure. The dominant clusters remain centred on energy and system performance, while social, behavioural, and economic aspects do not drive the main research clusters. This shows that research has mostly focused on how much energy PV can produce on existing buildings [47]. It has paid less attention to how to design buildings and neighbourhoods so that PV can be well integrated from the start [50].

From an architectural perspective, this is a critical gap. Preventive integration into architecture means that PV is considered in the initial sketches and analyses of building form and size, not after the roof and facade are already fixed [11]. It includes decisions about building orientation, roof shape and slope, height and spacing between buildings, the position of services, and the location of inverters, cable routes, and technical rooms. It also covers how PV modules are combined with shading devices, balcony railings or facade elements in a way that respects proportion, rhythm and views [51]. The current bibliometric results indicate that these questions remain underrepresented in the literature. In contrast, there is much more work on technical optimisation of PV modules on standard pitched or flat roofs [15]. If the situation stays the same, future housing may still use PV only as an extra technical element. It will not be fully integrated into the design of buildings and neighbourhoods [11].

Several gaps can be identified based on these findings. First, there is a lack of design-oriented studies that connect PV performance with building and neighbourhood form. Only a limited number of studies systematically test different roof types, facade configurations or urban layouts and translate them into practical design guidelines. Second, social and behavioural aspects appear only weakly in the main keywords. Topics such as how residents accept PV, how it looks, how it is maintained, and whether it is affordable and fair are less studied, even though they are crucial for successful real projects. Third, many housing situations are still poorly covered. These include dense multi-family blocks, informal settlements, social housing, historic districts and mixed-use neighbourhoods, where PV integration is both technically and socially challenging. In addition, residential buildings should not be treated as a single category. PV integration conditions differ substantially between single-family housing, low-rise apartment buildings, mid-rise housing and high-rise residential towers.

These gaps open up several directions for future work. More studies are clearly needed that link energy simulation with architectural and urban design. This could include using parametric models to examine how changes in roof shape, facade design, courtyard size, or street layout affect PV potential and the quality of space. There is a need for research on “PV-ready” guidelines for new housing. Such guidelines would define structural grids, unshaded areas, PV integration into roofs and facades, and links with building services, helping architects and developers plan PV from the beginning. Future studies at the neighbourhood scale could analyse how to plan blocks, open spaces and streets. The aim is to make PV generation, shading, daylighting and outdoor comfort support each other instead of conflicting. More comparative work is also needed across residential typologies. The architectural integration of PV systems varies greatly between detached houses, attached housing, low-rise apartment blocks and high-rise residential buildings.

It would also be helpful to have more empirical research on residents and stakeholders. Studies of in-use buildings and neighbourhoods with integrated PV could show how people actually use the systems. They could also explain how residents see their homes and which design choices help or harm long-term performance. Studies that compare cases in less-studied regions and climates could widen the data. They could then be used to develop recommendations adapted to local rules and codes. Finally, more focused bibliometric analyses are needed on themes such as facade PV, PV in existing housing and local energy communities. These studies could provide more detail on which new themes are emerging in the field.

Overall, the results show that researchers have established a strong technical foundation for PV in residential buildings, with active international cooperation and a growing body of studies. The next step is to use this foundation to develop design methods that plan PV in advance. This can help make PV a normal, integrated element of buildings and neighbourhoods instead of something added later on top of completed roofs and facades.

5. Conclusion

This paper presented a bibliometric review of 1485 Scopus-indexed publications on solar PV systems in residential buildings (2010–July 2026). Using Bibliometrix/Biblioshiny, VOSviewer and Excel, the study combined performance analysis with science mapping. It showed how the field grew, who the main contributors were, and how key themes were organised.

The results show that the field is expanding rapidly and is strongly interdisciplinary. They also showed that energy and engineering perspectives clearly dominate the field, and that most publications come from a relatively small group of journals, authors, institutions and countries. Most research comes from North America, Europe, Australia, and some Asian countries, while many regions with high solar potential and rapid housing growth are still weakly represented. Keyword analysis shows that most studies focus on PV technology, energy efficiency, system performance and the role of PV in low- and nearly zero-energy housing. Architectural, urban design, social and behavioural themes are present in the research, but remain less prominent than the dominant energy and system-performance topics.

On this basis, three main gaps were identified: (i) too few design-oriented studies that link PV performance with building and neighbourhood form and turn the results into clear design guidelines; (ii) little attention to how residents accept PV, how it looks, how it is maintained and who can afford it; and (iii) housing types and regions that are still underexplored, such as dense multi-family blocks, informal and social housing, historic areas and mixed-use neighbourhoods. Future studies need to link energy simulation and design more closely, develop PV-ready guidelines for new housing, and examine PV at the neighbourhood scale. They also need more real-life (in-use) investigations and more research on topics that are rarely covered, such as facade PV, retrofits and energy communities. The main contribution of this study is to connect bibliometric patterns with their architectural and urban design implications. It also shows where existing technical knowledge has not yet been translated into PV-ready guidance for residential buildings and neighbourhoods.

The study is limited because it used a single database (Scopus), focused on English-language publications, and relied on quantitative bibliometric methods. Nonetheless, the study provides a structured overview of research on PV-integrated housing. It also shows where more work is needed to make PV a normal, well-integrated part of residential architecture and neighbourhood planning, rather than a late technical add-on.

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