

Scientific Mapping of Renewable Energy in Rural Areas: A Bibliometric Analysis

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ABSTRACT

This bibliometric study examines the research landscape on renewable energy in rural areas, analyzing publication trends, key contributors, thematic clusters, and emerging research directions from 1979-2025. Utilizing the Scopus database, VOSviewer, and R software's Bibliometrix package, this paper applies the PRISMA methodology to analyze 3,332 peer-reviewed publications. Findings revealed a consistent annual growth in research and considerable academic influence. India dominates global contributions, followed by China, the United States, and European countries, with institutions like the Indian Institute of Technology, North China Electric Power University, and Tsinghua University playing leading roles. Thematic analysis points to three dominant research clusters: climate change and biomass, rural energy access and electrification, and solar power and hybrid systems, evidencing an interdisciplinary effort with visions of technology, economics, and policy. New research areas such as hybrid renewable energy systems, digital infrastructure, and decentralized energy alternatives speak to increased interest in scalable and sustainable options for rural communities. Collaboration networks exhibit established research centers, but there are opportunities for further interdisciplinary and cross-border collaboration development, especially in developing countries. These results strongly impact policymakers, academics, and the industry in demanding a joined-up approach toward deepening rural electrification and boosting global energy transition objectives.

1. Introduction

Clean, affordable, and renewable energy for rural communities remains a worldwide challenge [1]. With environmental degradation and energy security becoming daily global issues, renewable energy is increasingly emerging as an alternative to traditional fossil fuels [2]. For remote communities with unreliable or limited access to the national power grid [3], renewable energy technologies like solar, wind, biomass, and small hydropower offer feasible alternatives to reducing energy poverty, economic development, and protecting natural resources [4]. With the increasing recognition of the advantages of renewable energy in communities, many researchers have studied the power of renewable energy to improve the economy, living standards, and sound environmental management in rural areas. For instance, investment in renewable energy can greatly boost rural quality of life, particularly in Ecuador, where the proportion of renewable energy is strongly linked with the proportion of the rural population [5]. Likewise, the availability of solar and wind farms in rural regions has, in recent years, created more employment and raised revenue collection in America [6]. These are instances of how renewable energy fosters diversification in rural regions and economic resilience. Comparable trends have also been observed in parts of Africa and Asia, where rural electrification initiatives using off-grid solar and mini-hydro systems have supported agricultural productivity, small-scale enterprise growth, and improved public

services [7-8]. This implies that although the particular effects might differ by region, the economic advantages of renewable energy in rural areas are well established and increasingly reported in various socio-economic and geographic contexts.

Along with economic advantages, renewable energy contributes significantly to solving energy scarcity. Reliable and sustainable access to energy is critical for schools and hospitals whose services are essential to rural communities. Ranganathan et al. [9] highlight that renewable energy can deliver stable and sustainable power supply in rural regions, which is important for socio-economic development. Similarly, Yan et al. [10] highlight digital transformation as the major driver in improving energy usage and employing renewable technology, particularly in developing countries. The evidence shows that technology development and infrastructure improvement play an important role in maximizing the application of renewable energy among rural communities. Even though renewable energy is of great potential, its application in rural communities is limited by numerous challenges. Social acceptance and public participation are crucial to embrace renewable energy technologies effectively [11]. Additionally, low awareness and financial constraints hinder the process [12]. Unegbu et al. [13] also recognize the barriers to renewable energy uptake in rural Nigeria, highlighting the need for some interventions to overcome and drive sustainable energy adoption. Among the key success drivers in

tapping renewable alternatives is adjusting to the socio-economic setting and effectively responding to local determinants.

The past decades have seen an expansion in rural-based research on renewable energy, as evidenced by the growing interests of policymakers, researchers, and industry players in this research domain. Despite more research on renewable energy in rural communities, there is still a visible gap regarding understanding how the information has progressed over time and where efforts need to be placed in the future. Most of the current literature targets individual technologies, locations, or case studies; hence, one cannot observe the larger picture of how the discipline is emerging worldwide. What's missing is a comprehensive, data-driven overview that brings together key trends, influential works, and collaborative patterns in the research community. Correspondingly, a bibliometric analysis is helpful in this field and essential to provide policymakers with evidence-based information to guide energy policies and offer insights to academics and industry players to more effectively formulate focused research programs and practical interventions that respond to rural energy issues. Through analysis of scholarship, citation patterns, and keyword counts, bibliometric research helps identify areas of knowledge that have been underdeveloped or emerged as developing and trend issues, thus informing future research and policy issues. In order to achieve this aim, this paper specifically seeks to:

1. Examine the bibliometric findings related to renewable energy research in rural settings;
2. Identify the most frequently occurring keywords in the existing literature;
3. Determine the most influential articles, publications, countries, organizations, and authors in the field;
4. Analyze the structures and patterns of co-authorship networks;
5. Investigate the development of bibliographic coupling and co-citation networks; and
6. Explore the main thematic areas and emerging research directions identified through bibliometric analysis.

2. Methods

This study systematically examined renewable energy research in rural communities, focusing on developments, trends, seminal papers, and key authors using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [14]. PRISMA is a widely recognized framework for conducting and reporting systematic literature reviews. This comprises three key steps to achieve the objective: (1) identifying relevant research through database searching and data specification, (2) data screening and evaluating full-text articles for eligibility, and (3) Analysis of data. The analysis indicates the trend of development of renewable energy research and sketches possible areas of future studies. By examining structural arrangements, leading research patterns, journal influences, and citation rates [15], the study offers a broad perspective of the usability of renewable energy research toward socio-economic transformation among rural communities. Specifically, this article assesses how much renewable energy resources are utilized in rural areas [16].

2.1 Database searching and data specifications

Table 1 displays the data characteristics summary for a bibliometric analysis of renewable energy in rural communities. The research relies on the Scopus database with the search term

(renewable energy AND rural areas) used in article titles, abstracts, and keywords. It includes journal articles through February 2025 and covers a range of subject categories, including energy, environmental science, engineering, social sciences, agricultural and biological sciences, earth and planetary sciences, business, management and accounting, computer science, economics, econometrics, and finance. It only considers final-stage English publications and exports the data in CSV for analysis. This systematic process ensures a complete and multidisciplinary examination of renewable energy studies in rural areas.

Table 1 Summary of data characteristics of the bibliometric study.

Category	Specific standard requirements
Database	Scopus
Search query	("renewable energy" AND "rural areas")
Search category	Article title, abstract, keywords
Time frame	Articles published until February 2025
Subject area	(1) energy, (2) environmental science, (3) engineering, (4) social sciences, (5) agricultural and biological sciences, (6) earth and planetary sciences, (7) business, management and accounting, (8) computer science, (9) economics, econometrics and finance
Document type	Articles
Source type	Journal
Language	English
Publication stage	Final
Data export format	CSV

2.2 Data screening

Figure 1 displays a step-by-step screening method for this bibliometric analysis using the main PRISMA guidelines features [14]. First, the search yielded 4,381 records indexed in Scopus's database, with no records discarded before screening. The screening process had 1,049 excluded records because the subjects did not match the stated categories (182), it was of the wrong type of article (551), were not a journal publication (175), and were not written in the English language (110), still under press status (20), duplicates (9) or irrelevant (2). Considering the rigorous conditions, 3,332 articles were identified for inclusion in bibliometric analysis.

Although Scopus is known to have a broad coverage of peer-reviewed, high-quality literature, it has certain limitations that may influence the outcomes of this study. In particular, the database tends to overrepresent publications because it underrepresents outputs from the Global South and non-English publications. Conference papers and other non-journal documents were also ruled out to maintain consistency and scholarly thoroughness, as these are usually more extensive and checked research findings found in peer-reviewed journal articles.

2.3 Bibliometric analysis

Diverse software tools were used to present and analyze the bibliometric data to map the Philippines' contribution towards renewable energy research in rural areas. Biblioshiny, the web-based interactive add-on of the Bibliometric package [17] of RStudio [18], was first used to conduct bibliometric analysis. The Biblioshiny facility provides network analysis, thematic mapping, and trend visualization to allow the researcher to determine leading authors, keywords, citation patterns, and thematic clusters. Second, VOSviewer version 1.6.20 [19] was employed to generate network-based bibliometric visualizations, including co-authorship, keyword co-occurrence, and citation mapping. This instrument qualitatively

and quantitatively emphasized powerful world research clusters and prominent scholarly networks in renewable energy research and unraveled collaborative connections and theme strengths. Microsoft Excel analyzed trends for publication increases, geographic contributions, and citation frequencies.

give greater interest in technical progress and the latest power infrastructure for the optimization of rural electrification processes. Apart from this, the inclusion of geographically keywords such as Sub-Saharan Africa, Bangladesh, and Sudan underscores the strong research focus on addressing rural energy challenges in developing regions.

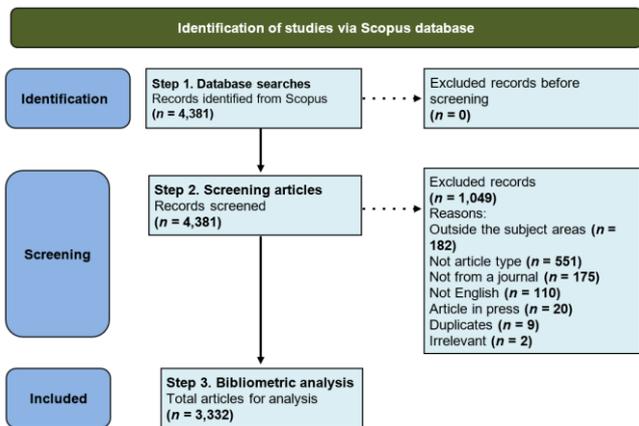


Fig. 1 the selection process.

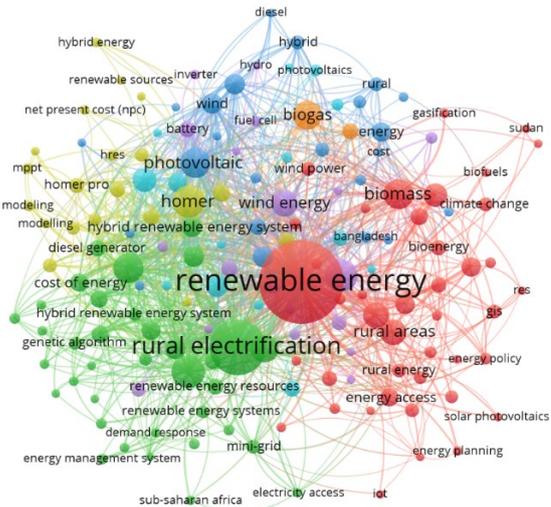
3. Results

3.1 Overview of the bibliometric information

Table 2 shows the data information of the bibliometric analysis. Research in this area has consistently increased in the field of study for renewable energy in rural areas from 1979 to 2025. Its academic influence is evident in the strong citation impact, suggesting that the work has significantly shaped scholarly conversations. The high international and interdisciplinary collaboration level reflects a global commitment to advancing knowledge in this area. Moreover, the active dissemination of findings through journal articles and conference papers, alongside the wide array of references and keywords, points to a research landscape that is both diverse and continually evolving.

3.2 Bibliometrics analysis of the dominant keywords

Figure 2 presents a bibliometric keyword analysis using (a) a co-occurrence network and (b) a word cloud to identify dominant themes and research patterns in renewable energy studies focused on rural areas. The co-occurrence in figure 2(a), larger nodes are for frequently occurring words, and the edges connecting them are for co-occurrence among academic papers. The most emphasized words are "renewable energy," "rural electrification," "biomass," "wind energy," "photovoltaic," and "solar energy," and they reflect the focal point of research interest in sustainable energy alternatives for rural communities. The network reveals several clusters, each addressing various research subfields. One of the clusters is focused on energy management systems, hybrid renewable energy systems, and cost calculation, focusing on economic viability and optimization techniques for rural energy systems. Another cluster is focused on biomass, bioenergy, energy access, and policy, focusing on the potential of renewable energy to alleviate energy poverty and identifying policy models. The third category includes wind power, photovoltaic-powered hydro, hybrid systems, and fuel cells, which reflect technical progress in rural power electrification. The employment of terms such as "HOMER Pro," "net present cost," and "cost of energy" is another reflection of growing interest in model and simulation packages to value renewable energy projects. Recurring keywords like "IoT," "smart grids," and "electricity access"



(a)



(b)

Fig. 2 bibliometric analysis of the keywords in publications of renewable energy in rural areas (a) co-occurrence of keywords (b) word cloud.

Table 2 Bibliometric data information.

Description	Results
Timespan	1979:2025
Sources (Journals and conference proceedings)	1,335
Documents	3,332
Annual growth rate %	7.83
Document average age	8.21
Average citations per document	19.84
References	98,531
Keywords plus	12,993
Author's keywords	6,815
Authors	9,371
Authors of single-authored documents	279
Single-authored documents	310
Co-authors per documents	3.59
International co-authorships %	24.22
Article	2,009
Conference paper	1,323

The word cloud in Figure 2 (b) supports these results by visually presenting the most used word in articles. All words such as "rural areas," "renewable energy resources," "rural electrification," "solar energy," and "wind power" often appear in visualization, showing their frequency in the literature. The use of terms such as "sustainable development," "economic analysis," and "energy policy" in the research suggests that research extends beyond the technological aspect to include economic sustainability and policy issues. Terms such as "alternative energy," "electric utilities," and "solar power generation" also suggest the different forms of energy solutions explored for rural areas.

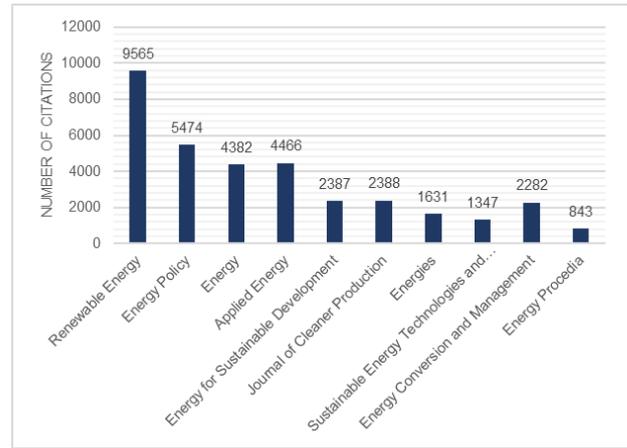
Table 3 The top ten most active countries, organizations and authors of renewable energy in rural areas.

Subject	Number of publications	Count of citations
Countries		
India	299	9,379
China	273	6,697
USA	117	3,909
UK	86	3,023
Germany	72	1,607
Spain	72	1,749
Malaysia	70	2,221
Italy	67	2,163
Indonesia	62	482
Iran	54	1,691
Organizations		
North China Electric Power University	94	554
Indian Institute of Technology	53	2,617
University of Tehran	52	981
Universiti Teknologi Malaysia	50	795
Islamic Azad University	46	547
Tsinghua University	42	1,221
Universitat Politècnica De Catalunya	39	770
Murdoch University	36	763
National Institute of Technology	35	1,933
Imperial College London	31	363
Authors		
Wang, Y.	24	387
Ferrer-Martí, L.	21	631
Ramakumar, R.	19	344
Zhang, Y.	18	310
Wang, X.	18	213
Saini, R. P.	17	1,051
Zhang, L.	16	365
Wang, Z.	16	303
Wang, S.	15	329
Li, X.	15	226

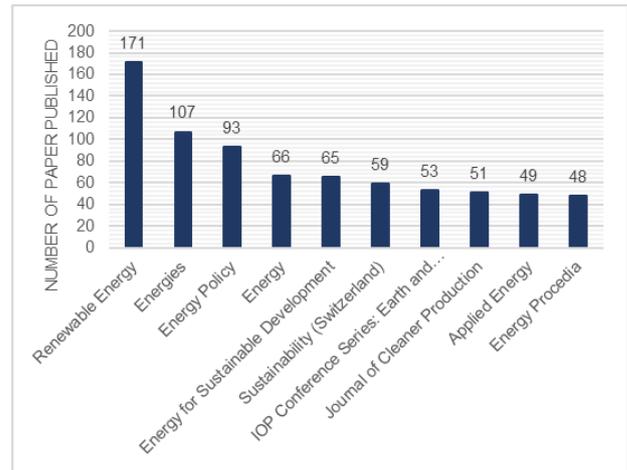
3.3 Bibliometric analysis of the citation and publication

Table 3 presents bibliometric findings about the most active countries, organizations, and authors regarding the publication and citation of their study for renewable energy in rural areas. Regarding most active countries, India leads in publication volume. It demonstrates the highest citation impact in the study of renewable energy in rural regions, with a share of 299 papers and 9,379 citations, followed by China (273 papers, 6,697 citations). The United Kingdom, the United States, and Germany also lead in publication volume and citation impact in such studies, where the U.S. has a share of 3,909 citations from 117 papers. Iran, Italy, and Malaysia represented Asia, and Europe was also part of the leads in publication volume and citation impact. Moreover, at the

organizational level, North China Electric Power University made the most publications (94) among the organizations. The Indian Institute of Technology has the largest number of citations (2,617 for 53 papers), which signifies it is the best in the area. Other strong institutions, such as Tsinghua University and the University of Tehran, innovate hybrid energy systems, biomass applications, and rural electrification. At the level of individual researchers, Wang, Y. (24 papers, 387 citations) and Ferrer-Martí, L. (21 papers, 631 citations) are some of the productive researchers. On the other hand, Saini, R. P. (17 papers, 1,051 citations) has the highest citation influence, especially for hybrid renewable energy systems.



(a)



(b)

Fig. 3 (a) the top ten most cited articles in the field of renewable energy in rural areas (b) the top ten journals with most published articles in the field of renewable energy in rural areas.

Figure 3 shows that Renewable Energy ranks as the most cited journal, with 9,565 citations (a), and the most prolific publication source, with 171 published articles (b), among the top journals in the sector. Other high-impact journals such as Energy Policy, Applied Energy, and the Journal of Cleaner Production are prominently engaged in sustainability, policy formation, and technological innovation themes. These publication patterns suggest a growing interdisciplinary focus on renewable energy applications for rural electrification, hybrid power systems, and sustainable agricultural practices. The concentration of research in these journals highlights emerging hubs of scholarly activity. It suggests increased opportunities for cross-sector collaboration, especially in policy influence and technology deployment tailored to rural contexts.

3.4 Bibliometric analysis of the co-authorship

Figure 4 illustrates a co-authorship network that visualizes collaborative relationships across authors, institutions, and countries in the field of rural renewable energy research. Present findings objectively, authors such as Raman Kumar and Mehdi Jahangiri are central players in the co-authorship network (a), bridging different groups of authors and facilitating cross-group collaborations. Similarly, institutions are clustered into isolated groups according to their collaborative pattern (b). The red cluster has the Indian Institute of Technology, Johns Hopkins University, the National University of Engineering, and the Basic Internet Foundation, Norway, indicating close in-group collaborations. The green cluster, on the other hand, has the Wireless World Research Forum, the University of Oulu, Finland, and the Indian Institute of Technology, and they form a distinct but related set of institutions. The relationships among these clusters are centered on cross-institutional cooperation, and certain institutions are hub nodes linking multiple research communities.

The ranking of each country in co-authorship (c) is portrayed through the magnitude of its node, with India, China, the United Kingdom, and the United States coming out as principal contributors to global renewable energy studies. Color-coded clusters identify regional or linguistic trends of collaboration: the red cluster, led by China, Malaysia, and Bangladesh, indicates tight intra-Asian research connections, whereas the green cluster links European and African countries, such as France, Spain, and South Africa, focusing on intercontinental collaborations. The blue cluster, with Italy, Finland, and Norway, captures another research network. The tight interlinkages between dominant nodes indicate that renewable energy studies are strongly globalized and that major nations are conduits of global collaboration.

3.5 Bibliometric analysis of the bibliographic coupling and co-citation

Figure 5 illustrates the result of bibliographic coupling and co-citation analysis. The bibliographic coupling of documents and sources shows several research clusters within the domain. The figure shows that bibliographic coupling recognizes similar documents based on mutual references, placing them into distinct research themes. Different colors depict the analysis of the three dominant clusters. The red cluster is dominated by sustainability and renewable energy research, with Sen and Bhattacharyya [20] and Martinot et al. [21] being major documents of reference. The blue cluster is dedicated to technological advances in energy policy, with Adefarati et al. [22] and Rad et al. [23] major contributors. The green cluster is applied engineering solutions-oriented, with Van der Horst [24] and Ramakumar [25] as major contributors. The proximity of the circles in this visualization shows the extent of correlation, with highly related documents having a high proportion of mutual references.

The co-citation map of sources and documents identifies the most influential publications defining the field. Co-citation mapping clusters sources according to how often they are cited together. The analysis identifies four large clusters, with "Renewable and Sustainable Energy" and "Energy Policy" overarching themes in the red and yellow clusters. The green cluster is for sources with an engineering advancement focus, and the blue cluster is for policy-based research. The biggest nodes, e.g., "Renew Sustain Energy Review" and "IEEE Transactions on Smart Grid," denote highly co-cited sources, reflecting their influence in the sector. The nature of

sources in various clusters portrays the interdisciplinary focus of renewable energy research, combining policy, engineering, and sustainability themes.

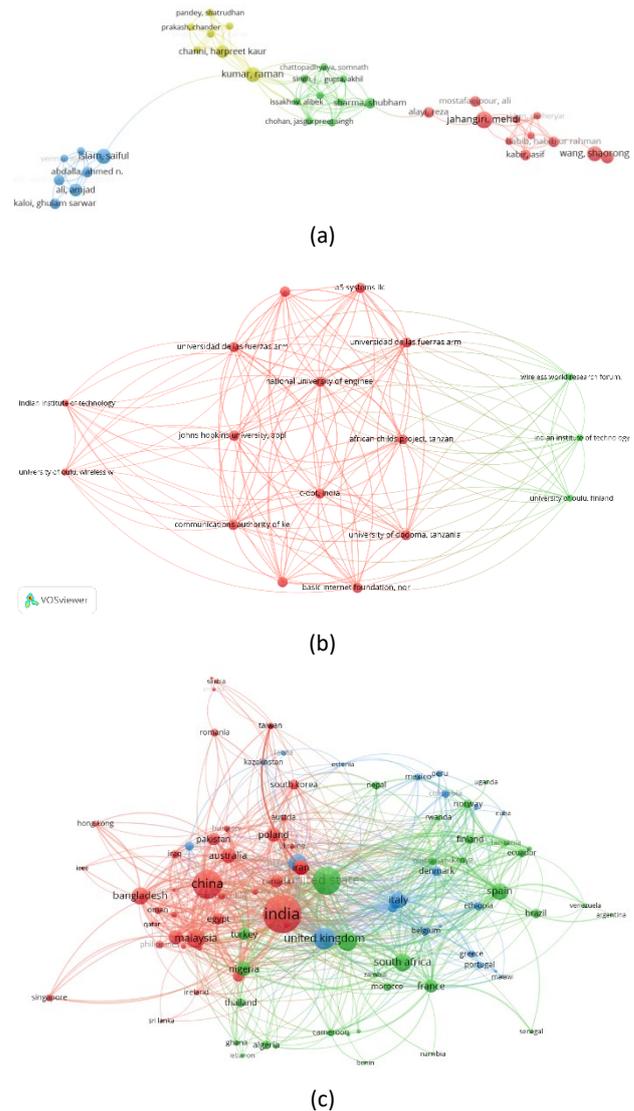
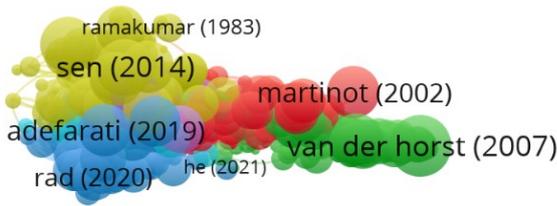


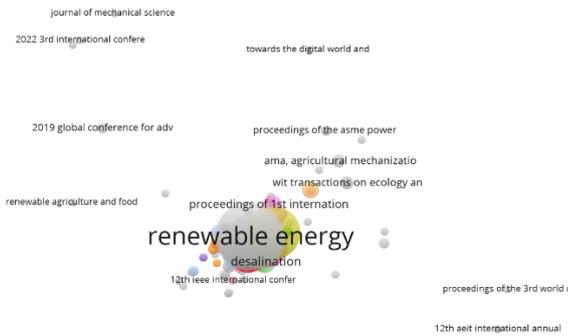
Fig. 4 (a) the co-authorship map of authors which indicates the authors that cooperate in the field of renewable energy (b) The co-authorship map of organizations (c) The co-authorship map of countries.

3.6 Bibliometric analysis of themes and trend topics

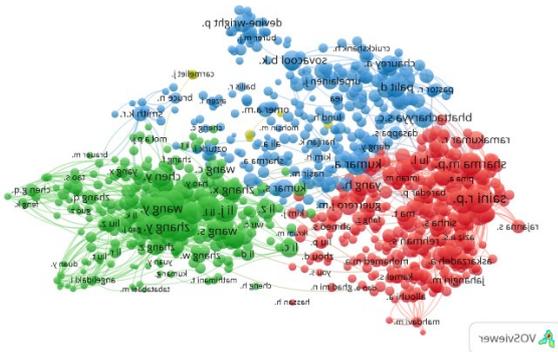
Figure 6 represents the bibliometric result of rural renewable energy research themes and trend issues. The distribution of the themes reveals three dominant clusters. The blue cluster comprises rural electrification and energy access studies, i.e., solar home systems, electricity supply, and mini-grid options. The red cluster signifies biomass, biogas, and climate change research on farm and anaerobic digestion-based electricity generation. Green cluster focuses on solar, hybrid systems, and natural resources, with research encompassing hydroelectric power plants, diesel engines, and electric power system management. The clusters signify a firm research emphasis on rural and agricultural sustainable energy sources adhering to international standards on energy transition.



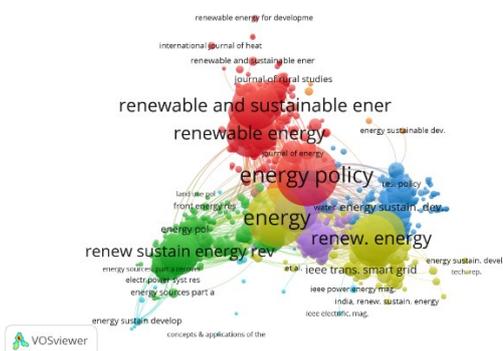
(a)



(b)



(c)

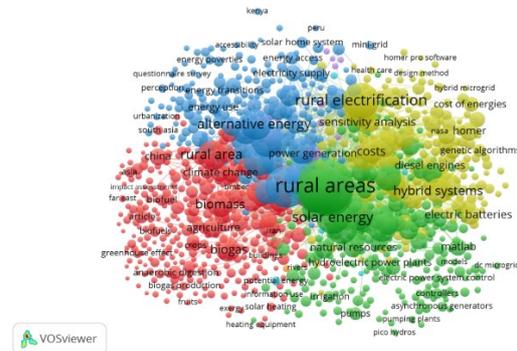


(d)

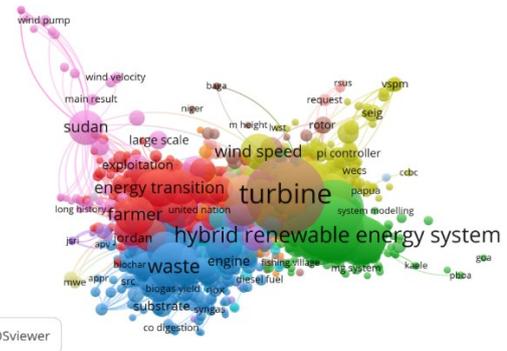
Fig. 5 bibliometric analysis of the bibliographic coupling and co-citation (a) bibliographic coupling of documents (b) bibliographic coupling of sources (c) co-citation of documents (d) co-citation of sources.

The trend topic network map indicates the shift in focus of renewable energy research. The change in focus over time is represented by the color gradient from purple to yellow. The recent

studies in yellow refer to emerging themes such as hybrid renewable energy systems, wind speed optimization, and system modeling. The red cluster reflects continued focus on energy transition, farmer use of energy, and biochar applications, whereas the blue cluster continues to examine waste-to-energy technologies and biogas. Notably, Sudan and other developing regions have become hotspots for wind pump and rural energy system studies, with increasing interest in decentralized and locally implementable renewable energy innovations.



(a)



(b)

Fig. 6 bibliometric analysis of themes (a) distribution of the themes (b) network map of the trend topics according to the keywords used from 1979-2025.

Figure 7 is a Sankey diagram of research themes in renewable energy from 1979 to 2025, with changing priorities and issues over time. Early research (1979-2011) focused on traditional themes such as "renewable energy sources," "biogas," "photovoltaic," and "energy management." From 2012 to 2019, the studies were more diversified with the addition of "wind energy," "distributed generation," and "GIS," showcasing increased interest in technological innovation and system performance. Throughout the 2020-2021 period, terms like "microgrid," change 2020-2025 period, "sustainable development," and "rural development" were in vogue, which also indicates the growing traction towards decentralized energy approaches and socio-economic implications. There is a greater concern with rural electrification, sustainability, and equity in 2022, as is apparent by the better attention to such phrases as "energy poverty," "community energy," "energy transition," and "anaerobic digestion." Moreover, the current phase reaffirms the same and embraces newer topics like "bioenergy," "energy cost," and "energy efficiency," putting importance on a newer focus area over cost-effectiveness and local energy solutions. This change reflects that renewable energy research evolved from technical-level innovations to sustainable systems thinking.

[42]. Technology advances with efficiency and cost reduction, threatening traditional energy markets and bringing sustainability increasingly into mainstream usage [43]. Moreover, behavioral science supports the achievement of such policies by facilitating changes in lifestyle and informing sustainable investment choices, hence harmonizing the world's energy policies with the socio-economic arena [44-45].

Fifth, the dominance of central references, i.e., by Sen and Bhattacharyya [20], Martinot et al. [21], Adefarati et al. [22], and Rad et al. [23], suggests that foundational works continue to influence the trajectories of ongoing research. The well-organized clusters of research also suggest experts in specific subfields, and the distance between documents in the coupling analysis suggests varying degrees of thematic convergence. Parallel to this, co-citation mapping recognizes key-influence sources such as "Renewable and Sustainable Energy Reviews" and "IEEE Transactions on Smart Grid," noting the overlap of engineering advances with policy and sustainability concerns. This structured categorization of sources into policy-stream, technology-stream, and sustainability-stream bodies of research is an even-handed methodology in framing concerns of rural electrification, keeping academic scholarship and policy-making in equal stead. The convergence of these clusters of research is imperative to promote cross-disciplinary collaborations as policy agendas enable public-private collaborations and adaptable approaches to cumulate electrification initiatives [46], technological innovation enhances extension and makes societies resilient [47], and studies that are sustainability-oriented guarantee long-term stability through linking sectors [48]. Despite the clear synergies between these fields, organizational and structural impediments to research cluster management exist. The intent must be made towards leveraging maximum interdisciplinary work and responsiveness of renewable energy research to evolving socioeconomic and technological needs [49].

Finally, anchoring three research areas in general—climate change and biomass, rural energy access and electrification, and solar power and hybrid systems—is an appropriate balance with global sustainability imperatives and agricultural and rural business decarbonization. Rural energy access promotion through mini-grids, solar home systems, and supply of electricity emphasizes the integration of biomass and biogas technologies, which is the position of agriculture in renewable energy technology. The diversification of energy sources with solar, hydro, and hybrid systems also illustrates the continuous improvement of efficiency and reliability. The trend is dynamic toward growing hybrid renewable energy systems, wind speed maximization, and system modeling toward more efficient and sustainable technology. The trend is especially vital in developing countries like Sudan, where locally suitable, decentralized technologies are increasingly utilized for off-grid electrification. Next-generation research should embrace interdisciplinary approaches that bridge technological innovation, policy-making, and localized implementation mechanisms to speed up these transitions. Renewable energy technology needs local adaptation to enhance reliability and affordability [50], while supportive policy should provide orderly structures that facilitate sustainability transitions through the elimination of regulatory and economic barriers [51-52]. In addition, public engagement is also essential for guaranteeing the success of the programs since differentiated communication strategies imposed through roles require stakeholders to interact with one another and foster ownership of energy solutions [53]. Despite such innovations, resistance to change and ongoing stakeholder

collaboration requirements are major challenges to rural energy mainstreaming. Overcoming these challenges through multidisciplinary collaborations will be essential to upgrading decentralized and site-specific renewable energy technologies and supporting rural energy transitions toward sustainability.

5. Conclusions

This bibliometric review highlights the key trends, contributors, and emerging directions in rural renewable energy research, with rising publications and citations reflecting a growing global focus, particularly from India, China, the United States, and Europe. Core themes such as rural electrification, sustainability, policy, and innovation dominate the field, while collaboration networks show stronger links across engineering, policy, and applied sciences. Foundational studies continue to shape the discourse, even as new topics like hybrid systems, IoT integration, and decentralized energy solutions are gaining ground. Future research should prioritize integrating IoT technologies into rural mini-grids to advance this field, especially in Sub-Saharan Africa and Southeast Asia, where energy access remains limited. Policymakers are encouraged to support interdisciplinary, cross-border partnerships that align technological advances with local needs. This study is limited to English-language publications indexed in Scopus, potentially underrepresenting research from non-English-speaking regions. It does not include grey literature or project-based reports, which may hold important insights into practical innovations.

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