“Interrelationship between decentralization of energy sources and their renewability: A bibliometric analysis of research trends and thematic evolution”

AUTHORS	Anargul Belgibayeva Artem Artyukhov Viera Kubičková Miroslava Čukanová Iuliia Myroshnychenko Ihor Ruzhytsky Serhiy Lyeonov

ARTICLE INFO	Anargul Belgibayeva, Artem Artyukhov, Viera Kubičková, Miroslava Čukanová, Iuliia Myroshnychenko, Ihor Ruzhytsky and Serhiy Lyeonov (2025). Interrelationship between decentralization of energy sources and their renewability: A bibliometric analysis of research trends and thematic evolution. *Environmental Economics*, *16*(3), 41-66. doi:10.21511/ee.16(3).2025.04
DOI	http://dx.doi.org/10.21511/ee.16(3).2025.04
RELEASED ON	Thursday, 07 August 2025
RECEIVED ON	Monday, 02 June 2025
ACCEPTED ON	Friday, 18 July 2025

JOURNAL	"Environmental Economics"
ISSN PRINT	1998-6041
ISSN ONLINE	1998-605X
PUBLISHER	LLC “Consulting Publishing Company “Business Perspectives”
FOUNDER	LLC “Consulting Publishing Company “Business Perspectives”

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
56	11	7

BUSINESS PERSPECTIVES

LLC "CPC "Business Perspectives"
Hryhorii Skovoroda lane, 10,
Sumy, 40022, Ukraine
www.businessperspectives.org

Anargul Belgibayeva (Kazakhstan), **Artem Artyukhov** (Slovakia, Poland, Ukraine), **Viera Kubičková** (Slovak Republic), **Miroslava Čukanová** (Slovak Republic), **Iuliia Myroshnychenko** (Germany, Ukraine), **Ihor Ruzhytsky** (Ukraine), **Serhiy Lyeonov** (Ukraine)

INTERRELATIONSHIP BETWEEN DECENTRALIZATION OF ENERGY SOURCES AND THEIR RENEWABILITY: A BIBLIOMETRIC ANALYSIS OF RESEARCH TRENDS AND THEMATIC EVOLUTION

Type of the article: Research Article

Received on: 2nd of June, 2025
Accepted on: 18th of July, 2025
Published on: 7th of August, 2025

Anargul Belgibayeva, Ph.D., Associate Professor, Department of Business and Services, Sh. Ualikhanov University, Kazakhstan.

Artem Artyukhov, D.Sc, Research Institute of Trade and Sustainable Business, Faculty of Commerce, University of Economics in Bratislava, Slovakia; WSEI University, Poland; Department of Marketing, Academic and Research Institute of Business, Economics and Management, Sumy State University, Ukraine.

Viera Kubičková, Prof. Ing., Ph.D., Department of Tourism, Faculty of Commerce, Bratislava University of Economics and Business, Slovak Republic.

Miroslava Čukanová, Ing., Ph.D., Department of Tourism, Faculty of Commerce, Bratislava University of Economics and Business, Slovak Republic.

Iuliia Myroshnychenko, Ph.D., Associate Professor, Department of Economics, Faculty of Business Administration and Economics, Paderborn University, Germany; Oleg Balatskyi Department of Management, Academic and Research Institute of Business, Economics and Management, Sumy State University, Ukraine.

Ihor Ruzhytsky, Private postgraduate educational institution "Institute of Professional Transformations", Ukraine.

Serhiy Lyeonov, Doctor of Economics, Professor, Department of Applied Social Sciences, Silesian University of Technology, Poland; Economic Cybernetics Department, Sumy State University, Ukraine. (Corresponding author)

Conflict of interest statement:
Author(s) reported no conflict of interest

Abstract

Decentralization and renewable energy have gained significant global attention due to their potential to enhance energy security, promote sustainability, and democratize energy access. This study aims to provide a comprehensive bibliometric analysis of research trends, key contributors, and thematic developments in the field of the decentralization of energy sources and their renewability. The research methodology involves a bibliometric analysis based on data extracted from the Scopus database, covering publications from 1973 to 2025. The analysis reveals exponential growth in research output, particularly after 2014, with over 3,700 publications recorded in 2023 alone. Citation trends indicate that foundational studies on decentralized microgrids and distributed energy systems remain highly influential, while recent works on blockchain-based energy trading and AI-driven energy management are gaining prominence. The study identifies China (11.7% of total publications), the United States (6.5%), and India (5.7%) as the leading contributors, with significant research activity also observed in European countries. Additionally, journals such as Applied Energy, Renewable Energy, and Energies serve as the primary publication platforms in this domain. Thematic analysis highlights a shift from bioenergy and land-use studies toward smart grids, energy storage, artificial intelligence, and decentralized finance for energy markets. Furthermore, co-authorship and international collaboration have increased significantly, with 25% of papers involving multi-country research efforts. Keyword analysis indicates growing research interest in emerging topics such as hydrogen energy, demand-side management, and digitalization in decentralized energy systems. These findings underscore the increasing interdisciplinary nature of decentralized energy research, integrating technological, economic, and policy dimensions.

Keywords decentralization, renewable energy, green energy, smart grids, energy storage

JEL Classification O13, Q20, Q42, Q48

INTRODUCTION

Due to growing concerns about climate change and the vital need to lower greenhouse gas emissions, decentralized renewable energy systems are becoming essential. Global agreements such as the Paris Agreement and national commitments to achieving net-zero emissions are driving investments in distributed energy systems, such as microgrids and community-led renewable projects, and distributed energy systems.

Advancements in solar PV, wind energy, battery storage, and smart grids have made decentralized energy systems more efficient, reliable, and scalable. AI, IoT, and blockchain further enhance energy management by improving grid resilience and enabling peer-to-peer energy trading. Blockchain supports local microgrid transactions, allowing consumers to invest in solar farms and trade surplus electricity, promoting renewable adoption through secure, transparent platforms. However, regulatory inconsistencies persist. AI's role in forecasting demand, optimizing operations, and maintaining grid stability, as seen in a Swiss pilot project managing energy consumption. IoT enhances demand-side management by connecting smart devices, improving efficiency, and reducing waste through real-time energy control.

Decentralized energy systems enhance security by reducing reliance on centralized grids, which are vulnerable to cyberattacks, natural disasters, and geopolitical conflicts. Countries are adopting local generation and storage to ensure reliable power, especially in remote or disaster-prone areas. Ukraine, for example, has integrated solar and wind into its infrastructure, strengthening energy resilience, as decentralized systems are harder to disrupt than centralized power plants (Prengaman, 2024).

The convergence of technological innovation, environmental urgency, energy security needs, and economic incentives makes this field one of the most critical and dynamic fields of research and policy expansion today. As the global shift towards a more sustainable, adaptable, and decentralized energy landscape accelerates, renewable energy systems and smart technologies will play an increasingly vital role.

1. LITERATURE REVIEW

The decentralization of energy systems is increasingly recognized as a transformative approach to enhancing energy security, sustainability, economic growth, and democratization. The shift towards decentralized energy solutions has been driven by technological advancements, policy evolution, financial mechanisms, and increasing social acceptance. Understanding the development of decentralized renewable energy requires an examination of the existing scientific landscape, including regulatory challenges, investment trends, socio-economic implications, and energy security concerns.

Recent research confirms the increasing relevance of decentralized renewable energy, addressing technological, policy, economic, and environmental challenges. Blockchain technology enhances secure energy transactions, while citizen participation plays a key role, as shown by Kostyuchenko et al. (2024) in Green Deal acceptance. Policy adaptation is crucial, with Mentel et al. (2020) and Dobrovolska et al. (2024) stressing the need for flexible, country-specific regulations. Firstová and Vysochyna (2024) explore socio-economic and environmental factors influencing national security in decentralization. Sustainable public policy fosters decentralization, as highlighted by Juracka et al. (2024) in circular economies and eco-innovation. Halynskyi and Telizhenko (2024) emphasize the protection of minority investors in renewable start-ups, supporting decentralization-driven entrepreneurship. Regional studies, including Olzhebayeva et al. (2023) on Central Asia and Vuichard et al. (2020) on Alpine solar power, underscore local engagement's impact, decentralization's social and environmental benefits are evident. Uddin et al. (2023) highlight the social advantages of decentralized solar energy in Bangladesh, while Badreddine and Larbi Cherif (2024) show how decentralization contributes to reducing air pollution and improving public health. Sedmíková et al. (2021) link energy consumption in the shadow economy to decentralization trends. On a global scale, Nihal et al. (2024) assess energy security in BRICS nations, Štreimikienė (2024) examines renewable energy in Nordic and Baltic countries, and Vasa et al. (2024) analyze the EU's economic and environmental energy transition drivers. Mukhtarov et al. (2023) highlight institutional quality's role in renewable transitions. This research underscores decentralized renewable energy's ongoing evolution, demonstrating its growing significance in sustainable and resilient energy systems.

Energy security remains a key driver of decentralization. Koilo (2024) assesses geopolitical risks, linking Russia's invasion of Ukraine to decentralized energy security concerns. Wołowiec et al. (2022) analyze sustainable governance and energy security in Europe, highlighting how de-

http://dx.doi.org/10.21511/ee.16(3).2025.04

centralization can mitigate energy losses. Sotnyk et al. (2023) explore household energy efficiency trends, and De Moraes e Soares et al. (2024) analyze asymmetries in energy consumption and public spending efficiency across municipalities.

Technological innovation plays a crucial role in decentralized energy management, facilitating digitalization, smart grids, and blockchain-based peer-to-peer energy trading. Chygryn et al. (2023) highlight the significance of smart transformation in the global energy sector, with systematic reviews indicating a shift towards digitalization and decentralized energy solutions. Vakulenko et al. (2023) analyze the carbon-neutral economy, identifying innovation as a primary driver in energy decentralization. Delcea et al. (2024) explore the role of energy communities in decentralization, highlighting their contribution to sustainable energy transitions.

Regulatory frameworks significantly influence the adoption of decentralized renewable energy. Myroshnychenko et al. (2024) conducted a bibliometric analysis identifying regulatory barriers that hinder renewable energy entrepreneurship.

Financial investments play a pivotal role in decentralized renewable energy expansion. Krause et al. (2024) and Makarenko et al. (2023) conducted a research landscape analysis on green energy financing, underscoring the importance of sustainable finance in decentralized energy systems. Moroz and Lyeonov (2024) explore financial-fiscal instruments supporting renewable energy projects, while Artyukhov et al. (2024) analyze global investment patterns, demonstrating how economic diversity impacts decentralized energy funding. Streimikiene et al. (2024) discuss the European Green Course and its emphasis on sustainable finance. Wüstenhagen and Menichetti (2012) provide a conceptual framework for renewable energy investment strategies, identifying future opportunities in decentralization.

Decentralized energy plays a crucial role in reducing carbon emissions and enhancing environmental sustainability. Ziabina et al. (2023) discuss the determinants of green development and energy balance transformation, with a focus on waste management and energy efficiency. Matvieieva et al. (2023) analyze waste incineration's impact on public health, emphasizing the importance of decentralized waste-to-energy solutions.

Bibliometric analyses (Myroshnychenko et al., 2024; Krause et al., 2024; Sotnyk et al., 2023) highlight gaps in decentralized renewable energy research. While policy and financial mechanisms are well-explored, there is a lack of bibliometric studies on technological innovation, long-term economic impacts, and decentralization in developing economies. Moreover, empirical studies on social acceptance and behavioral factors in decentralized energy adoption remain limited. Kostyuchenko et al. (2024) and Vuichard et al. (2020) stress the importance of local participation in decentralization, but further bibliometric analysis is needed to assess global trends in social acceptance. The literature demonstrates that decentralized renewable energy is a rapidly evolving field with significant technological, regulatory, financial, socio-economic, and environmental implications. While decentralization enhances energy security, sustainability, and economic resilience, challenges such as regulatory barriers, financial constraints, and infrastructural limitations persist. Addressing these gaps requires interdisciplinary research and innovative policy solutions.

This study aims to provide a structured, data-driven overview of decentralization and renewable energy research, tracking its evolution, growth trends, and impact. It examines the most prolific authors, institutions, and countries involved, analyze thematic clusters, conceptual developments, and citation patterns, and identify dominant research themes to guide future studies in this critical area.

2. METHODOLOGY

2.1. Data collection

This study employs bibliometric analysis to explore the research landscape on the interaction between the decentralization of energy sources and their renewability. Data were retrieved from the Scopus database, one of the most comprehensive bibliographic sources, using an advanced query strategy. The search string incorporated terms related to decentralization, energy management, and various renewable energy sources such as solar, wind, bioenergy, hydropower, and marine energy (Lyeonov, 2025). The data retrieval process ensured coverage from 1973 to 2025, capturing a broad temporal scope of research publications – 31,296 documents. The sample was limited to articles, conference papers, book chapters, and books; as a result, it consists of 28,761 documents.

2.2. Data processing and cleaning

The retrieved dataset included metadata such as titles, abstracts, author information, document types, publication years, keywords, citations, and affiliations. The completeness of metadata was assessed using the Biblioshiny application, revealing that essential fields such as titles, abstracts, and citation data were well-populated, ensuring reliability in bibliometric analysis (Table 1). However, missing information in some fields, particularly corresponding author details and science categories, was noted and factored into the analysis limitations.

Table 1 allows us to understand how much information is missing for various metadata fields in the dataset from Scopus and how that affects the quality of your bibliometric analysis. Most essential fields (title, abstract, authors, journal, citations) are well-populated, ensuring reliable bibliometric analysis. Keywords and Keywords Plus have moderate missing data, which may affect topic modelling or co-word analysis, but from these two categories, Keywords (Authors) are preferable. Corresponding author information is missing for a third of the records, limiting research on collaboration networks. Science Categories are entirely missing, meaning no field-based classification is possible.

2.3. Bibliometric analysis

A range of bibliometric indicators was employed to evaluate the research output, impact, and collaboration patterns in the field of decentralization and renewable energy. The key bibliometric analyses conducted include:

Table 1. Completeness of metadata of the sample of documents related to the interaction between the decentralization of energy sources and their renewability

Source: Authors' evaluations in the Biblioshiny App.

Description	Missing Counts	Missing, %	Status	Interpretation
Abstract	0	0.00	Excellent	No abstracts are missing; analysis relying on abstracts (e.g., topic modelling, keyword co-occurrence) will be reliable
Document Type	0	0.00	Excellent	All documents have a type (article, conference paper, book, book chapter), ensuring accurate classification
Language	0	0.00	Excellent	No language data are missing, ensuring proper categorization
Publication Year	0	0.00	Excellent	All documents have a publication year, which is essential for time-based trend analysis.
Title	0	0.00	Excellent	No titles are missing, making document-level identification and citation analysis reliable
Total Citation	0	0.00	Excellent	No citation data are missing, ensuring an accurate citation impact analysis
Journal	67	0.23	Good	A small fraction of documents are missing journal information, which may slightly impact source analysis
Author	91	0.32	Good	Most documents have author details, so author-based metrics (e.g., author productivity, collaboration) are largely reliable
Affiliation	436	1.52	Good	Some affiliation data are missing, which may slightly affect institutional impact studies.
Cited References	916	3.18	Good	Most documents have cited references, so co-citation analysis and reference-based metrics remain largely valid
DOI	2565	8.92	Good	Some records lack DOIs, which may impact accurate document retrieval and citation tracking
Keywords	3925	13.65	Acceptable	A noticeable percentage of missing keywords may reduce the accuracy of keyword-based analyses
Indexed Keywords	3982	13.85	Acceptable	Similar to Keywords, missing data might limit topic-related research trends
Corresponding Author	9023	31.37	Poor	A significant proportion lacks corresponding author information, reducing the reliability of author collaboration and correspondence network analyses

http://dx.doi.org/10.21511/ee.16(3).2025.04

- scientific production analysis examines the annual growth rate of publications, the average document age, and the citation impact over time;
- authorship and collaboration patterns analyze the number of authors per document, the extent of international collaboration, and the distribution of single-authored versus co-authored works;
- source analysis identifies core journals publishing in the field using Bradford's Law, highlighting key outlets where research is concentrated;
- citation analysis evaluates the most cited papers and authors to determine influential research and key contributors;
- keyword and thematic evolution analysis investigates the occurrence and co-occurrence of keywords to map the conceptual evolution of research themes over time;
- institutional and country-level contributions assess the geographical distribution of research activity and institutional affiliations of authors.

2.4. Data visualization

To enhance the interpretation of bibliometric results, visual analytics tools within the Biblioshiny App are utilized to generate:

- annual scientific production trends;
- co-authorship and co-citation networks;
- thematic maps and keyword co-occurrence networks;
- Bradford's Law visualization for source impact;
- Lotka's Law analysis to assess author productivity.

The methodology adopted provides a comprehensive bibliometric overview of research on the decentralization of energy sources and their renewability. By integrating data extraction, processing, bibliometric analysis, and visualization, this study offers valuable insights into the intellectual structure and emerging trends in the field.

3. RESULTS

Decentralization and renewable energy are a rapidly growing research field, with a 9.64% annual growth rate and 28,761 publications. A high citation rate (21.13 citations per document) reflects strong academic recognition. While research dates back to 1973, interest has surged in recent years. The broad range of indexed keywords highlights its multidisciplinary nature. Collaboration is prevalent, with 24.97% of studies involving international partnerships, reinforcing its global relevance. Journal articles (18,216) dominate, followed by conference papers (9,221), which showcase emerging trends, while books and chapters contribute theoretical insights but are less frequent.

The oldest publication in the sample, by Patton et al. (1973), is a special compilation for the 16th Annual Meeting of the Association of Engineering Geologists in Hollywood, California. It includes 49 papers across three sections: Geology, Seismicity, and Environmental Impact. The Environmental Impact section (11 papers) explores geology's role in environmental assessments, coastal erosion, sedimentation, marine geology, sustainable resource use, land-use planning, and pollution control.

Figure 1 illustrates the growth of scientific publications on energy decentralization and renewables over time.

From 1973 to 2000, publications remained low and fluctuated, indicating that decentralized energy was not yet a mainstream research focus. Early exponential growth ($y = 4.6815e^{0.088x}$, $R^2 = 0.8456$) began to emerge.

Between 2000 and 2013, a gradual increase in output followed a polynomial trend ($y = 5.0305x^2 - 286.91x + 4{,}148.9$; $R^2 = 0.9903$). This period coincided with rising global awareness of renewables, early energy decentralization policies, and initiatives like the Kyoto Protocol (1997, enforced 2005). Attention also shifted toward biofuels, nuclear energy, smart grids, and distributed energy systems, alongside advances in solar PV and wind energy.

Post-2014, research output surged, following a steep exponential trajectory ($y = 4.2067e^{0.1306x}$, $R^2 = 0.9958$), with publications rising from hundreds to 3,719 in 2023. This growth aligns with global renewable energy adoption, decentralized energy policies (e.g., microgrids, community-based systems), technological advancements (battery storage, smart grids), economic incentives, and blockchain-based energy trading. Key drivers include the Paris Agreement (2015) and national decarbonization commitments.

Source: Authors' visualization using Excel, based on data from the Biblioshiny App.

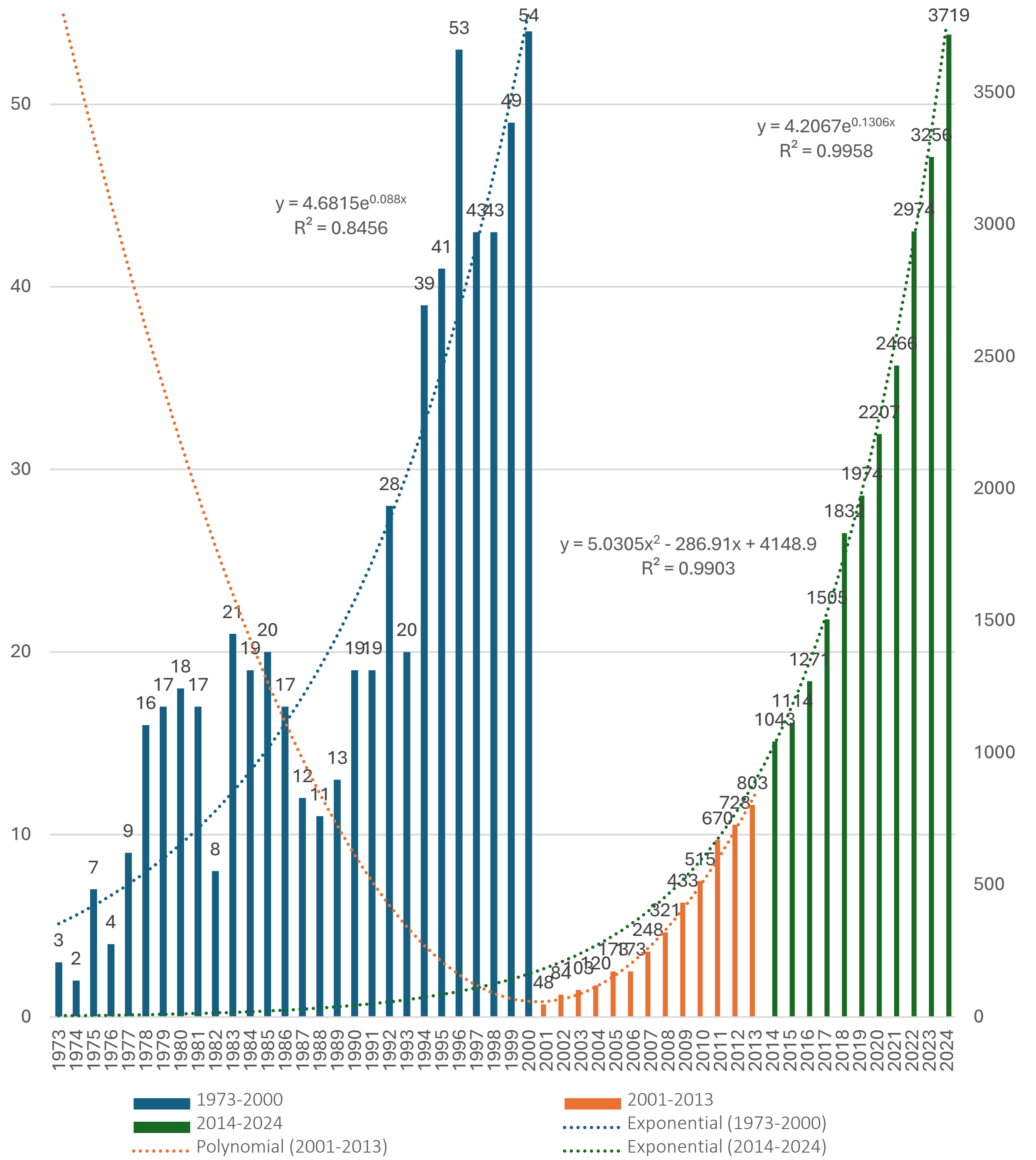
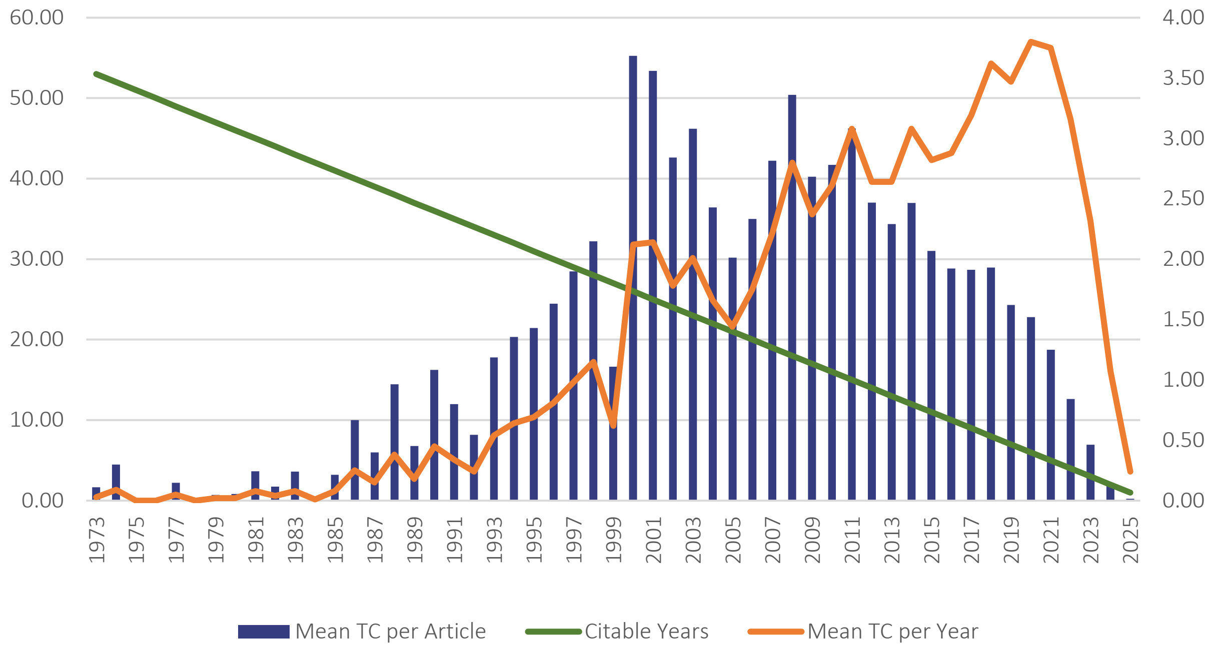


Figure 1. Annual scientific production of scientific publications related to the decentralization of energy sources and their renewability

http://dx.doi.org/10.21511/ee.16(3).2025.04

Source: Authors' visualization using Excel, based on data from the Biblioshiny App.



Note: Mean TC per Article – the average total citations per article published in a given year; Mean TC per Year – the average citations per year, which normalizes citation impact by the number of years since publication; Citable Years – the number of years each publication has been available for citation.

Figure 2. Bibliometric indicators related to citation trends for research on the decentralization of energy sources and their renewability over time

The 2014–2024 trend suggests continued exponential growth, though a recent plateau or slight dip may result from 2024 publication delays (Scopus indexing), a shift towards AI, IoT, and energy storage integration, and the maturation of fundamental research, leading to more applied and policy-driven studies.

Figure 2 provides bibliometric indicators related to citation trends for research on the decentralization of energy sources and their renewability over time.

From 1973 to 2000, research on decentralization and renewable energy was limited, with annual publications rarely exceeding 50. Despite this, early studies had a high citation impact, shaping future developments as they became key references in policy discussions.

Between 2001 and 2013, research output surged, driven by global policy changes such as the Kyoto Protocol (2005) and advancements in solar photovoltaics, microgrids, and distributed energy systems. Highly cited works, including Huang et al. (2011) with 1,560 citations and Chen et al. (2011) with 1,555 citations, reflect the growing influence of studies from this period.

The 2014–2020 phase saw rapid expansion, with annual publications exceeding 2,000. Although citation averages declined due to increased volume, key studies on smart grids, blockchain energy trading, and storage solutions maintained a strong impact. The 2015 Paris Agreement further fueled interest in decentralized energy. Notable studies included research on supercapacitors (He et al., 2012 – 1,367 citations), green grabbing (Fairhead et al., 2012 – 1,366 citations), and municipal solid waste gasification (Arena, 2012 – 1,039 citations).

Between 2021 and 2025, publications surged, peaking at 3,719 in 2024. However, average citations per article declined, mainly due to citation lag, as newer studies have had less time to accumulate references. This does not indicate reduced research impact but reflects the time-dependent nature of citations. Additionally, data for 2024 and 2025 remain incomplete, with many papers yet to be indexed or widely cited.

Source: Authors' evaluations in the Biblioshiny App.

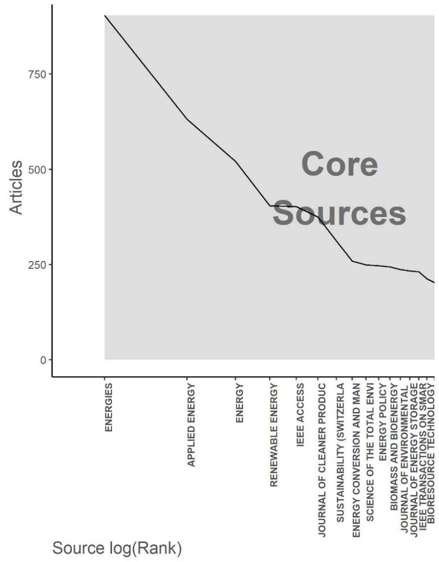


Figure 3. Core sources, according to Bradford's Law, publishing the most research on decentralization of energy sources and their renewability

The Bradford's Law visualization from Biblioshiny provides insights into the core sources that publish the most research on the decentralization of energy sources and their renewability (Figure 3). Bradford's Law states that a small set of highly productive journals accounts for the majority of publications on a topic, while many other journals contribute fewer articles.

Bradford's Law confirms that a small number of key journals dominate research dissemination in this field. The findings suggest that interdisciplinary and high-impact journals such as Applied Energy, Renewable Energy, and Energy are critical in advancing knowledge on the decentralization of energy sources and their renewability.

Table A1 in Appendix A presents bibliometric indicators for top journals (H-index ≥ 40) publishing research on decentralization and renewable energy. Applied Energy leads the field with an h-index of 89, a g-index of 134, and 31,156 citations, followed by Energy (h-index of 88, g-index of 129, 25,814 citations). IEEE Transactions on Smart Grid stands out with the highest m-index (4.938), reflecting its rapid impact since its launch in 2010.

High-impact journals, such as Renewable Energy and Energy Policy, exceed 17,000 citations, highlighting their role in policy and technology discussions. The Journal of Cleaner Production maintains a strong influence on sustainability research, with an m-index of 2.462 and a g-index of 93. IEEE Access, with the highest m-index (5.5), and Energies (904 publications, h-index 51) are rapidly growing, becoming major sources for contemporary studies.

Established journals, such as Energy Conversion and Management (since 1980) and the International Journal of Hydrogen Energy (since 1983), continue to hold high cumulative citations, maintaining long-term influence. Meanwhile, emerging journals like the Journal of Energy Storage and Sustainability (Switzerland) are gaining prominence with high m-index scores.

A Lotka's Law analysis of decentralization and renewable energy research reveals that most authors contribute only one publication, while a smaller group produces multiple works. 76.4% of authors (50,796) have written just one paper, 12.7% (8,446) have published two, and only 4.3% (2,871) have authored three. The number of researchers decreases as publication output rises, with very few contributing four or more papers. This aligns with Lotka's Law, which indicates that a small group of prolific researchers drives the field.

Table A2 in Appendix A highlights some of the most influential authors in decentralization and renewable energy research. Zhang Y. leads with the highest h-index (47) and g-index (87), reflecting both prolific output and strong citation impact.

http://dx.doi.org/10.21511/ee.16(3).2025.04

With 8,750 citations across 265 papers since 2009, Zhang Y. is a key contributor to the field. Similarly, Liu Y. holds an h-index of 43 and a g-index of 75, with 6,530 citations over 235 papers since 2006, indicating sustained research influence.

Other productive authors include Wang X. (h-index 41) and Wang J. (h-index 39), each exceeding 4,700 citations. The m-index, which measures research impact growth, is highest for Zhang Y. (2.765), demonstrating rapid influence expansion.

The data confirm Lotka's Law, where a small group of prolific researchers drives the field. These high-impact authors not only publish frequently but also receive significant citations, making their work foundational. The dominance of Chinese-origin surnames (Zhang, Liu, and Wang) suggests that China is a leading force in decentralization and renewable energy research, aligning with its major investments in renewable technologies, smart grids, and decentralized energy systems.

The m-index trends indicate that certain researchers are gaining influence rapidly, signaling an evolving field where newer studies are being widely recognized at an accelerating pace.

Table A3 in Appendix A presents a list of institutions with 100 or more publications related to the decentralization of energy sources and their renewability. This analysis highlights the most active research institutions contributing to the field.

The top contributors include North China Electric Power University (589 articles), Tsinghua University (560 articles), and Islamic Azad University (421 articles). These institutions have a significant presence in energy-related research, reflecting strong academic and governmental support for decentralization and renewable energy initiatives.

China has emerged as a dominant research hub, with several institutions – such as Shanghai Jiao Tong University (393), Zhejiang University (336), Southeast University (284), and Huazhong University of Science and Technology (279) – making substantial contributions. This aligns with China's national policies promoting renewable energy and smart grid development.

European institutions such as Aalborg University (399), Technical University of Denmark (264), Politecnico di Milano (199), and Delft University of Technology (197) play a major role in advancing renewable energy systems, policy research, and technological innovations. These universities are known for their expertise in wind energy, decentralized energy solutions, and smart grid technologies.

Leading American institutions such as the University of California (221), Michigan State University (145), Cornell University (116), and North Carolina State University (106) also contribute significantly. The National Renewable Energy Laboratory (104) is another key player, indicating the importance of U.S. government-funded energy research in decentralization and renewable integration.

Several institutions from Southeast Asia and the Middle East also show strong involvement, such as Nanyang Technological University (225), National University of Singapore (166), University of Tehran (130), and King Abdulaziz University (110). Their contributions reflect the growing importance of decentralized energy solutions in rapidly developing regions.

The dominance of Chinese institutions suggests that China is leading global research efforts in decentralized and renewable energy. European universities continue to make technological and policy-driven advancements, while U.S. institutions contribute through government research labs and university collaborations. The increasing presence of universities from Asia, the Middle East, and Latin America indicates growing global engagement with decentralized energy solutions.

Table A4 in Appendix A presents the most active countries regarding research output on the decentralization of energy sources and their renewability, focusing on the number of published articles, Single Country Publications, and Multiple Country Publications. China leads with 3,373 articles (11.7%), driven by its aggressive policies on renewable energy, decentralized grids, and smart technology. The USA follows with 1,865 articles (6.5%), though with a lower MCP share (19.2%), indicating a stronger domestic focus. India (1,650 articles, 5.7%) and Italy (1,207 articles, 4.2%) are also key contributors, with Italy showing a higher MCP (22.4%), reflecting stronger European collaborations.

European nations such as the UK (668 articles, MCP 38.8%), Spain (631 articles, MCP 33.6%), and Germany (805 articles, MCP 26.5%) prioritize multinational research efforts, likely through EU-funded projects. Iran (33.8%), Australia (33.1%), and Canada (31.3%) also demonstrate strong international collaboration.

Among emerging economies, Brazil (30.6%), Turkey (16.3%), and Indonesia (17.8%) are expanding their decentralized energy research, with Brazil focusing on bioenergy and distributed solar systems. The highest MCP % values appear in Saudi Arabia (53.6%), Pakistan (55.7%), and Algeria (44.4%), suggesting reliance on international partnerships due to funding constraints or developing research infrastructure.

These trends highlight collaboration opportunities with highly active countries, guiding policymakers to strengthen international research networks and foster knowledge exchange in decentralized renewable energy.

Table A5 in Appendix A presents the top 10 globally cited papers on decentralization and renewable energy, highlighting key contributions to the field. The most cited paper, Huang et al. (2011), has 1,560 citations (104 per year) and introduces the concept of the "Energy Internet", an innovative architecture for integrating distributed renewable energy and storage inspired by the Information Internet. The high total citations per year (TCpY) of this and Chen et al. (2012) indicate their lasting impact. This reflects the rapid expansion of decentralized energy research during 2011–2012, driven by smart grid advancements and policy developments.

Table A6 in Appendix A ranks the top 10 most locally cited papers, focusing on influence within the Biblioshiny dataset. The most locally cited work, Palma-Behnke et al. (2013), has 160 local and 673 global citations, proposing an Energy Management System for microgrids using a Rolling Horizon strategy to improve efficiency. Another key study by Zhang et al. (2013), with 138 local and 664 global citations, explores optimization strategies for renewable energy microgrids. Other influential works cover microgrid planning (Kanchev et al., 2011 – 132 LC), hybrid energy systems (Moghaddam et al., 2011 – 128 LC), and community renewable frameworks (Walker & Devine-Wright, 2008 – 111 LC), reflecting the growing interest in energy resilience, hybrid systems, and community-driven renewables.

Some papers have high LC/GC ratios, indicating strong relevance within this research area. Palma-Behnke et al. (2013) (23.77%) and Moghaddam et al. (2011) (23.53%) show strong connections to decentralization studies, while others, like Dragicevic et al. (2014) (10.05%), have broader interdisciplinary influence. Recent papers (e.g., Bukar et al., 2019) show rising LC/GC ratios, suggesting a growing focus on AI-based energy forecasting, advanced optimization, and policy-driven decentralization in future research.

Figure 4 highlights the most cited references within the analyzed dataset on the decentralization of energy sources and their renewability. Each entry represents an influential work frequently referenced in the field. The number next to each reference corresponds to the number of citations within the dataset.

The most cited reference is Boyd and Vandenberghe (2004), which has 120 citations, suggesting that this work plays a foundational role in the research field. This reference is a comprehensive textbook that delves into the theory and applications of optimization problems where both the objective function and the feasible region are convex. This structure ensures the local minimum is also a global minimum, facilitating more efficient and reliable solution methods.

Figure 5 provides an overview of the evolution of key research terms in the decentralization of energy sources and their renewability over time. The y-axis lists the research terms, while the x-axis represents the years these topics have been studied. The size of the circles corresponds to the frequency of a given term in publications, showing how research interest has shifted over time.

http://dx.doi.org/10.21511/ee.16(3).2025.04

Source: Authors' evaluations in the Biblioshiny App.

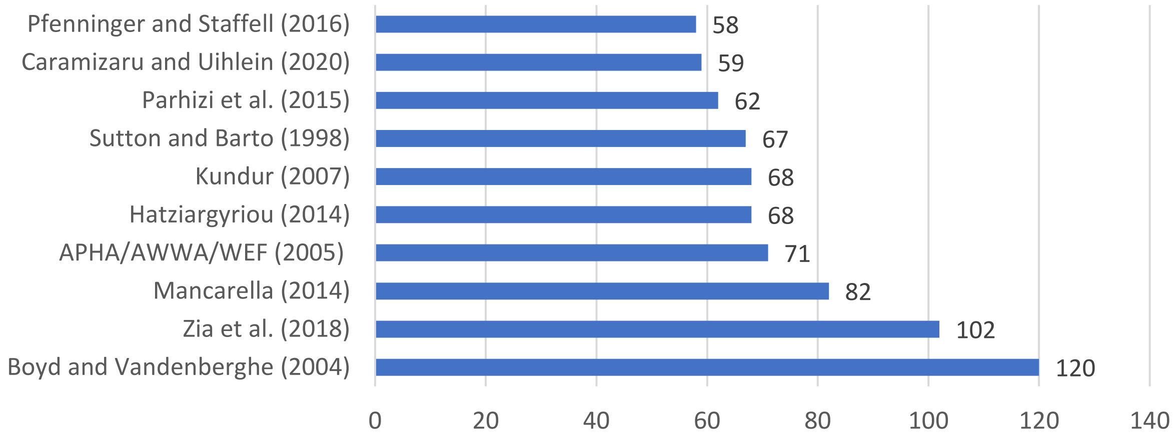


Figure 4. Ten of the most cited references within the analyzed dataset, dedicated to energy sources' decentralization and renewability

The earliest research topics (before 2005) focused on bioenergy, biomass energy, biodiesel, energy crops, carbon sequestration, and land use, indicating an initial emphasis on biomass-based renewable energy solutions and environmental impacts. Much of the research during this period explored agricultural residues, biofuels, and sustainable land management for energy production.

Between 2005 and 2015, research interest shifted towards life cycle assessment, distributed generation, load management, and energy storage, highlighting concerns about efficiency, grid integration, and sustainability assessments. During this phase, smart grids, demand response, and microgrids emerged as key focus areas, reflecting the growing adoption of decentralized energy systems and intelligent power distribution mechanisms.

From 2015 onward, there was a rapid increase in studies on digitalization and automation in energy systems, as seen in terms such as machine learning, the Internet of Things, and battery energy storage systems. This trend indicates a substantial shift towards AI-driven energy management, predictive analytics, and real-time monitoring in decentralized grids. The appearance of renewable energy communities and energy transition during this period reflects the increasing role of community-based energy models and decentralized energy policies.

More recently, green hydrogen, grid stability, and electric vehicles have emerged as prominent topics, suggesting that future research will likely emphasize hydrogen-based energy solutions, enhancing grid resilience, and integrating transportation with decentralized energy systems.

The thematic evolution visualization (Figure 6) presents the progression of key research themes over different time periods, showing how core topics in decentralization and renewable energy have evolved. The bars represent dominant themes in each time period, while connecting lines indicate the transition and continuity of research topics over time. The time slices in the visualization were chosen based on distinct trends in research output and thematic evolution in this field.

The evolution of decentralization and renewable energy research has shifted through distinct phases.

From 1973 to 2000, studies focused on solar energy, renewable energy, biomass, and climate change, highlighting early exploration of alternative energy sources and their climate impact. The prominence of biomass and solar suggests they were the first renewable technologies to gain traction.

Between 2001 and 2013, biomass became a dominant theme, reflecting growing interest in bioenergy as a sustainable fuel. The introduction of distributed generation marked the shift toward decentralized energy systems, expanding research beyond energy production to grid integration.

Source: Authors' evaluations in the Biblioshiny App.

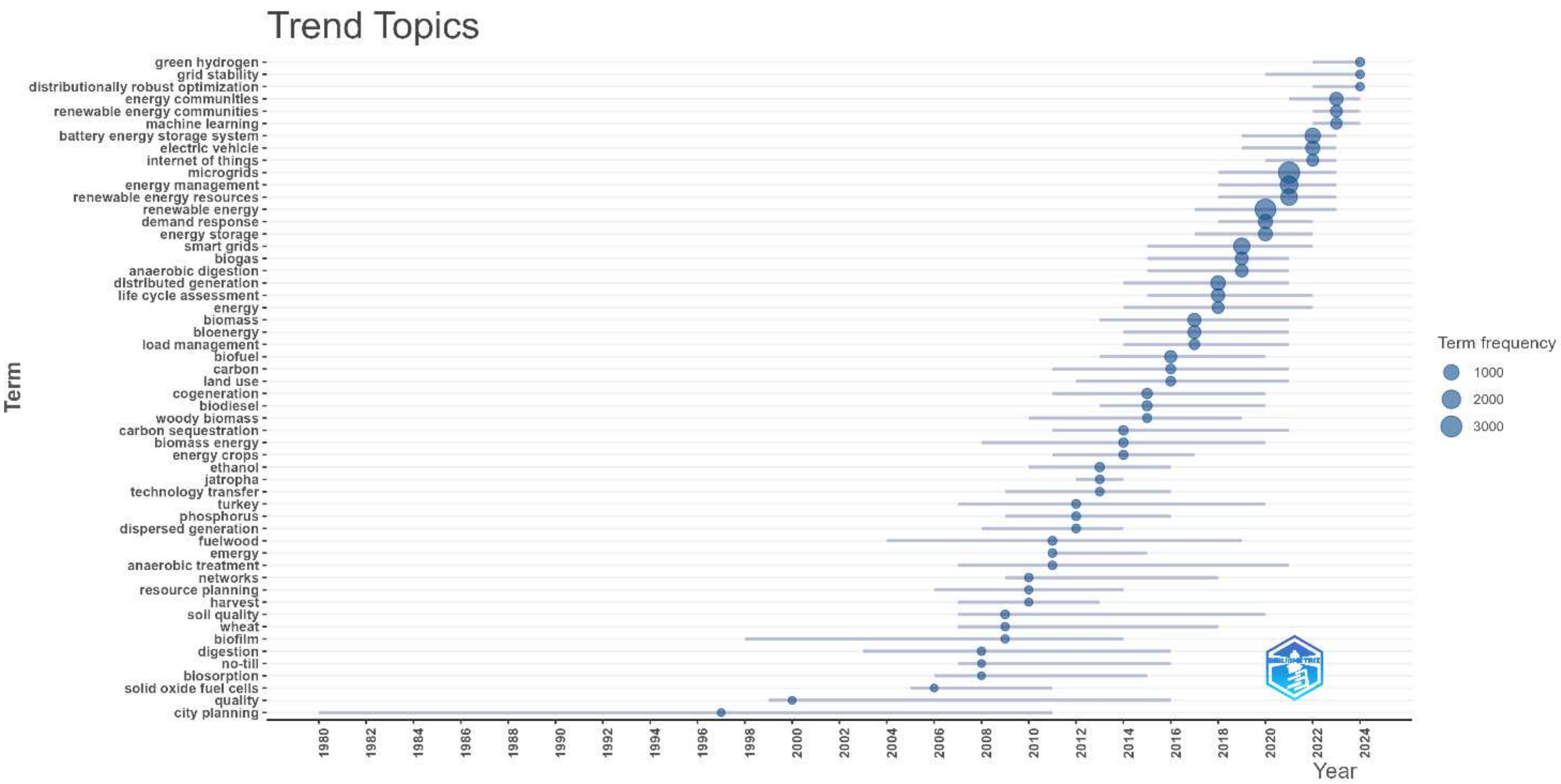


Figure 5. Evolution of key research terms in the field of decentralization of energy sources and their renewability over time

http://dx.doi.org/10.21511/ee.16(3).2025.04

Source: Authors' evaluations in the Biblioshiny App.

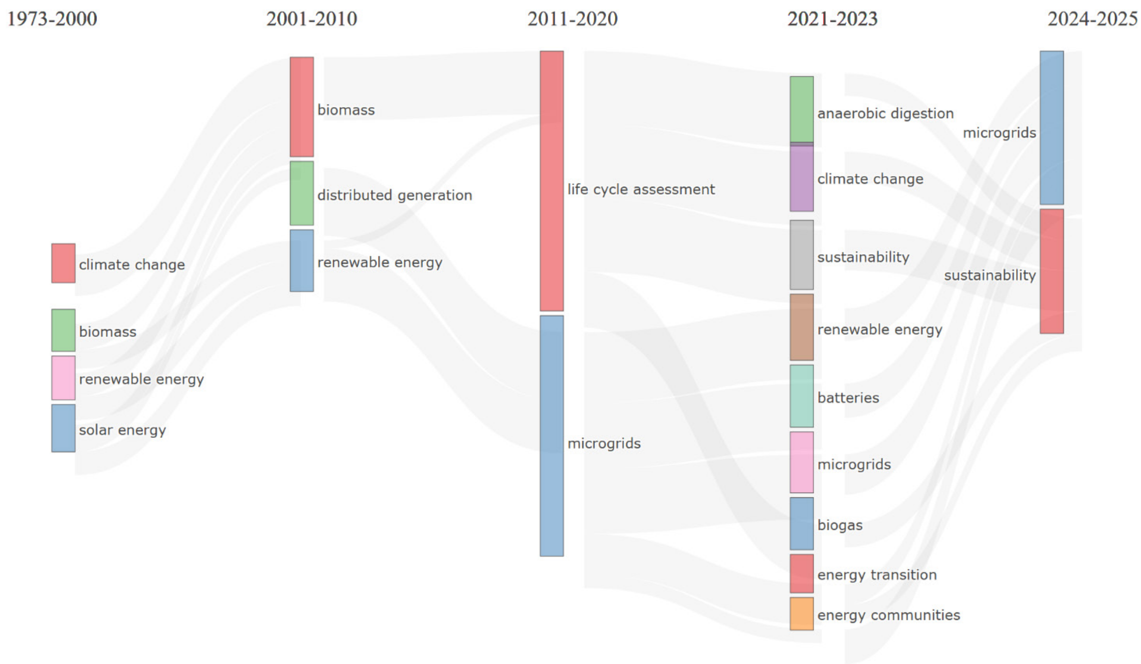


Figure 6. Thematic evolution of core topics in decentralization and renewable energy

From 2014 to 2024, research expanded to microgrids, sustainability, and life cycle assessment, emphasizing localized, resilient energy systems and evaluating renewables' long-term environmental and economic impact.

The latest phase focuses on digitalization, advanced grid management, and techno-economic analysis. Topics like AI, power management, blockchain, and demand-side management highlight research on intelligent energy control, decentralized markets, and energy optimization. Blockchain suggests a growing interest in peer-to-peer trading and decentralized finance. At the same time, techno-economic analysis indicates a shift toward assessing decentralized energy's economic feasibility and business models.

The thematic maps (Appendix B, Figures B1-B4) categorize decentralized energy research by centrality (importance) and density (development level).

Between 1973 and 2000 (Figure B1), research focused on renewable energy, anaerobic digestion, biogas, cogeneration, city planning, and solar energy, shaping decentralized energy and urban planning. Climate change, biofuels, and carbon sequestration were niche but well-developed topics, while forest management, energy crops, and biofilm appeared as emerging or declining themes. Biomass, environmental impact, and bioenergy remained widely studied but evolving.

From 2001 to 2013 (Figure B2), research shifted toward renewable energy, smart grids, and distributed generation, making them central themes. Bioenergy topics like biomass and biofuels gained attention, but with uncertain long-term significance.

Between 2014 and 2024 (Figure B3), research focused on microgrids and energy management, promoting localized, resilient energy systems. Sustainability and energy efficiency remained key but required further interdisciplinary integration.

Looking ahead to 2025 and beyond (Figure B4), microgrids, renewable energy, energy management, sustainability, and machine learning are expected to dominate, with high influence and ongoing development. Blockchain, decentralized applications, demand-side management, optimal scheduling, and energy policy are emerging but not yet fully integrated. Resource management, energy consumption, and source apportionment

Source: Authors’ evaluations in the Biblioshiny App.

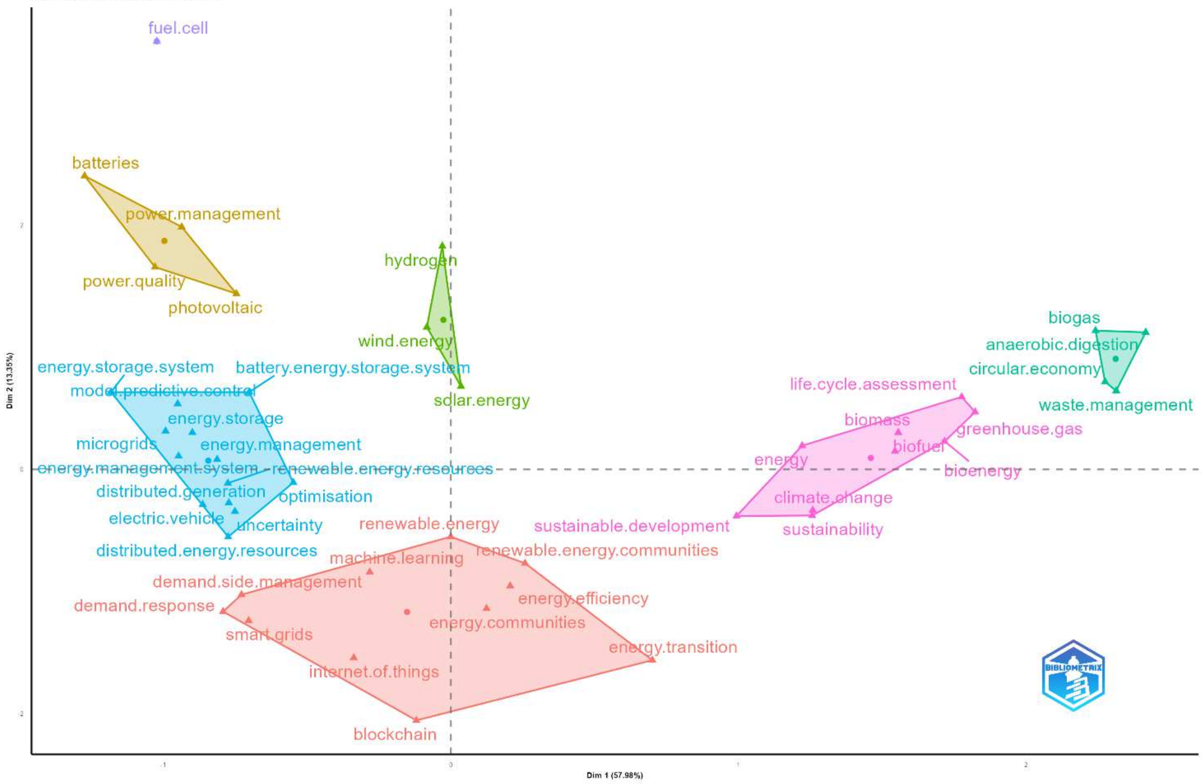


Figure 7. Fractal multidimensional analysis of the relationship between key research topics in decentralization of energy sources and their renewability

appear as emerging or declining themes, while ecosystem services, bioenergy, environmental impact, and power management remain fundamental.

The analysis suggests that microgrids and renewable energy will remain dominant while blockchain, AI, and machine learning increasingly optimize decentralized energy systems. Demand-side management and techno-economic analysis are gaining momentum, while bioenergy and sustainability continue to provide a foundational research base.

The Conceptual Structure Map (Figure 7) generated by the Biblioshiny App provides a multidimensional analysis of the relationship between key research topics in the decentralization of energy sources and their renewability. The Multiple Correspondence Analysis method clusters related concepts based on co-occurrence patterns.

The horizontal axis (Dim 1 – 57.85%) differentiates two key research perspectives: technological and operational aspects on the left, covering microgrids, energy storage, and optimization, and sustainability and energy transition on the right, focusing on climate change, bioenergy, and renewable energy communities. The vertical axis (Dim 2 – 12.35%) distinguishes between energy production and management strategies, with the upper half emphasizing energy storage, power quality, and hydrogen technologies. In contrast, the lower half focuses on digitalization, smart grids, and decentralized control mechanisms.

Several thematic clusters emerge within this framework. The Microgrid & Energy Management cluster addresses microgrids, battery storage, distributed energy, electric vehicles, and smart grids, tackling operational challenges in decentralized energy. The Digitalisation & Energy Transition cluster highlights the role of blockchain, IoT, machine learning, and demand-side management in optimizing decentralized energy solutions. The Sustainability & Environmental Impact cluster focuses on climate change, biofuels, biomass, and life cycle assessment, reflecting policy and environmental concerns. The Hydrogen & Renewable Energy cluster underscores the growing

http://dx.doi.org/10.21511/ee.16(3).2025.04

role of hydrogen, wind, and solar energy in renewable integration. The Energy Quality & Storage Solutions cluster explores batteries, power management, and photovoltaic systems, aiming to enhance grid stability. Meanwhile, the Circular Economy & Waste Management cluster examines biogas, anaerobic digestion, and circular economy principles, highlighting waste-to-energy conversion in decentralized systems.

This analysis underscores the interdisciplinary nature of decentralized renewable energy research, revealing the complex interplay between technological advancements, sustainability goals, and energy transition strategies.

4. DISCUSSION

This bibliometric analysis highlights the rapid growth of decentralized renewable energy research, particularly after 2014, driven by global policies, technological advances, and financial investments. The surge in publications and citations confirms decentralized energy systems' increasing academic and practical significance.

China, the U.S., and India lead research output, with 25% international collaboration, reflecting the global nature of the field. Core themes have shifted from bioenergy and land use to smart grids, AI-driven management, and blockchain-based energy trading, supporting findings of Chygryn et al. (2023) and Krause et al. (2024) on the role of digitalization.

Keyword analysis and thematic evolution indicate a transition from bioenergy and land use towards smart grids, AI integration, energy storage, and decentralized finance, in line with Kostyuchenko et al. (2024) and Vuichard et al. (2022). The growing occurrence of 'blockchain,' 'energy storage,' and 'AI' highlights the shift towards digital energy markets and autonomous systems.

Citation analysis shows foundational studies on microgrids and distributed energy remain influential, while newer research on blockchain, AI-driven optimization, and hydrogen energy is rapidly gaining traction, as noted by Myroshnychenko et al. (2024) and Delcea et al. (2024). China's leadership in green energy – driven by institutions such as North China Electric Power University and Tsinghua University – aligns with trends identified by Vakulenko et al. (2023).

Regulatory barriers remain a key challenge, as highlighted by Myroshnychenko et al. (2024) and Mentel et al. (2020), with policy inconsistencies hindering adoption. Sustainable finance mechanisms are essential for scaling decentralized energy, as noted by Artyukhov et al. (2024). This study underscores the need for adaptive policies to support decentralized infrastructure while ensuring economic viability.

The thematic analysis also confirms that energy democratization and decentralized finance are gaining prominence, with blockchain-based energy trading platforms enabling peer-to-peer transactions. This aligns with findings from Wüstenhagen and Menichetti (2012), who predicted the financialization of decentralized energy markets.

5. LIMITATIONS

Despite the comprehensive approach of this bibliometric analysis, several limitations must be acknowledged.

The study relies solely on Scopus, excluding research from Web of Science, IEEE Xplore, and Google Scholar, as well as non-indexed reports and policy documents, potentially omitting relevant studies. Citation analysis is time-sensitive – recent publications may be undervalued due to lower citation counts, while older works may dominate rankings despite reduced relevance.

Missing metadata in Scopus, such as author details and indexed keywords, may affect collaboration networks and keyword analyses, introducing potential biases. Automated keyword indexing may not always reflect a publication's full thematic scope, impacting co-word analysis and thematic evolution studies. Additionally, this study is based on bibliographic records rather than full-text content, limiting insights into methodologies, theoretical frameworks, and policy recommendations.

As decentralized energy and renewables evolve, trends like blockchain energy trading, AI-driven management, and smart grids are rapidly emerging. While bibliometric analysis offers a historical and quantitative perspective, it may not fully capture real-time technological advancements or policy shifts.

CONCLUSION

This study aimed to provide a comprehensive bibliometric analysis of research on the interaction between energy sources' decentralization and renewability. This study sought to identify key contributors, influential works, and emerging research directions in the field by examining publication trends, citation impact, collaboration patterns, and thematic evolution.

This study applied a bibliometric analysis using Scopus data (1973–2025), processed through Biblioshiny, to examine publication trends, citation impact, collaboration patterns, and emerging research themes. Key bibliometric laws and data visualization techniques mapped the intellectual structure of the field.

This study uncovered a strong and accelerating trajectory of research on the decentralization of energy sources and their renewability, with publication output increasing from under 100 annually in the early 2000s to over 3,700 in 2023. China leads in publication volume, followed by the United States and India, while European countries play a central role in shaping regulatory and technological discussions. A high average of 4.07 authors per paper and a 25% international collaboration rate underscore the global and cooperative nature of this research domain.

The results clearly indicate a thematic evolution in the field. Early studies on bioenergy and distributed generation laid the foundation, but recent research has pivoted toward digital technologies. Smart grids, AI-driven optimization, and blockchain-based energy trading have emerged as dominant topics, reflecting the sector's shift toward intelligent and decentralized management. Co-word analysis and thematic mapping further confirm the rising prominence of energy storage systems, hydrogen energy, demand-side management, and decentralized finance. These patterns suggest a consolidation of technological, economic, and environmental priorities under a common research agenda.

High-impact journals such as Applied Energy, Renewable Energy, and Energies serve as the main platforms for dissemination, with citation trends affirming the long-term influence of foundational work alongside the growing visibility of recent innovations. Institutional analysis shows that leading Chinese and European universities are key drivers of research output, while countries with high multiple-country publication shares, such as the UK and Germany, reinforce the value of collaborative frameworks. The field is not only expanding rapidly but also becoming increasingly multidisciplinary, offering rich opportunities for advancing sustainable and decentralized energy systems worldwide.

This study provides insights for future research, guiding scholars, policymakers, and industry stakeholders in advancing decentralized renewable energy solutions.

AUTHOR CONTRIBUTIONS

Conceptualization: Anargul Belgibayeva, Artem Artyukhov, Viera Kubičková, Miroslava Čukanová, Iuliia Myroshnychenko, Ihor Ruzhytsky, Serhiy Lyeonov.
Data curation: Serhiy Lyeonov.
Formal analysis: Serhiy Lyeonov.
Funding acquisition: Artem Artyukhov, Viera Kubičková, Miroslava Čukanová.
Investigation: Serhiy Lyeonov.
Methodology: Iuliia Myroshnychenko, Serhiy Lyeonov.

http://dx.doi.org/10.21511/ee.16(3).2025.04

Project administration: Serhiy Lyeonov.
Resources: Artem Artyukhov, Viera Kubičková, Miroslava Čukanová.
Software: Viera Kubičková, Iuliia Myroshnychenko, Serhiy Lyeonov.
Supervision: Serhiy Lyeonov.
Validation: Anargul Belgibayeva, Iuliia Myroshnychenko, Serhiy Lyeonov.
Visualization: Artem Artyukhov, Ihor Ruzhytsky, Serhiy Lyeonov.
Writing – original draft: Anargul Belgibayeva, Artem Artyukhov, Viera Kubičková, Miroslava Čukanová, Iuliia Myroshnychenko, Ihor Ruzhytsky, Serhiy Lyeonov.
Writing – review & editing: Anargul Belgibayeva, Artem Artyukhov, Viera Kubičková, Miroslava Čukanová, Iuliia Myroshnychenko, Ihor Ruzhytsky, Serhiy Lyeonov.

ACKNOWLEDGMENT

This study was prepared as part of the project IZURZ1_224119/1 (Swiss National Science Foundation).

FUNDING

The publication was funded by the project VEGA 1/0271/23 Sustainable renewal of spa tourism in the Slovak Republic in the context of the impacts of civilization crises.

REFERENCES

1. Arena, U. (2012). Process and technological aspects of municipal solid waste gasification. A review. *Waste Management, 32*(4), 625-639. https://doi.org/10.1016/j.wasman.2011.09.025
2. Artyukhov, A., Yeremenko, O., Artyukhova, N., Lapidus, A., Churikanova, O., & Bliumska-Danko, K. (2024). Investment Patterns in Diverse Economies: A Bibliometric Study of Global Transformations. *Financial Markets, Institutions and Risks, 8*(3), 163-186. https://doi.org/10.61093/fmir.8(3).163-186.2024
3. Badreddine, A., & Larbi Cherif, H. (2024). Public health improvement by reducing air pollution: A strategy for the transition to renewable energy. *Health Economics and Management Review, 5*(1), 1-14. https://doi.org/10.61093/hem.2024.1-01
4. Boyd, S., & Vandenberghe, L. (2004). *Convex Optimization*. Cambridge: Cambridge University Press. Retrieved from https://web.stanford.edu/~boyd/cvxbook/bv_cvxbook.pdf
5. Bukar, A. L., Tan, C. W., & Lau, K. Y. (2019). Optimal sizing of an autonomous photovoltaic/wind/battery/diesel generator microgrid using a grasshopper optimization algorithm. *Solar Energy, 188*, 685-696. https://doi.org/10.1016/j.solener.2019.06.050
6. Chaouachi, A., Kamel, R. M., Andoulsi, R., & Nagasaka, K. (2013). Multiobjective Intelligent Energy Management for a Microgrid. *IEEE Transactions on Industrial Electronics*, *60*(4), 1688-1699. https://doi.org/10.1109/TIE.2012.2188873
7. Chen, C.-Y., Yeh, K.-L., Aisyah, R., Lee, D.-J., & Chang, J.-S. (2011). Cultivation, photobioreactor design and harvesting of microalgae for biodiesel production: A critical review. *Bioresource Technology, 102*(1), 71-81. https://doi.org/10.1016/j.biortech.2010.06.159
8. Chygryn, O., Bektas, C., & Havrylenko, O. (2023). Innovation and Management of Smart Transformation Global Energy Sector: Systematic Literature Review. *Business Ethics and Leadership, 7*(1), 105-112. https://doi.org/10.21272/bel.7(1).105-112.2023
9. Clarens, A. F., Resurreccion, E. P., White, M. A., & Colosi, L. M. (2010). Environmental Life Cycle Comparison of Algae to Other Bioenergy Feedstocks. *Environmental Science & Technology, 44*(5), 1813-1819. https://doi.org/10.1021/es902838n
10. Crawley, D. B., Hand, J. W., Kummert, M., & Griffith, B. T. (2008). Contrasting the capabilities of building energy performance simulation programs. *Building and Environment, 43*(4), 661-673. https://doi.org/10.1016/j.buildenv.2006.10.027
11. De Moraes e Soares, R., Morais Nunes, A., Pinheiro, P., Catarina Kaizeler, A., & Martins, V. (2024). Asymmetries in energy consumption: Efficiency of public spending across Portuguese municipalities. *Public and Municipal Finance, 13*(2), 110-128. https://doi.org/10.21511/pmf.13(2).2024.10
12. Delcea, C., Oprea, S.-V., Dima, A. M., Domenteanu, A., Bara, A., & Cotfas, L.-A. (2024). Energy communities: Insights from scientific publications. *Oeconomia Copernicana, 15*(3), 1101-1155. https://doi.org/10.24136/oc.3137
13. Dobrovolska, O., Schmidtke, K., Krause, J., Matukhno, O., & Cierjacks, A. (2024). Effectiveness of

reforms to eliminate obstacles in the development of sustainable energy in different countries of the world. *Problems and Perspectives in Management, 22*(3), 1-13. https://doi.org/10.21511/ppm.22(3).2024.01

14. Dragicevic, T., Guerrero, J. M., Vasquez, J. C., & Skrlec, D. (2014). Supervisory Control of an Adaptive-Droop Regulated DC Microgrid with Battery Management Capability. *IEEE Transactions on Power Electronics, 29*(2), 695-706. https://doi.org/10.1109/tpel.2013.2257857
15. Fairhead, J., Leach, M., & Scoones, I. (2012). Green Grabbing: a new appropriation of nature? *Journal of Peasant Studies, 39*(2), 237-261. https://doi.org/10.1080/03066150.2012.671770
16. Firstová, J., & Vysochyna, A. (2024). Optimisation of socio-economic, environmental and public health determinants of national security for post-pandemic recovery. *Health Economics and Management Review, 5*(1), 67-79. https://doi.org/10.61093/hem.2024.1-05
17. Halynskyi, D., & Telizhenko, O. (2024). Fair Business Leadership: Is Protecting Minority Investors Important to the Development of Start-Ups in Clean and Digital Energy?. *Business Ethics and Leadership, 8*(4), 57-68. https://doi.org/10.61093/bel.8(4).57-68.2024
18. He, Y., Chen, W., Li, X., Zhang, Z., Fu, J., Zhao, C., & Xie, E. (2012). Freestanding Three-Dimensional Graphene/MnO2 Composite Networks As Ultralight and Flexible Supercapacitor Electrodes. *ACS Nano, 7*(1), 174-182. https://doi.org/10.1021/nn304833s
19. Huang, A. Q., Crow, M. L., Heydt, G. T., Zheng, J. P., & Dale, S. J. (2011). The Future Renewable Electric Energy Delivery and Management (FREEDM) System: The Energy Internet. *Proceedings of the IEEE, 99*(1), 133-148. https://doi.org/10.1109/jproc.2010.2081330
20. Juracka, D., Valaskova, K., & Nica, E. (2024). Sustainable public policy instruments: revealing global interest in circular economy and eco-innovations. *Administratie si Management Public, 43*(43), 6-24. https://doi.org/10.24818/amp/2024.43-01
21. Kanchev, H., Lu, D., Colas, F., Lazarov, V., & Francois, B. (2011). Energy Management and Operational Planning of a Microgrid with a PV-Based Active Generator for Smart Grid Applications. *IEEE Transactions on Industrial Electronics, 58*(10), 4583-4592. https://doi.org/10.1109/tie.2011.2119451
22. Koilo, V. (2024). Macroeconomic and energy impacts of Russia's invasion of Ukraine: A comparative analysis across countries. *Geopolitics under Globalization, 5*(1), 19-34. https://doi.org/10.21511/gg.05(1).2024.02
23. Kostyuchenko, N., Reidl, K., & Wüstenhagen, R. (2024). Does citizen participation improve acceptance of a Green Deal? Evidence from choice experiments in Ukraine and Switzerland. *Energy Policy, 189*, 114106. https://doi.org/10.1016/j.enpol.2024.114106
24. Krause J., Myroshnychenko, I., Tiutiunyk, S., & Latysh, D. (2024). Financial Instruments of the Green Energy Transition: Research Landscape Analysis. *Financial Markets, Institutions and Risks, 8*(2), 198-212. https://doi.org/10.61093/fmir.8(2).198-212.2024
25. Kundur, P. (2007). *Power system stability and control*, McGraw-Hill Inc. https://dl.poweren.ir/downloads/PowerEn/Book/2019/Jun/Power%20System%20Stability%20and%20Control%20-%20Prabha%20Kundur%20%28PowerEn.ir%29.pdf
26. Lewandowski, I., Scurlock, J. M. O., Lindvall, E., & Christou, M. (2003). The development and current status of perennial rhizomatous grasses as energy crops in the US and Europe. *Biomass and Bioenergy, 25*(4), 335-361. https://doi.org/10.1016/S0961-9534(03)00030-8
27. Lyeonov, S. (2025). *Search query in Scopus database*. Zenodo. Retrieved from https://zenodo.org/uploads/14989530
28. Makarenko, I., Bilan, Y., Streimikiene, D., & Rybina, L. (2023). Investments support for Sustainable Development Goal 7: Research gaps in the context of post-COVID-19 recovery. *Investment Management and Financial Innovations, 20*(1), 151-173. https://doi.org/10.21511/imfi.20(1).2023.14
29. Matvieieva, Yu., Sulym, V., Rosokhata, A., & Jasnikowski, A. (2023). Influence of Waste Incineration and Obtaining Energy from it to the Public Health for Certain Territories: A Bibliometric and Substantive Study. *Health Economics and Management Review, 4*(1), 71-80. https://doi.org/10.21272/hem.2023.1-07
30. Mentel, G., Vasilyeva, T., Samusevych, Y., Vysochyna, A., Karbach, R., & Streimikis, J. (2020). The evaluation of economic, environmental and energy security: composite approach. *International Journal of Global Environmental Issues, 19*(1-3), 177-195. https://doi.org/10.1504/ijgenvi.2020.10037581
31. Merabet, A., Tawfique Ahmed, K., Ibrahim, H., Beguenane, R., & Ghias, A. M. Y. M. (2017). Energy Management and Control System for Laboratory Scale Microgrid Based Wind-PV-Battery. *IEEE Transactions on Sustainable Energy, 8*(1), 145-154. https://doi.org/10.1109/TSTE.2016.2587828
32. Moghaddam, A. A., Seifi, A., Niknam, T., & Alizadeh Pahlavani, M. R. (2011). Multi-objective operation management of a renewable MG (micro-grid) with back-up micro-turbine/fuel cell/battery hybrid power source. *Energy, 36*(11), 6490-6507. https://doi.org/10.1016/j.energy.2011.09.017
33. Moroz, A., & Lyeonov, S. (2024). Stimulating Financial-Fiscal Instruments of Supporting Development of Renewable Energy Sources: Bibliometric Analysis. *Financial Markets, Institutions and Risks, 8*(4), 179-203. https://doi.org/10.61093/fmir.8(4).179-203.2024
34. Mukhtarov, S., Aliyev, J., Borowski, P. F., & Disli, M. (2023). Institutional quality and renewable energy transition: Empirical evidence from Poland. *Journal of International Studies, 16*(3), 208-218. https://doi.org/10.14254/2071-8330.2023/16-3/12
35. Myroshnychenko, I., Podosynnikov, S., Halynskyi, D., Ushkalov, M., & Chuhai, O. (2024). Regulatory Barriers for Entrepreneurship and Start-Ups in Renewable

Energy: Bibliometric Analysis. *SocioEconomic Challenges, 8*(3), 181-210. https://doi.org/10.61093/sec.8(3).181-210.2024

36. Nihal, A., Areche, F. O., López, J. M. M., Araujo, V. G. o. S., Cárdenas, J. A. L., & Ober, J. (2024). Synergistic evaluation of energy security and environmental sustainability in BRICS geo-political entities: An integrated index framework. *Equilibrium. Quarterly Journal of Economics and Economic Policy, 19*(3), 793-839. https://doi.org/10.24136/eq.3088
37. Niknam, T., Azizipanah-Abarghooee, R., & Narimani, M. R. (2012). An efficient scenario-based stochastic programming framework for multi-objective optimal micro-grid operation. *Applied Energy, 99,* 455-470. https://doi.org/10.1016/j.apenergy.2012.04.017
38. Olzhebayeva, G., Buldybayev T., Pavalkis D., Kireyeva, A., & Micekiene, A. (2023). Is there interest in green deal research in Central Asia? *Economics and Sociology, 16*(3), 302-322. https://doi.org/10.14254/2071-789X.2023/16-3/16
39. Palma-Behnke, R., Benavides, C., Lanas, F., Severino, B., Reyes, L., Llanos, J., & Saez, D. (2013). A Microgrid Energy Management System Based on the Rolling Horizon Strategy. *IEEE Transactions on Smart Grid, 4*(2), 996-1006. https://doi.org/10.1109/tsg.2012.2231440
40. Patton Jr. J. A., Fife P. K., Yelverton Ch. A., Slosson J. E., Hauge C. J., Spangle W. E., Mader G. G., Leighton F. B., Zion W. R., Henderson R., & Heath E. G. (1973). Geology, seismicity, and environmental impact. *Proceedings of the 16th Annual Meeting of the Association of Engineering Geologists in Hollywood,* October 1973. California. Retrieved from https://scispace.com/pdf/seismic-safety-guide-3j18b23rag.pdf
41. Prengaman, P. (2024). *Ukraine has seen success in building clean energy, which is harder for Russia to destroy*. AP News. Retrieved from https://apnews.com/article/ukraine-clean-renewable-energy-russian-bombing-distributed-1f226213742c-c057f9f65208167e6f38
42. Ray, D. K., Ramankutty, N., Mueller, N. D., West, P. C., & Foley, J. A. (2021). Recent patterns of crop yield growth and stagnation. *Nature Communications, 3*(1), 1293. https://doi.org/10.1038/ncomms2296
43. Roberts, K. G., Gloy, B. A., Joseph, S., Scott, N. R., & Lehmann, J. (2010). Life Cycle Assessment of Biochar Systems: Estimating the Energetic, Economic, and Climate Change Potential. *Environmental Science & Technology, 44*(2), 827-83. https://doi.org/10.1021/es902266r
44. Sedmíková, E., Vasylieva, T., Tiutiunyk, I., & Navickas, M. (2021). Energy Consumption in Assessment of the Shadow Economy. *European Journal of Interdisciplinary Studies, 13*(2), 47-64. Retrieved from https://ejist.ro/files/pdf/475.pdf
45. Sotnyk, I., Kurbatova, T., Trypolska, G., Sokhan, I., & Koshel, V. (2023). Research trends on development of energy efficiency and renewable energy in households: A bibliometric analysis. *Environmental Economics, 14*(2), 13-27. https://doi.org/10.21511/ee.14(2).2023.02
46. Štreimikienė, D. (2024). Renewable energy penetration in Nordic and Baltic countries of the EU. *Journal of International Studies, 17*(1), 97-107. https://doi.org/10.14254/2071-8330.2024/17-1/6
47. Streimikiene, D., Mikalauskas, I., Lėckienė, V., Pisula, T., & Mikalauskiene, A. (2024). The role of sustainable finance in the context of the European green course. *Economics and Sociology, 17*(1), 54-79. https://doi.org/10.14254/2071-789X.2024/17-2/3
48. Uddin, G. S., Abdullah-Al-Baki, C., Donghyun, P., Ahmed, A., & Shu, T. (2023). Social benefits of solar energy: Evidence from Bangladesh. *Oeconomia Copernicana, 14*(3), 861-897. https://doi.org/10.24136/oc.2023.026
49. Vakulenko, I., Saher, L., & Shymoshenko, A. (2023). Systematic literature review of carbon-neutral economy concept. *SocioEconomic Challenges, 7*(1), 139-148. https://doi.org/10.21272/sec.7(1).139-148.2023
50. Vasa, L., Kubatko, O., Sotnyk, I., Piven, V., Trypolska, G., & Pysmenna, U. (2024). Economic and environmental drivers of renewable energy transition in the EU. *Environmental Economics, 15*(2), 232-245. https://doi.org/10.21511/ee.15(2).2024.16
51. Vuichard, P., Broughel, A., Wüstenhagen, R., Tabi, A., & Knauf, J. (2022). Keep it local and bird-friendly: Exploring the social acceptance of wind energy in Switzerland, Estonia, and Ukraine. *Energy Research & Social Science, 88,* 102508. https://doi.org/10.1016/j.erss.2022.102508
52. Walker, G., & Devine-Wright, P. (2008). Community renewable energy: What should it mean? *Energy Policy, 36*(2), 497-500. https://doi.org/10.1016/j.enpol.2007.10.019
53. Wołowiec, T., Kolosok, S., Vasylieva, T., Artyukhov, A., Skowron, Ł., Dluhopolskyi, O., & Sergiienko, L. (2022). Sustainable Governance, Energy Security, and Energy Losses of Europe in Turbulent Times. *Energies, 15*(23), 8857. https://doi.org/10.3390/en15238857
54. Wüstenhagen, R., & Menichetti, E. (2012). Strategic choices for renewable energy investment: Conceptual framework and opportunities for further research. *Energy Policy, 40,* 1-10. https://doi.org/10.1016/j.enpol.2011.06.050
55. Zhang, Y., Gatsis, N., & Giannakis, G. B. (2013). Robust Energy Management for Microgrids with High-Penetration Renewables. *IEEE Transactions on Sustainable Energy, 4*(4), 944-953. https://doi.org/10.1109/tste.2013.2255135
56. Ziabina, Y., Iskakov, A., & Senyah, M. M. (2023). Waste management system: key determinants of green development and energy balance transformation. *SocioEconomic Challenges, 7*(2), 161-172. https://doi.org/10.21272/sec.7(2).161-172.2023

APPENDIX A

Table A1. Key bibliometric indicators for top academic journals publishing research on decentralization and renewable energy sources

Source: Authors' evaluations in the Biblioshiny App.

Source	h_index	g_index	m_index	TC	NP	PY_start
Applied Energy	89	134	2.342	31,156	631	1988
Energy	88	129	1.796	25,814	521	1977
IEEE Transactions on Smart Grid	79	137	4.938	20,079	231	2010
Energy Conversion and Management	72	108	1.565	14,790	259	1980
Renewable Energy	71	111	2.088	17,412	404	1992
Energy Policy	70	125	2.188	17,452	247	1994
Journal Of Cleaner Production	64	93	2.462	14,934	375	2000
Bioresource Technology	63	106	1.8	13,551	213	1991
Biomass And Bioenergy	60	109	1.765	13,973	244	1992
Waste Management	58	94	2.071	10,707	202	1998
IEEE Access	55	83	5.5	10,397	402	2016
Science of the Total Environment	53	76	2.789	8,418	249	2007
Energies	51	73	3.4	14,920	904	2011
International Journal of Electrical Power and Energy Systems	47	79	2.35	7,449	188	2006
Journal of Environmental Management	46	77	1.586	7,612	237	1997
Environmental Science and Technology	44	97	1.63	9,483	102	1999
IEEE Transactions on Power Systems	43	77	1.344	6,018	86	1994
Water Research	43	74	1.075	5,735	98	1986
Resources, Conservation and Recycling	42	69	1.167	5,343	116	1990
IEEE Transactions on Sustainable Energy	41	78	2.733	6,140	89	2011
IEEE Transactions on Industry Applications	40	67	2.353	4,794	117	2009
Sustainable Cities and Society	39	60	2.786	4,475	141	2012
International Journal of Hydrogen Energy	38	71	0.884	5,534	141	1983
Journal of Energy Storage	37	54	3.364	4,326	233	2015
Renewable And Sustainable Energy Reviews	37	65	1.276	4,539	111	1997
Sustainability (Switzerland)	37	53	3.083	5,245	312	2014
IEEE Transactions on Industrial Informatics	36	64	2.571	4,184	79	2012
Energy And Buildings	35	61	1.591	3,949	94	2004
Water Science and Technology	34	56	0.773	3,635	114	1982
Solar Energy	32	61	0.711	3,881	89	1981
Sustainable Energy Technologies and Assessments	31	50	2.385	3,052	109	2013
Energy Reports	30	40	2.727	2,794	177	2015
GCB Bioenergy	30	51	1.875	2,997	94	2010
International Journal of Life Cycle Assessment	30	52	1.579	2,715	60	2007

Note: h-index – Hirsch Index, measures a journal's impact based on the number of highly cited articles; g-index – accounts for overall citation performance, giving more weight to highly cited papers; m-index – adjusts the h-index based on the years since first publication, showing the growth rate of a journal's impact; TC (Total Citations) – the cumulative number of citations received by articles in the journal; NP (Number of Papers) – the number of papers published in this research domain; PY_start – the year when the journal started publishing research on the decentralization of energy sources and their renewability during.

http://dx.doi.org/10.21511/ee.16(3).2025.04

Table A2. Key bibliometric indicators for the most influential authors in decentralization and renewable energy research

Source: Authors' evaluations in the Biblioshiny App.

Author	h_index	g_index	m_index	TC	NP	PY_start
Zhang Y.	47	87	2.765	8,750	265	2009
Liu Y.	43	75	2.15	6,530	235	2006
Wang X.	41	63	1.952	4,783	200	2005
Wang J.	39	68	1.95	5,224	192	2006
Liu J.	38	65	1.9	4,628	175	2006
Wang Y.	37	63	1.682	4,975	222	2004
Guerrero J.M.	36	75	2.25	5,759	108	2010
Li Y.	35	69	2.059	5,409	223	2009
Wang H.	35	68	2.188	5,013	168	2010
Wang Z.	35	58	1.296	3,788	153	1999
Li Z.	34	64	1.619	4,311	134	2005
Li J.	31	53	1.292	3,212	152	2002
Wang S.	30	61	1.5	3,912	107	2006
Zhang L.	30	50	1.765	2,693	103	2009
Liu Z.	29	49	1.611	2,602	101	2008
Wang C.	29	52	1.45	2,837	94	2006
Zhang X.	29	54	1.611	3,464	166	2008
Liu X.	28	54	1.867	3,097	121	2011
Wang L.	28	52	1.474	3,073	133	2007
Zhang J.	28	47	1.867	2,427	134	2011
Zhou Y.	28	48	1.75	2,577	108	2010
Li X.	27	62	1.35	4,161	152	2006
Chen Y.	26	49	1.444	2,660	140	2008
Li H.	26	49	1.368	2,638	131	2007
Wang B.	26	53	1.182	2,903	75	2004
Xu Y.	26	53	1.625	2,958	96	2010
Li C.	25	49	1.667	2,538	86	2011
Wu Y.	25	52	1.786	2,763	78	2012

Note: h-index – Hirsch Index, a measure of an author's research impact, where a value of *h* means the author has *h* papers cited at least *h* times; g-index – a variation of the h-index that gives more weight to highly cited papers; m-index – the h-index normalized by the number of years since the author's first publication, showing research impact growth; TC (Total Citations) – the total number of citations received by the author's publications; NP (Number of Papers) – the total number of papers published by the author; PY_start – the year of the author's first publication in this domain.

Table A3. List of institutions with 100 or more publications related to the decentralization of energy sources and their renewability

Source: Authors' evaluations in the Biblioshiny App.

Affiliation	Articles	Affiliation	Articles
North China Electric Power University	589	Hunan University	139
Tsinghua University	560	University of Cagliari	139
Not reported	492	Beijing Normal University	135
Islamic Azad University	421	University of São Paulo	132
Aalborg University	399	University of Tehran	130
Shanghai Jiao Tong University	393	Sapienza University of Rome	129
Zhejiang University	336	Tongji University	129
Southeast University	284	Chalmers University of Technology	128
Huazhong University of Science and Technology	279	University of Minnesota	125
Tianjin University	277	Aalto University	124
Technical University of Denmark	264	Aristotle University of Thessaloniki	121
Xi'an Jiaotong University	259	University of New South Wales	120
South China University of Technology	230	University of Florida	119
Nanyang Technological University	225	Cornell University	116
University Of California	221	Guangdong University of Technology	116

Table A3 (cont.). List of institutions with 100 or more publications related to the decentralization of energy sources and their renewability

Affiliation	Articles	Affiliation	Articles
Sichuan University	219	Utrecht University	116
Beijing	211	Northeastern University	115
Wuhan University	210	Indian Institute of Technology	114
Politecnico Di Milano	199	Swedish University of Agricultural Sciences	111
Delft University of Technology	197	University of Padova	111
National Institute of Technology	192	King Abdulaziz University	110
Shandong University	189	Ghent University	109
Department of Electrical Engineering	188	Peking University	109
National Technical University of Athens	185	RWTH Aachen University	109
Politecnico Di Torino	175	University of Engineering and Technology	109
University of Tabriz	167	Iran University of Science and Technology	108
China Agricultural University	166	University of Bologna	108
National University of Singapore	166	University Of Naples Federico II	108
The Hong Kong Polytechnic University	165	North Carolina State University	106
Chongqing University	161	National Renewable Energy Laboratory	104
Michigan State University	145	Lund University	103
Hohai University	143	Universiti Teknologi Malaysia	101
Riga Technical University	143	Eindhoven University of Technology	100
University of Genoa	141	University of Science and Technology of China	100

Table A4. Most active countries in research output on the decentralization of energy sources and their renewability

Source: Authors' evaluations in the Biblioshiny App.

Country	Articles	Articles, %	SCP	MCP	MCP, %
China	3,373	11.7	2,467	906	26.9
USA	1,865	6.5	1,507	358	19.2
India	1,650	5.7	1,422	228	13.8
Italy	1,207	4.2	937	270	22.4
Germany	805	2.8	592	213	26.5
United Kingdom	668	2.3	409	259	38.8
Spain	631	2.2	419	212	33.6
Iran	610	2.1	404	206	33.8
Australia	468	1.6	313	155	33.1
Canada	463	1.6	318	145	31.3
Brazil	412	1.4	286	126	30.6
France	388	1.3	248	140	36.1
Japan	351	1.2	263	88	25.1
Korea	325	1.1	237	88	27.1
Netherlands	292	1	183	109	37.3
Sweden	274	1	182	92	33.6
Portugal	273	0.9	182	91	33.3
Greece	267	0.9	200	67	25.1
Turkey	263	0.9	220	43	16.3
Poland	261	0.9	208	53	20.3
Finland	216	0.8	129	87	40.3
Denmark	214	0.7	132	82	38.3
Malaysia	185	0.6	109	76	41.1
Saudi Arabia	179	0.6	83	96	53.6
Austria	173	0.6	107	66	38.2
Morocco	169	0.6	139	30	17.8
Egypt	160	0.6	94	66	41.3
Pakistan	158	0.5	70	88	55.7
Switzerland	156	0.5	99	57	36.5
Belgium	147	0.5	100	47	32

http://dx.doi.org/10.21511/ee.16(3).2025.04

Table A4 (cont.). Most active countries in research output on the decentralization of energy sources and their renewability

Country	Articles	Articles, %	SCP	MCP	MCP, %
Mexico	146	0.5	116	30	20.5
Norway	143	0.5	82	61	42.7
South Africa	140	0.5	90	50	35.7
Thailand	137	0.5	101	36	26.3
Indonesia	135	0.5	111	24	17.8
Algeria	126	0.4	70	56	44.4
Romania	108	0.4	79	29	26.9

Note: Articles, % – share of articles affiliated to this country; SCP – single country publications; MCP – multiple country publications; MCP, % – share of multiple country publications in the whole number of published articles.

Table A5. Top 10 most globally cited documents focus on the decentralization of energy sources and their renewability

Source: Authors' evaluations in the Biblioshiny App.

Title	Author (s)	Source	Year	DOI	TC	TCpY	NTC
The Future Renewable Electric Energy Delivery and Management (FREEDM) System: The Energy Internet	Huang, A. Q., Crow, M. L., Heydt, G. T., Zheng, J. P., Dale, S. J.	*Proceedings of the IEEE, 99*(1), 133-148	2011	10.1109/ JPROC.2010.2081330	1,560	104.00	33.72
Cultivation, photobioreactor design and harvesting of microalgae for biodiesel production: A critical review	Chen, C.-Y., Yeh, K.-L., Aisyah, R., Lee, D.-J., Chang, J.-S.	*Bioresource Technology, 102*(1), 71-81	2011	10.1016/j. biortech.2010.06.159	1,555	103.67	33.61
Freestanding Three-Dimensional Graphene/MnO2 Composite Networks as Ultralight and Flexible Supercapacitor Electrodes	He, Y., Chen, W., Li, X., Zhang, Z., Fu, J., Zhao, C., Xie, E.	*ACS Nano, 7*(1), 174-182	2012	10.1021/nn304833s	1,367	105.15	39.78
Green Grabbing: a new appropriation of nature?	Fairhead, J., Leach, M., Scoones, I.	*Journal of Peasant Studies, 39*(2), 237-261	2012	10.1080 /03066150.2012.671770	1,366	97.57	36.90
Contrasting the capabilities of building energy performance simulation programs	Crawley, D. B., Hand, J. W., Kummert, M., Griffith, B. T.	*Building and Environment, 43*(4), 661-673	2008	10.1016/j. buildenv.2006.10.027	1,252	69.56	24.84
Recent patterns of crop yield growth and stagnation	Ray, D. K., Ramankutty, N., Mueller, N. D., West, P. C., Foley, J. A.	*Nature Communications, 3*(1)	2012	10.1038/ncomms2296	1,199	85.64	32.39
The development and current status of perennial rhizomatous grasses as energy crops in the US and Europe	Lewandowski, I., Scurlock, J. M. O., Lindvall, E., Christou, M.	*Biomass and Bioenergy, 25*(4), 335-361	2003	10.1016/ S0961-9534(03)00030-8	1,170	50.87	25.31
Process and technological aspects of municipal solid waste gasification. A review	Arena, U.	*Waste Management, 32*(4), 625-639	2012	10.1016/j. wasman.2011.09.025	1,039	74.21	28.07
Environmental Life Cycle Comparison of Algae to Other Bioenergy Feedstocks	Clarens, A. F., Resurreccion, E. P., White, M. A., Colosi, L. M.	*Environmental Science & Technology, 44*(5), 1813-1819	2010	10.1021/es902838n	946	59.13	22.68
Life Cycle Assessment of Biochar Systems: Estimating the Energetic, Economic, and Climate Change Potential	Roberts, K. G., Gloy, B. A., Joseph, S., Scott, N. R., Lehmann, J.	*Environmental Science & Technology, 44*(2), 827-833	2010	10.1021/es902266r	900	56.25	21.58

Note: TC – total citations of the documents; TCpY – The yearly citation rate, indicating the impact and relevance over time; NTC – normalized total citations (adjusted citation count for cross-comparison).

Table A6. Top 10 most locally cited documents focus on the decentralization of energy sources and their renewability

Source: Authors' evaluations in the Biblioshiny App.

Document	Authors	Source	DOI	Year	LC	GC	LC/GC	NLC	NGC
A Microgrid Energy Management System Based on the Rolling Horizon Strategy	Palma-Behnke, R., Benavides, C., Lanas, F., Severino, B., Reyes, L., Llanos, J., Saez, D.	*IEEE Transactions on Smart Grid, 4*(2), 996-1006	10.1109/TSG.2012.2231440	2013	160	673	23,77	94,33	19,58
Robust Energy Management for Microgrids with High-Penetration Renewables	Zhang, Y., Gatsis, N., Giannakis, G.B.	*IEEE Transactions on Sustainable Energy, 4*(4), 944-953	10.1109/TSTE.2013.2255135	2013	138	664	20,78	81,36	19,32
Energy Management and Operational Planning of a Microgrid With a PV-Based Active Generator for Smart Grid Applications	Kanchev, H., Lu, D., Colas, F., Lazarov, V., Francois, B.	*IEEE Transactions on Industrial Electronics, 58*(10), 4583-4592	10.1109/TIE.2011.2119451	2011	132	899	14,68	68,14	19,43
Multi-objective operation management of a renewable MG (micro-grid) with back-up micro-turbine/fuel cell/battery hybrid power source.	Moghaddam, A. A., Seifi, A., Niknam, T., Alizadeh Pahlavani, M. R.	*Energy, 36*(11), 6490-6507	10.1016/j.energy.2011.09.017	2011	128	544	23,53	66,07	11,76
Community renewable energy: What should it mean?	Walker, G., Devine-Wright, P.	*Energy Policy, 36*(2), 497-500	10.1016/j.enpol.2007.10.019	2008	111	720	15,42	108,63	14,29
Multiobjective Intelligent Energy Management for a Microgrid	Chaouachi, A., Kamel, R. M., Andoulsi, R., Nagasaka, K.	*IEEE Transactions on Industrial Electronics, 60*(4), 1688-1699	10.1109/TIE.2012.2188873	2013	96	582	16,49	56,60	16,93
Energy Management and Control System for Laboratory Scale Microgrid Based Wind-PV-Battery	Merabet, A., Tawfique Ahmed, K., Ibrahim, H., Beguenane, R., Ghias, A. M. Y. M.	*IEEE Transactions on Sustainable Energy, 8*(1), 145-154	10.1109/TSTE.2016.2587828	2017	82	377	21,75	50,66	13,15
Supervisory Control of an Adaptive-Droop Regulated DC Microgrid With Battery Management Capability	Dragicevic, T., Guerrero, J. M., Vasquez, J. C., Skrlec, D.	*IEEE Transactions on Power Electronics, 29*(2), 695-706	10.1109/TPEL.2013.2257857	2014	76	756	10,05	39,40	20,44
Optimal sizing of an autonomous photovoltaic/wind/battery/diesel generator microgrid using grasshopper optimization algorithm	Bukar, A. L., Tan, C. W., Lau, K. Y.	*Solar Energy, 188,* 685-696	10.1016/j.solener.2019.06.050	2019	76	365	20,82	59,06	15,01
An efficient scenario-based stochastic programming framework for multi-objective optimal micro-grid operation	Niknam, T., Azizipanah-Abarghooee, R., Narimani, M. R	*Applied Energy, 99,* 455-470	10.1016/j.apenergy.2012.04.017	2012	68	387	17,57	42,90	10,45

Note: LC – local citations; GC – global citation; LC/GC – local citations to global citation ratio (%); NLC – Normalized Local Citations; NGC– Normalized Global Citations.

http://dx.doi.org/10.21511/ee.16(3).2025.04

APPENDIX B

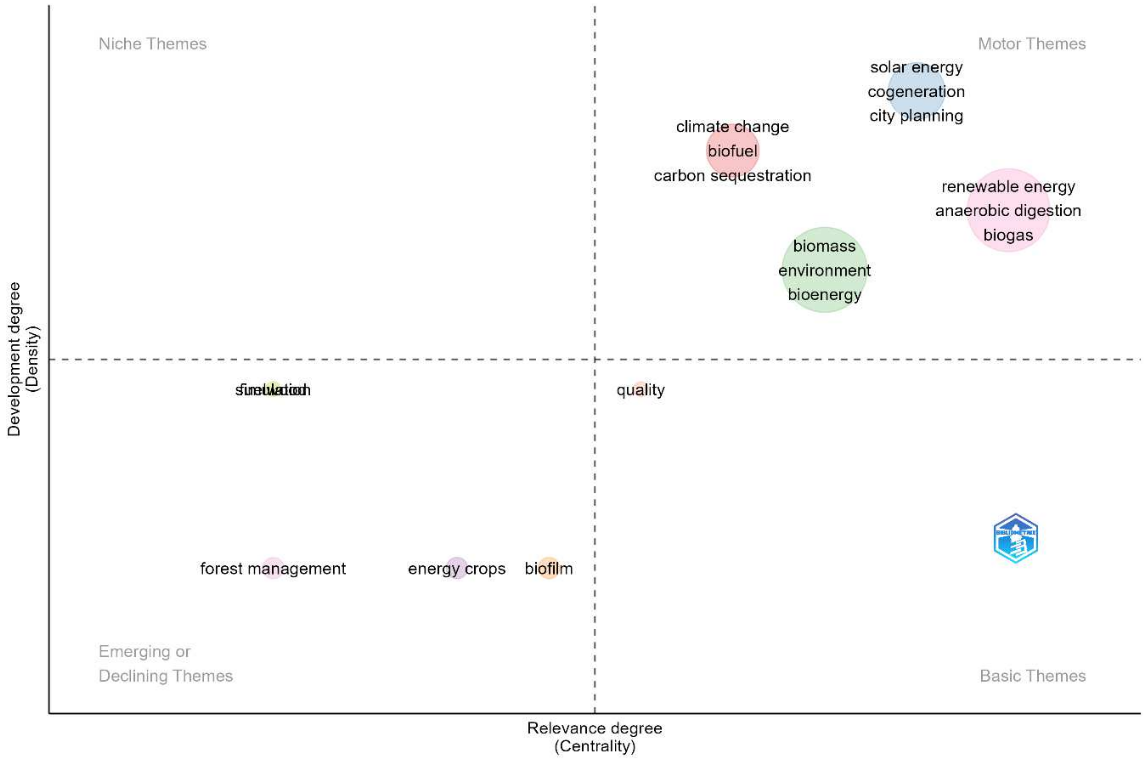


Figure B1. Thematic map of key research themes related to the decentralization of energy sources and their renewability during 1973–2000

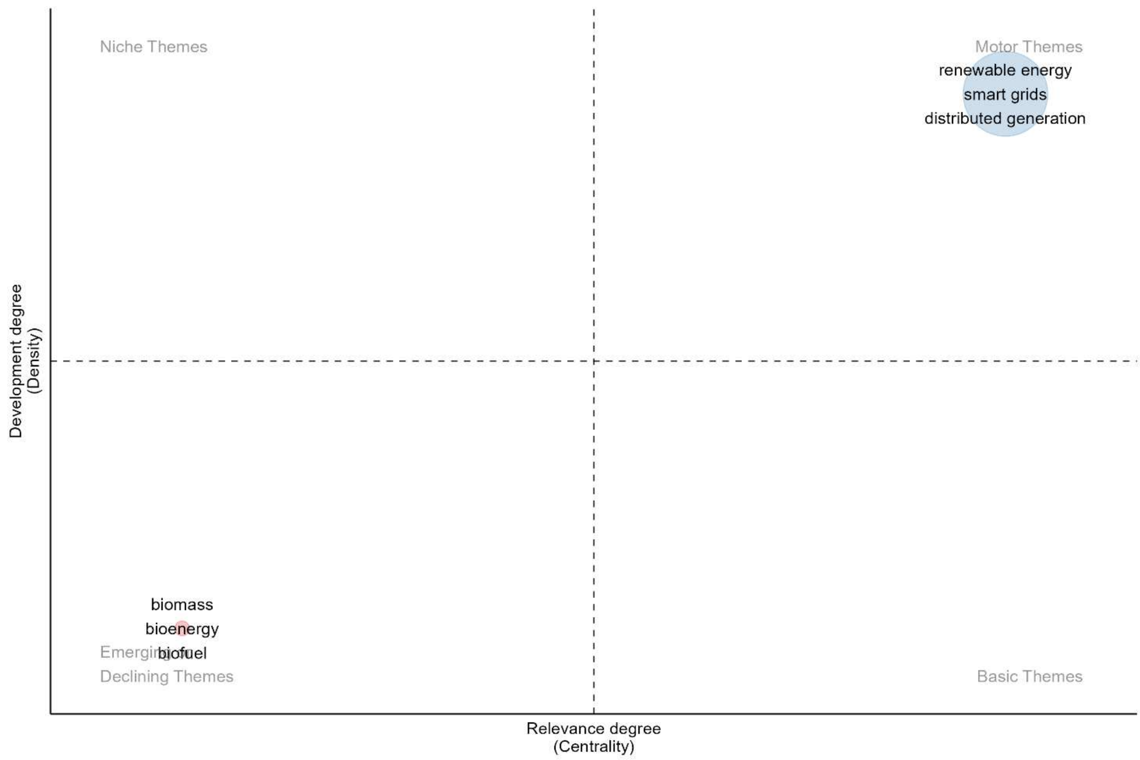


Figure B2. Thematic map of key research themes related to the decentralization of energy sources and their renewability during 2001–2013

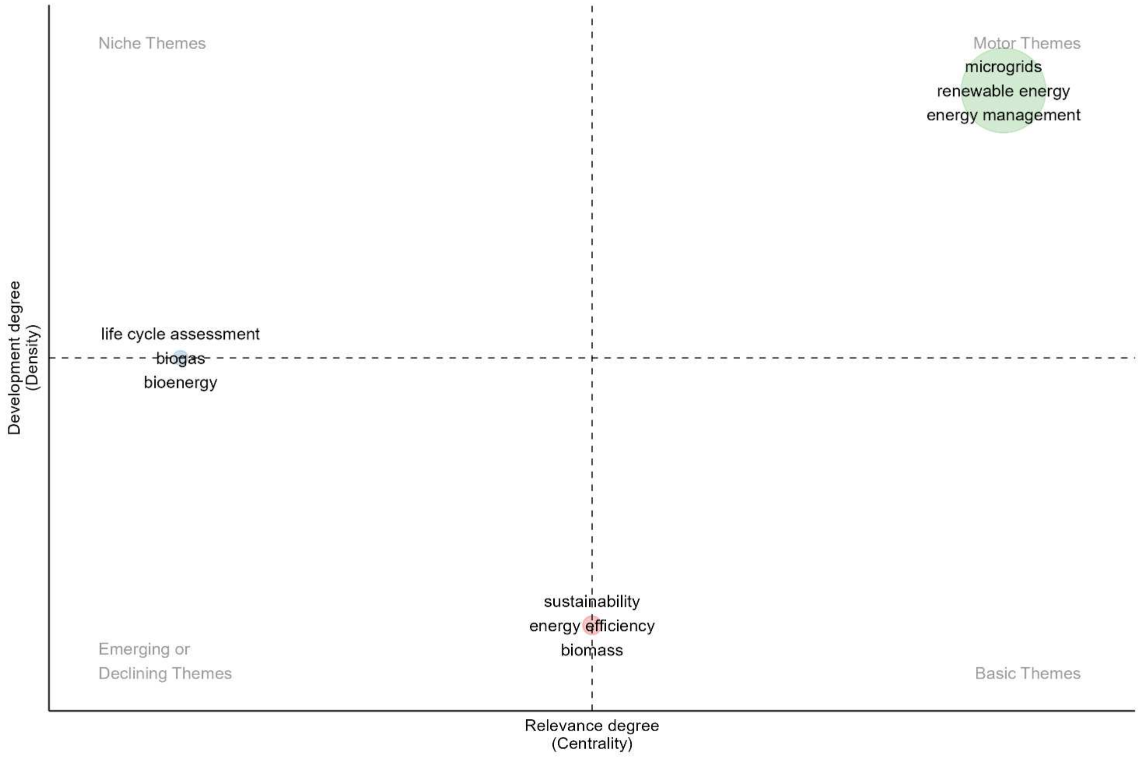


Figure B3. Thematic map of key research themes related to the decentralization of energy sources and their renewability during 2014–2024

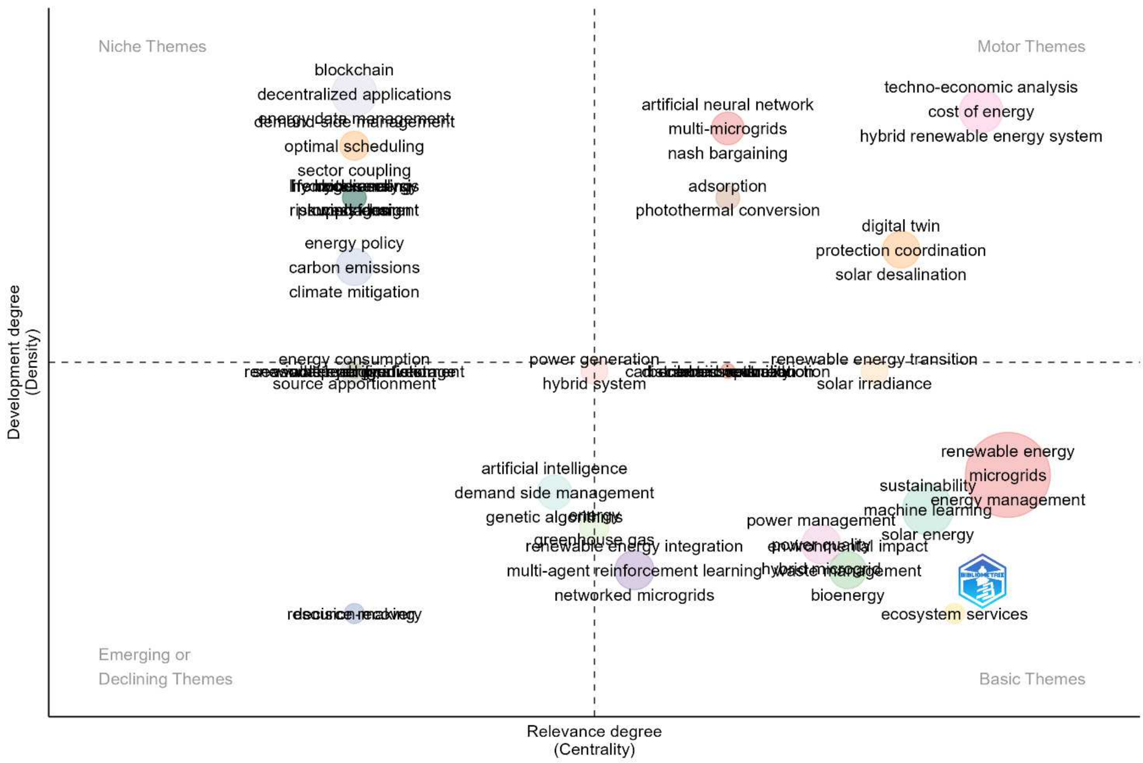


Figure B4. Thematic map of key research themes related to the decentralization of energy sources and their renewability during 2025–2025

http://dx.doi.org/10.21511/ee.16(3).2025.04