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The dynamics of energy communities and innovative cooperatives: Mapping current knowledge and future trends

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ABSTRACT

Cooperative forms of organization have led to major advances in energy use in the last decade. A common cooperative form in the energy sector is that of energy communities. These energy communities produce, distribute, and consume their own sustainable energy. To explore this cooperative structure and create knowledge on the topic, this study presents a comprehensive bibliometric analysis of the scientific literature on energy communities and cooperatives. Using bibliographic coupling, co-citation analysis, and keyword co-occurrence, the analysis identifies key themes and interconnections in this research field. The findings reveal major focus areas and key characteristics, including renewable energy, community energy, energy transition, policy, participation, governance, and innovation. The study highlights the importance of integrating technological innovation, community involvement, and cooperative models to advance sustainable energy systems in energy communities. Finally, this study makes a unique contribution through its holistic mapping of the research landscape. It thus provides an original synthesis of key themes and gaps in the literature. The proposal of seven future research directions, 14 research objectives, and 21 research questions creates a comprehensive framework designed to guide future academic inquiry and inform policy and practice in the evolving field of energy communities and cooperatives.

Introduction

Business development and technological advances in the last decade have produced new forms of organizations (Nair, 2011). Simultaneously, improvements in energy development and production have benefited sustainable practices (Goni et al., 2021), methods of energy storage (Panwar et al., 2011), management, and administration (Estevão & Lopes, 2024). In this context, cooperative forms of organization have led to major progress in terms of energy use (Santos et al., 2024). Cooperatives are groups of citizens, companies, or public organizations who democratically agree to pursue common objectives (Bretos & Marcuello, 2017). At the intersection between the energy industry and cooperatives lie energy communities (Tarhan, 2015). These energy communities are groups that promote the use and production of renewable and sustainable energy (Gui & MacGill, 2018). These groups target energy self-sufficiency and sustainable goals such as reducing environmental impact and enhancing economic productivity by lowering production and consumption costs (Caramizaru & Uihlein, 2020).

Cooperative energy communities pursue various goals to ensure sustainability and success (Lazzolino et al., 2022). Self-generation of energy using renewable sources such as solar energy, biomass, and wind energy is central to these communities, showing that energy self-consumption is a viable option for energy management in cooperatives (Lode et al., 2022). Moreover, these communities promote environmental sustainability, prioritizing the use of clean and renewable energies that can support actions to reduce the carbon footprint and combat climate change and global warming (Recker et al., 2012).

Additionally, like in traditional cooperative models (Zeuli et al., 2004), energy communities emphasize citizen participation as a key to success (Fischer et al., 2021). Accordingly, energy producers are also consumers, coming to be known as prosumers (Inês et al., 2020). Such initiatives foster citizen involvement in energy management, driven primarily by economic and sustainable motivations (Olkkonen et al., 2017).

Scholars have studied the development of energy communities from different perspectives (Gjorgievski et al., 2021; Lazzolino et al., 2022). However, there is a gap in the study of the relationship between small

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business energy communities that promote sustainable energy use among participants and cooperative energy communities that rely on democratic decision making to pursue social, sustainable, and cooperative objectives in addition to economic goals. Therefore, this research examines the relationship between cooperatives and energy communities to comprehend their nature, characteristics, and paths to successful cooperative energy community models. This study thus addresses the following research question (RQ1): *What are the characteristics of cooperative energy communities, and how do they influence the development of traditional cooperatives*?

Bibliometric analysis is used to respond to this question. The analysis provides an understanding of the published studies that link energy communities with cooperatives and identifies possible patterns, trends, and common characteristics (Ribeiro-Navarrete et al., 2024). Bibliographic coupling, keyword co-occurrence analysis, and author co-citation analysis are used to achieve the study aims, echoing the approach of authors such as Lafont et al. (2023), Luo et al. (2020), and Sánchez-Robles et al. (2024).

The study is organized as follows. After the introduction, Section 2 presents the literature review. Next, Section 3 outlines the methodology. The results of the bibliometric analysis are presented in Section 4. Section 5 discusses the findings and presents a number of future research questions. Finally, Section 6 concludes and outlines the theoretical and practical implications of the study.

Literature review

Energy communities are groups of citizens who collectively produce, manage, and consume energy (Klagge & Meister, 2018). These initiatives typically prioritize the use of local and renewable energy sources (Özgül et al., 2020). As noted by Hufen and Koppenjan (2015), energy communities seek to maximize energy use to prevent losses during transport and distribution to distant locations. According to Gui and MacGill (2018), the operational model in energy communities is based on democratic organizational structures, meaning that all members can vote on community decisions. Thus, like cooperatives, energy communities are characterized by the principles of collaboration, solidarity, and mutual benefit (Wirth, 2014). Members of an energy community focus not only on the economic profitability of their actions but also on the social, environmental, and sustainable well-being of the community (Savelli & Morstyn, 2021). In light of these values, Otamendi-Irizar et al. (2022) noted that energy community initiatives drive the transition toward a more sustainable organizational and energy consumption model.

Lode et al. (2022) reported that, historically, energy communities have been linked to social and environmental movements in response to energy crises and climate change or global warming concerns. Oteman et al. (2014) noted that the first energy communities emerged in Europe in the Netherlands, Denmark, and Germany through entrepreneurial ventures aimed at reducing dependency on unsustainable fuels.

Crucially, the cooperative structure in the energy sector has undergone changes by incorporating new technologies (Cusa, 2022) and adapting democratic principles to the regulatory and economic systems governing simple cooperative enterprises (D'Alpaos & Andreolli, 2021). Energy communities focus not only on storing and consuming sustainable energy but also on generating electricity from renewable sources. Hence, they have organizational strategies and collaborative structures related to energy distribution, storage, and intelligent management (Cusa, 2022). Bashi et al. (2023) noted that the sustainable potential of these actions means that they have been supported by public institutions and large companies. Through their corporate social responsibility (CSR) programs, such companies have raised public awareness about the importance of sustainability in the energy sector (Saura et al., 2023).

Given these features of cooperative energy organizations and communities, their development is linked to key economic production concepts such as the collaborative economy, sustainable economy, and energy transition (Vespermann et al., 2020). The collaborative economy is characterized by sharing resources to achieve common benefits within an organization (Gjorgievski et al., 2021). The sustainable economy supports the functioning of energy cooperatives (Lowitzsch et al., 2023), which, as emphasized by many sustainability theories (Elzen et al., 2004; Walker, 2012), correctly adopt practices that can reduce environmental impact and promote the responsible use of natural resources. Based on cooperative perspectives and the notions of autonomy, independence, democracy, and collaborative participation in economic affairs, energy community structures in cooperatives are founded on the principles of equity and shared benefits (Bashi et al., 2023). Finally, the theory of energy transition described by Elzen et al. (2004) describes the shift toward more sustainable energy production strategies and systems. This theory proposes the design of more efficient systems to meet energy demand sustainably and efficiently, breaking away from the reliance on fossil fuels.

Governments play a fundamental role in the development of cooperative energy communities (Heldeweg & Saintier, 2020; Saura et al., 2022). Legislation and regulations supporting these initiatives offer incentives and subsidies to help encourage the creation of energy cooperatives. However, in some countries regulations do not support such initiatives, and regulatory barriers can hinder the production and consumption of sustainable energy sources (Gui & MacGill, 2018). As noted by Dóci et al. (2015), the role of public institutions is therefore vital for the viability of such energy communities. D'Alpaos and Andreolli (2021) emphasized that these incentives are linked to feed-in tariffs, tax credit reductions, and direct subsidies or preferential financing programs.

The structural models of traditional cooperatives mean that the use of current business models and organizational structures to manage energy communities are important issues (Barnes et al., 2024). For example, in terms of cooperative organization, elected boards of directors are responsible for daily management and oversight of energy operations. However, the nature of these communities means that financing models may depend on various contributions from members, subsidies, bank loans, or even external investments that receive a small return from the development of these sustainable communities (Bashi et al., 2023).

Energy communities focus on sustainable energy sources such as photovoltaic, wind, biomass, and hydropower (Mehta & Tiefenbeck, 2022). The choice of sustainable energy source depends directly on the technology needed to extract natural resources according to what is available in a given region and the preferences of each community. Kazmi et al. (2021) noted that a key issue when organizing energy communities, besides the acquisition of energy, is the integration of costly energy storage systems that must be correctly installed and managed. Therefore, an important aspect relates to generating resources in a given distribution infrastructure and with certain energy management technologies.

Specific knowledge is necessary for energy communities to use these resources correctly. Hence, they also invest in support to help them efficiently develop their sustainable strategic plans (Sillak et al., 2021). For instance, smart grids enable reliable energy distribution, and demand management systems for cooperative members help them balance energy demand and use (Binyamin et al., 2024).

Finally, technological innovation is a key aspect for the success of energy cooperatives. The reason is that, through technological innovation, these cooperatives can reduce the costs of infrastructure and management systems while maximizing the economic resources of the community (Di Lorenzo et al., 2021). In the long term, both the infrastructure and management systems must be sustainable, not only economically but also in terms of energy, so that energy communities can continue to pursue their social, sustainable, and environmental goals (Selvakkumaran & Ahlgren, 2021).

Methodology

The present study is based on bibliometric analysis using VOSviewer software (Van Eck & Waltman, 2011). Bibliometric analysis is a research method used for quantitative assessment of the academic literature in a specific field. It involves descriptive statistical analysis of articles and the use of indicators to understand the development, structure, and dynamics of research topics. By analyzing publication patterns, citation networks, and keyword trends, bibliometric analysis provides insights into the intellectual landscape of a given domain. As noted earlier, this study follows a similar approach to Ribeiro-Navarrete et al., (2024), Lafont et al. (2023), Luo et al. (2020), and Sánchez-Robles et al. (2024).

Bibliometric analysis was used to explore the academic research on energy communities and cooperatives. Three primary bibliometric techniques were employed in this study: bibliographic coupling, co-citation analysis, and keyword co-occurrence. Each of these methods served a specific purpose in mapping the research landscape and identifying key trends and relationships. First, bibliographic coupling identified connections between documents that share common references (Hsiao & Chen, 2020). By analyzing bibliographic coupling, the aim was to uncover clusters of closely related research based on citation patterns. This technique revealed emerging research streams and thematic groups in the literature on energy communities and cooperatives. Second, co-citation analysis examined how often pairs of documents were cited together by subsequent publications (Hou et al., 2018). This method identified the intellectual structure of the research field by highlighting influential works and key authors. Co-citation analysis pinpointed the foundational studies and key contributors to research on energy communities and cooperatives. Lastly, keyword co-occurrence analysis focused on the frequency and relationships between keywords in the collected publications. By examining keyword co-occurrence, the study sought to identify dominant themes, research trends, and the conceptual structure of the literature (Lis, 2018). This method provided insights into the main topics of discussion and their interconnections within the research community.

Using the proposed techniques, this study provides an analysis of the academic landscape of energy communities and cooperatives. The findings reveal key research themes, influential studies, and emerging trends. They thereby contribute to a deeper understanding of the study of these cooperative models and their impact on sustainable development. This methodological approach ensures that the study is thorough, detailed, and pertinent to the current state of the art in bibliometric studies (Luo et al., 2020; Sánchez-Robles et al., 2024).

Sample description

Data were sourced from the Web of Science (WoS) database. Specifically, data came from the Social Sciences Citation Index (SSCI) and the Science Citation Index Expanded (SCI-EXPANDED). These databases were chosen for their comprehensive coverage of high-quality academic journals (Mongeon & Paul-Hus, 2016; Saura et al., 2022a). The search was conducted on July 21, 2024, using specific criteria to ensure the relevance and quality of the retrieved documents. The search terms were: "Energy cooperatives" (Topic) AND "Energy communities" (Topic). To refine the search, filters were applied to include only original research articles and to focus on specific categories relevant to the study's aims. The complete search query used in WoS was as follows:

Energy cooperatives (Topic) and Energy communities (Topic) and Article (Document Types) and Environmental Studies or Environmental Sciences or Green Sustainable Science Technology or Economics or Computer Science Information Systems or Engineering Environmental or Regional Urban Planning or Business or Computer Science Interdisciplinary Applications or Computer Science Software Engineering or Development Studies or Urban Studies or Management or Operations Research Management Science or Engineering Multidisciplinary or International Relations or Law or Sociology or Agricultural Engineering or Political Science or Education Educational Research or Education Scientific Disciplines or Ethics or Public Administration or Communication or Agriculture Multidisciplinary or Agricultural Economics Policy (Web of Science Categories)

The search yielded 286 results, covering a wide range of research on energy cooperatives and energy communities published between January 1993 and July 2024. These articles were distributed across 62 WoS categories, indicating the interdisciplinary nature of this research field. The most common categories of publications were Environmental Studies (111 articles; 38%), Environmental Sciences (95 articles; 32%), Energy Fuels (66 articles; 22%), Green Sustainable Science Technology (63 articles; 21%), and Economics (47 articles; 16%). These categories were aligned with the study's aims given their focus on the environmental, economic, and technological aspects of energy communities and cooperatives. The prominence of the Environmental Studies and Environmental Sciences categories highlights the emphasis on sustainability and environmental impact in research on energy communities and cooperatives (see Fig. 2).

Fig. 2 shows that the number of publications on energy communities and cooperatives has followed an upward trend, indicating growing academic interest in this area. This section describes the trends in publications up to the year 2012. Fig. 1 shows that the number of publications has increased substantially over time. The year 2023 saw the most publications, with 45, accounting for 15% of the total of 288 publications. The year 2021 had the next most publications, with 37 (12%), and 2020 had 34 publications (11%). The number of publications in these recent years reflects increasing interest in the topic of energy communities and cooperatives. In 2024, there were 28 publications, representing 9% of the total. In 2022, there were 24 publications, making up 8% of the total. Hence, there has been a steady flow of research in recent years that has maintained the momentum of previous years.

The years 2019 and 2018 had 21 (7%) and 20 (6%) publications, respectively, further highlighting the upward trend. In 2017, the number of publications (16) was slightly lower (5%). In the year 2016, there were 11 publications (3%), and, in 2015, there were 12 publications (4%). Between 2012 and 2014, the publication count was consistent, with six publications each year (2% of the total each). This period was the start of the buildup toward the higher publication numbers observed in the following years. Before 2012, the number of publications was notably lower. In 2011 and 2001, there were three publications each year (1% of the total). Similarly, in 2000, 2008, and 2009, there were two publications (0.69%). The earliest recorded publications in this data set were from 1993, 1994, 1997, 1998, and 2002, each contributing just one publication (0.34%). The year 2010 also had a single publication, indicating that interest in this field was beginning to gain traction.

Overall, the data in Fig. 1 indicate that research on energy communities and cooperatives has grown substantially, particularly in the past decade. The increasing number of publications reflects the increasing importance and recognition of these topics within the academic community. This upward trend suggests that energy communities and cooperatives are becoming important areas of study, likely driven by the prominence of global sustainability goals and the transition to renewable energy systems.

In relation to publication categories, the data reveal valuable insights into the multidisciplinary nature of research on energy communities and cooperatives (see Fig. 2). The analysis focused on the top 15 categories. Collectively, they illustrate the breadth and depth of academic interest in these areas.

Environmental Studies accounted for the most publications (111), representing 38% of the total. This high percentage underscores the strong links between energy communities, cooperatives, and environmental sustainability. Next, Environmental Sciences accounted for 95 publications, constituting 32% of the total. This category typically

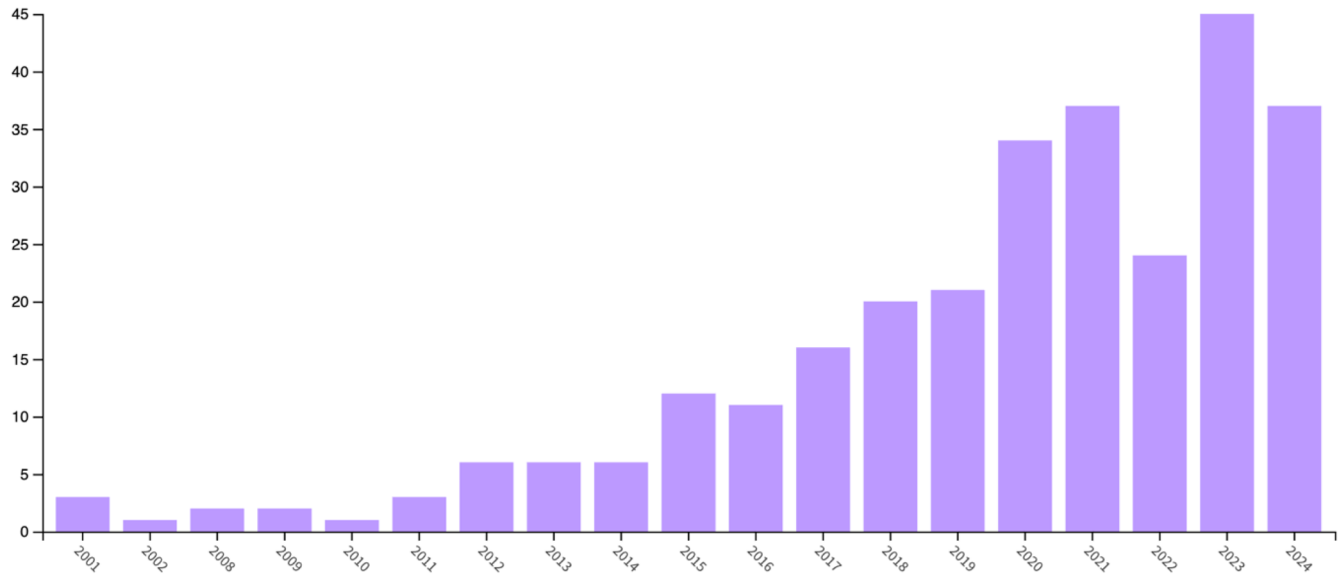

Fig. 1. Total articles published in WoS from January 2001 to June 2024 by year
Source: Authors based on WoS results.

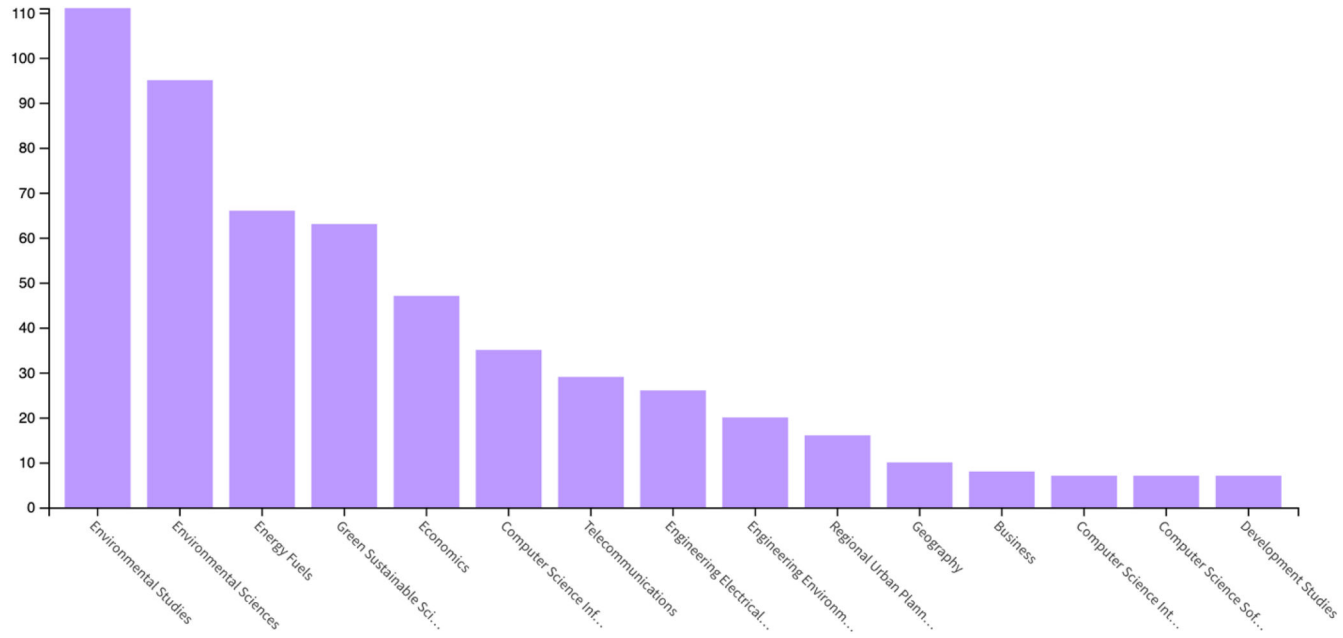

Fig. 2. Percentage of studies by category in WoS
Source: Authors based on WoS results.

includes studies on the scientific and technical aspects of environmental systems affected by energy production and consumption. Energy Fuels had the next most publications, with 66 (22% of the total). This category highlights the critical role of energy innovation in advancing the goals of energy communities.

The Green Sustainable Science Technology category had 63 publications (21%). Publications in this category typically explore technological advances and innovative approaches to sustainability, reflecting the importance of integrating green technologies in cooperative energy projects. The Economics category accounted for 47 publications (16% of the total). Studies in this category often focus on the economic implications and benefits of cooperative energy systems such as cost savings and economic resilience, as well as the socioeconomic impacts of adopting these models on communities. In the realm of technology, Computer Science Information Systems accounted for 35 publications (12%), and Telecommunications accounted for 29 publications (10%). These categories highlight the growing overlap between technology and energy management. Electrical Engineering accounted for 26 publications (9% of the total). This category addresses the engineering challenges and solutions related to the integration of renewable energy systems and the development of smart grid technologies within cooperative frameworks. Similarly, Engineering Environmental accounted for 20 publications (6%) on engineering approaches to addressing environmental issues associated with energy production and distribution in community settings.

Regional Urban Planning accounted for 16 publications (5%). Publications in this category focus on the spatial and urban planning aspects of energy community implementation. They explore how cooperative

models can be integrated into urban development to enhance sustainability and livability. Geography accounted for 10 publications (3%). This category often includes studies on the spatial distribution and geographical implications of energy communities. These studies highlight the regional differences and localized benefits of cooperative energy solutions. Business accounted for eight publications (2%), reflecting research on business models, management strategies, and organizational aspects of energy cooperatives. Two categories (Computer Science Interdisciplinary Applications and Computer Science Software Engineering) each accounted for seven publications (2%). These publications focus on the application of computer science principles and software engineering in developing and managing energy systems within cooperative frameworks. Development Studies also accounted for seven publications (2%). Studies in this category focus on the role of energy cooperatives in promoting socioeconomic development and enhancing quality of life in communities. Finally, Urban Studies also accounted for 7 publications (2%). These publications examine the impact of cooperative energy models on urban areas, addressing issues such as urban resilience, sustainability, and community engagement.

This diversity of categories reflects the interdisciplinary nature of research on energy communities and cooperatives. These categories underscore the critical role of energy communities in promoting environmental sustainability, technological innovation, economic resilience, and socioeconomic development. The growing number of publications across these diverse fields reflects increasing academic recognition of the importance of energy communities and cooperatives in addressing contemporary energy and sustainability challenges.

Finally, analysis of the countries contributing studies of energy communities and cooperatives was performed. WoS data revealed that Germany led in research output with 51 publications, accounting for 17% of the total sample. Germany was followed by the United States, with 40 publications (13%), and China, with 37 publications (12%). The Netherlands and England were also responsible for a high number of publications, with 34 (11%) and 27 (9%) publications, respectively. Spain, Italy, and France produced 25 (8%), 23 (8 %), and 14 (4%) publications, respectively. Belgium, India, and Switzerland contributed 13 (4%), 12 (4%), and 12 (4%) publications, respectively. There were additional contributions from Australia, with 11 publications (3%), Canada and South Korea, each with 10 publications (3%), and Denmark, with 9 publications (3%).

This geographic distribution of the top 15 countries in terms of research output indicates a diverse global interest in this research area. Most studies were from developed countries with advanced energy and environmental policies. The WoS data indicated that 63 countries contributed to the literature on energy communities and cooperatives.

Analysis of results

Bibliographic coupling

In this study, bibliographic coupling analysis was conducted using VOSviewer. The analysis identified 10 items, forming three clusters, with 34 links and a cumulative link strength of 5,174. This analysis provided a visualization of how research on energy communities and cooperatives is interconnected, highlighting key areas of focus and collaboration within the field.

Energy Research & Social Science was a leading source, with 33 publications, 974 citations, and a total link strength of 3,295. This journal's high link strength and citation count underscore its influence on the discourse on energy communities and cooperatives, reflecting its comprehensive coverage of social science perspectives on energy issues. *Energy Policy*, with 29 publications, 2,080 citations, and a total link strength of 2,558, was found to be a core journal in this area. Its high citation count and link strength indicate substantial contributions to policy-related discussions and the shaping of energy policy frameworks.

Energy Sustainability and Society, with 5 publications and 123 citations, had a total link strength of 1,192. Despite having fewer publications, this journal's high link strength reflects its impactful and focused contributions to discussions of sustainability within energy communities. *Environmental Innovation and Societal Transitions* had five publications and 34 citations, with a total link strength of 688. This value indicates its emerging relevance in linking socioeconomic factors with environmental innovation in the context of energy studies. This result shows the role of this journal in bridging the gap between innovative practices and socioeconomic impacts.

The *Journal of Cleaner Production* had eight documents and 316 citations, with a total link strength of 505. This journal is renowned for its contributions to the scholarly discourse on cleaner production within energy communities, emphasizing sustainable production practices and environmental management. *IEEE Access* had 15 documents and 465 citations, but a lower total link strength of 131. However, it was still an important source. This journal primarily contributes technological and engineering perspectives on energy cooperatives, reflecting its focus on practical and technical solutions in the energy sector.

These findings highlight the diverse range of influential sources contributing to research on energy communities and cooperatives. Each source has a varying degree of impact and interconnectedness. The bibliographic coupling analysis (Table 1) underscores the importance of these journals in shaping the academic landscape and advancing knowledge in this multidisciplinary field.

Fig. 3 provides a network map of the journals. It reveals the relationships among them in the form of three distinct clusters. This network visualization helps explain how different journals contribute to the overall discourse on energy communities and cooperatives. The three clusters represent distinct thematic groups that contribute to the broader understanding of energy communities and cooperatives. This clustering emphasizes the multidisciplinary nature of this field.

The network map shows strong interactions between several key journals. *Energy Research & Social Science* is a central node in the network, indicating its strong influence and connectivity in this research area. *Energy Policy* is another major node, reflecting its critical role in discussions of energy community policy. These journals form the backbone of the network, suggesting that they are pivotal in shaping research and policy directions. *Sustainability* also plays a crucial role in the network, showing its importance in discussions of sustainable practices and the environmental impact of energy communities. Despite having fewer publications, *Energy Sustainability and Society* has strong connections, indicating that it has focused and impactful contributions to the discourse on sustainability. *Environmental Innovation and Societal Transitions* also plays a relevant role by linking socioeconomic factors with environmental innovation. It thus bridges the gap between innovative practices and socioeconomic impacts. The *Journal of Cleaner Production* offers a platform for contributions in the area of cleaner production and sustainable practices within energy communities, underlining its

Table 1
Bibliographic coupling results.

Source	Documents	Citations	Total link strength
Energy Research & Social Science	33	974	3295
Energy Policy	29	2080	2558
Sustainability	16	392	1891
Energy Sustainability and Society	5	123	1192
Environmental Innovation and Societal Transitions	5	34	688
Journal of Cleaner Production	8	316	505
IEEE Access	15	465	131
Renewable Energy	11	247	121
Applied Sciences	4	48	66
Sustainable Cities and Society	4	59	32
Science of the Total Environment	4	64	1

Source: Authors based on WoS results.

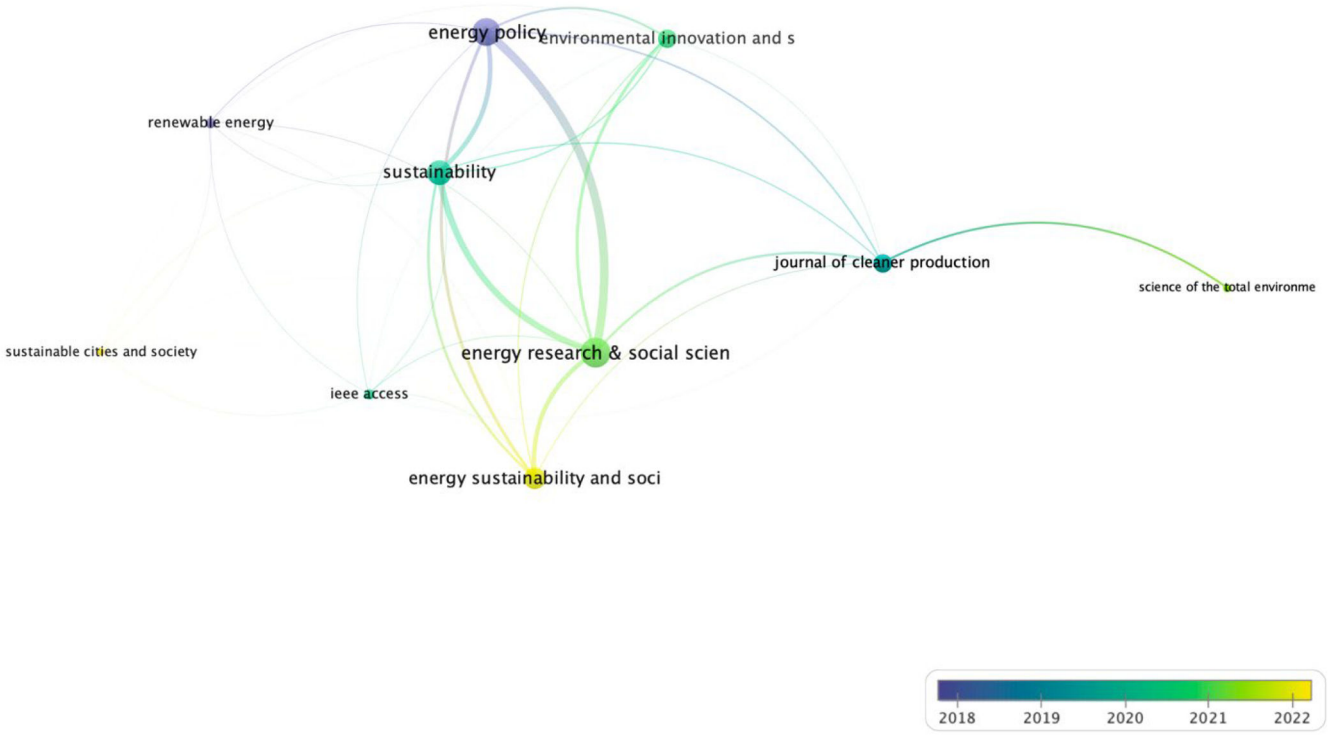

Fig. 3. Bibliographic coupling network
Source: Authors based on WoS results.

emphasis on environmental management.

Likewise, *IEEE Access* provides essential technological and engineering insights, reflecting its importance in the practical and technical aspects of energy cooperatives. *Renewable Energy* is less central but nonetheless contributes substantially to discussions on renewable energy sources and their integration into cooperative models. *Applied Sciences* and *Sustainable Cities and Society* also contribute to the discourse by focusing on the application of scientific principles and sustainable urban practices, respectively. Lastly, *Science of the Total Environment* occupies a peripheral position but nonetheless connects to broader environmental discussions. It thus plays a role by covering a wide range of environmental studies related to energy communities.

Co-citation analysis

Co-citation analysis is a bibliometric method that involves evaluating the frequency with which two documents are cited together by other documents. This analysis helps provide an understanding of the intellectual structure of a research field by identifying the relationships between influential works and key authors. When two documents are co-cited, it suggests that they share a conceptual or thematic connection. Analysis of these co-citations thus reveals important trends and clusters within the literature (Öberg, 2023).

For this analysis, a filter was applied to include only authors with at least 29 citations (Karanam et al., 2024). This criterion ensured that the analysis focused on the most influential contributors within the field. The initial data set contained 10,749 authors. The citation filter reduced this number to 20 authors, who were selected for detailed analysis (see Fig. 4).

The co-citation analysis identified three distinct clusters. Collectively these three clusters encompass 189 links with a total link strength of 4,499. These clusters represent groups of authors who are frequently cited together, indicating their joint influence on the field. Each cluster highlights a different thematic focus, showing how various aspects of energy communities and cooperatives are interconnected in the academic literature. This refined approach provides a view of the main contributors and studies that shape the discourse on energy communities and cooperatives. Fig. 4 illustrates the three clusters.

In the red cluster, the prominent authors are Bauwens and Ostrom, indicating their major influence and connectivity within this group. The size of the nodes for these authors suggests a high number of citations as an indication of their importance in the co-citation network. This cluster is densely connected, which reflects the strong interrelationships among the authors.

Key authors in the green cluster are Seyfang and Smith. These authors have a substantial influence within their group. The node sizes and number of connections reflect their central role in this network. This cluster is highly connected to the others. This level of connectivity suggests that there are strong interactions and citation links with authors in different clusters, highlighting the interlinked nature of the research field.

Finally, in the blue cluster, the main authors are Holstenkamp and Yildiz. This cluster is smaller but still strongly connected. The node sizes indicate that these authors are influential within their cluster given the multiple citation links connecting them to other prominent researchers in the field. This cluster has connections with the red and green clusters. These connections indicate cross-collaborations and shared citations and emphasize the collaborative nature of research in energy communities and cooperatives.

The most cited authors with the highest link strength in Fig. 4 are shown in Table 2.

Table 2 shows the total publications and citations of the main authors. The historical trend in research output on energy community cooperatives can be visualized in Fig. 5. The figure shows the growth in scientific contributions and studies, as well as citations, from the 1993 to 2024.

Table 3 presents an adapted summary of the main academic contributions, including article title, journal, and total citations. These studies are the main contributions in the field of energy communities and cooperatives.

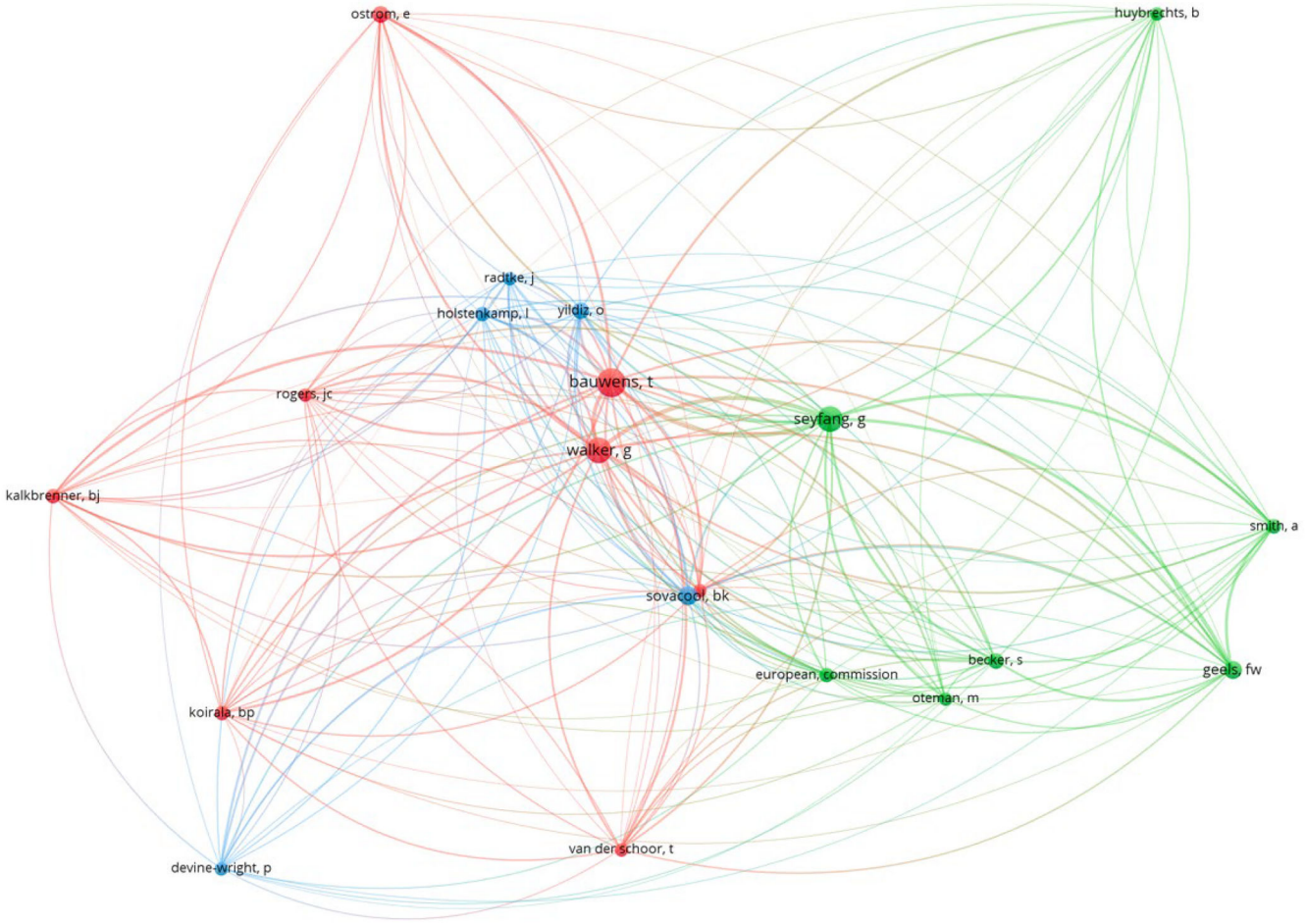

Fig. 4. Co-citation analysis network
Source: Authors based on WoS results.

Table 2
Author co-citation analysis and total link strength.

Author	Citations	Total link strength
Bauwens, F.	139	1538
Seyfang, G.	114	1252
Walker, G.	113	1245
Geels, F. W.	56	663
Sovacool, B. K.	60	630
Yildiz, O.	49	619
Becker, S.	40	534
Smith, A.	38	524
Kalkbrenner, B. J.	37	468
Holstenkamp, L.	37	454
Radtke, J.	32	437
van Veelen, B.	28	424
Koirala, B. P.	36	409
Oteman, M.	29	408
Rogers, J. C.	32	401

Source: Authors based on WoS results.

Keyword co-occurrence

The most frequently occurring keywords and their link strengths (see Table 4) can reveal powerful insights in bibliometrics. The keyword "renewable energy" had 66 occurrences and a link strength of 205. These results reflect the central role of renewable energy sources in the discourse on energy communities. The keyword "community energy" appeared 54 times, with a link strength of 171. These results indicate the importance of local and community-based energy initiatives. Next, the keyword "cooperatives" was cited 43 times, with a link strength of 147. These results indicate the importance of cooperative models in the energy sector. The term "power" occurred 37 times, with a link strength of 120. These results reflect discussions on the generation and distribution of power within energy communities.

Additionally, "Germany" had 24 occurrences and a link strength of 115. These results suggest a geographic focus, indicating that important research on energy communities within Europe has been conducted in Germany. The keyword "energy transition" was cited 31 times, with a link strength of 106. These results highlight the shift from traditional energy systems to more sustainable models. The keyword "energy cooperatives" had 25 occurrences and a link strength of 94. These results reflect a specific focus on cooperatives within the energy sector. The keyword "policy" appeared 24 times, with a link strength of 85. These results point to the role of policy and regulatory frameworks in shaping energy communities. Also, "participation" appeared 24 times, with a link strength of 78. These results underline the involvement and engagement of community members in energy initiatives. Finally, the keyword "wind energy" had 19 occurrences and a link strength of 75. These results indicate the prominence of wind energy projects in the context of community energy.

The other keywords presented in Table 4 correspond to the primary themes in research on energy communities and cooperatives. The emphasis on renewable energy, community involvement, and cooperative models shows that energy communities are relevant in many research fields linked to sustainability.

In the network analysis, a filter was applied in VOSviewer. A total of 23 items were identified (see Fig. 6). These items were organized into

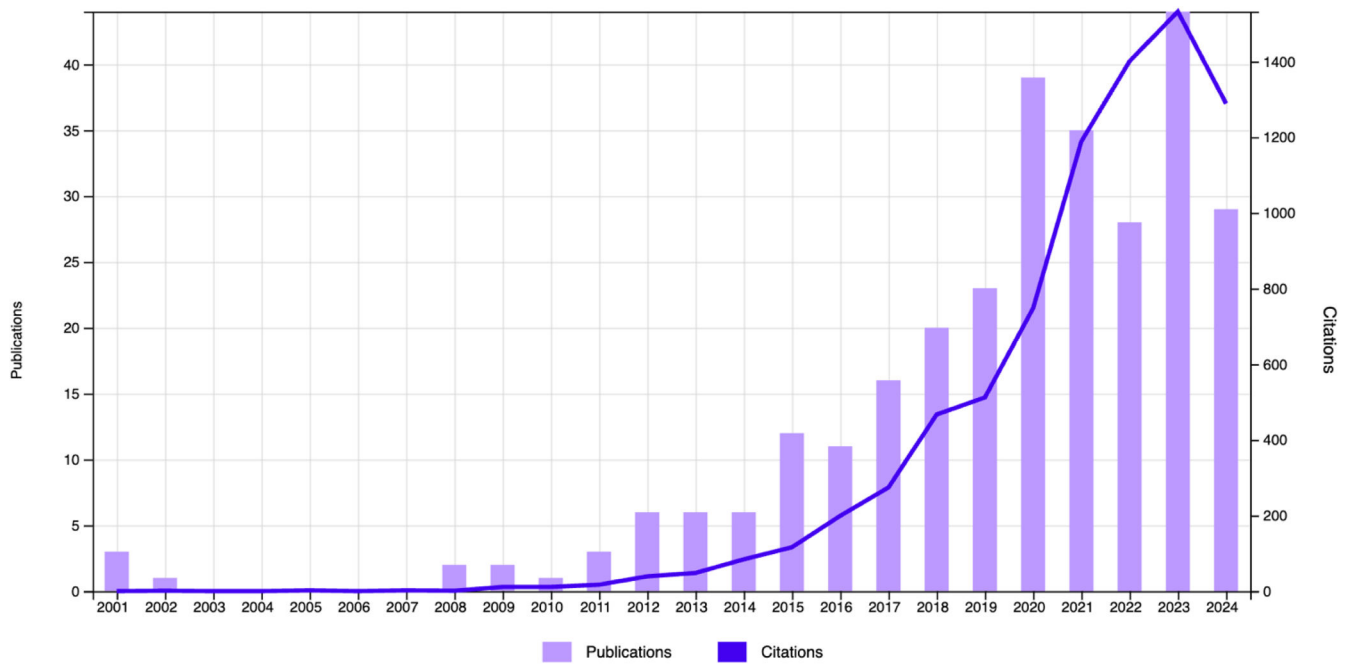

Fig. 5. Total publications and citations from 1993 to 2024
Source: Authors based on WoS results.

Table 3
Main contributions to research on energy communities and cooperatives in WoS by journal, title, and citations.

Authors	Title	Journal	Average citations per year	Total citations
Walker (2008)	What are the barriers and incentives for community-owned means of energy production and use?	*Energy Policy*	17.82	303
Bauwens et al. (2016)	What drives the development of community energy in Europe? The case of wind power cooperatives	*Energy Research & Social Science*	30.22	272
Inês et al. (2020)	Regulatory challenges and opportunities for collective renewable energy prosumers in the EU	*Energy Policy*	44.4	222
Bauwens (2016)	Explaining the diversity of motivations behind community renewable energy	*Energy Policy*	19.11	172
Bauwens and Devine-Wright (2018)	Positive energies? An empirical study of community energy participation and attitudes to renewable energy	*Energy Policy*	19.14	134
Wirth (2014)	Communities matter: Institutional preconditions for community renewable energy	*Energy Policy*	10.82	119
Becker et al. (2017)	Community energy and social entrepreneurship: Addressing purpose, organisation and embeddedness of renewable energy projects	*Journal of Cleaner Production*	14.38	115
Van der Schoor et al. (2016)	Challenging obduracy: How local communities transform the energy system	*Energy Research & Social Science*	12.67	114
Kunze and Becker (2015)	Collective ownership in renewable energy and opportunities for sustainable degrowth	*Sustainability Science*	11.4	114
Viardot (2013)	The role of cooperatives in overcoming the barriers to adoption of renewable energy	*Energy Policy*	8.5	102

Source: Adapted from WoS results.

Table 4
Keyword co-occurrence analysis.

Keyword	Occurrences	Total link strength
Renewable energy	66	205
Community energy	54	171
Cooperatives	43	147
Power	37	120
Germany	24	115
Energy transition	31	106
Energy cooperatives	25	94
Policy	24	85
Participation	24	78
Wind energy	19	75
Transitions	20	73
Electricity	25	71
Governance	20	70
Innovation	16	55

Source: Authors based on WoS results using VOSviewer.

three clusters, with 167 links and a total link strength of 838. The requirements for inclusion in the sample were a minimum of 15 keyword occurrences. As indicated earlier, 23 keywords were selected for the network maps from a total of 1,775 keywords. This approach provides a detailed view of the main topics and their interrelationships in research on energy communities and cooperatives. Likewise, the network map in Fig. 6 shows the interconnections among the selected keywords.

The central keyword "renewable energy" is strongly connected to "community energy," "energy transition," and "cooperatives," reflecting the core themes of the topic. The frequent co-occurrence of these keywords indicates a strong focus on the integration of renewable energy sources in community-based and cooperative frameworks. "Community energy" is closely linked to "policy," "participation," and "sustainability," highlighting the importance of regulatory frameworks, community involvement, and sustainable practices in the development of energy communities. These connections suggest that successful community energy projects often rely on supportive policies and active participation

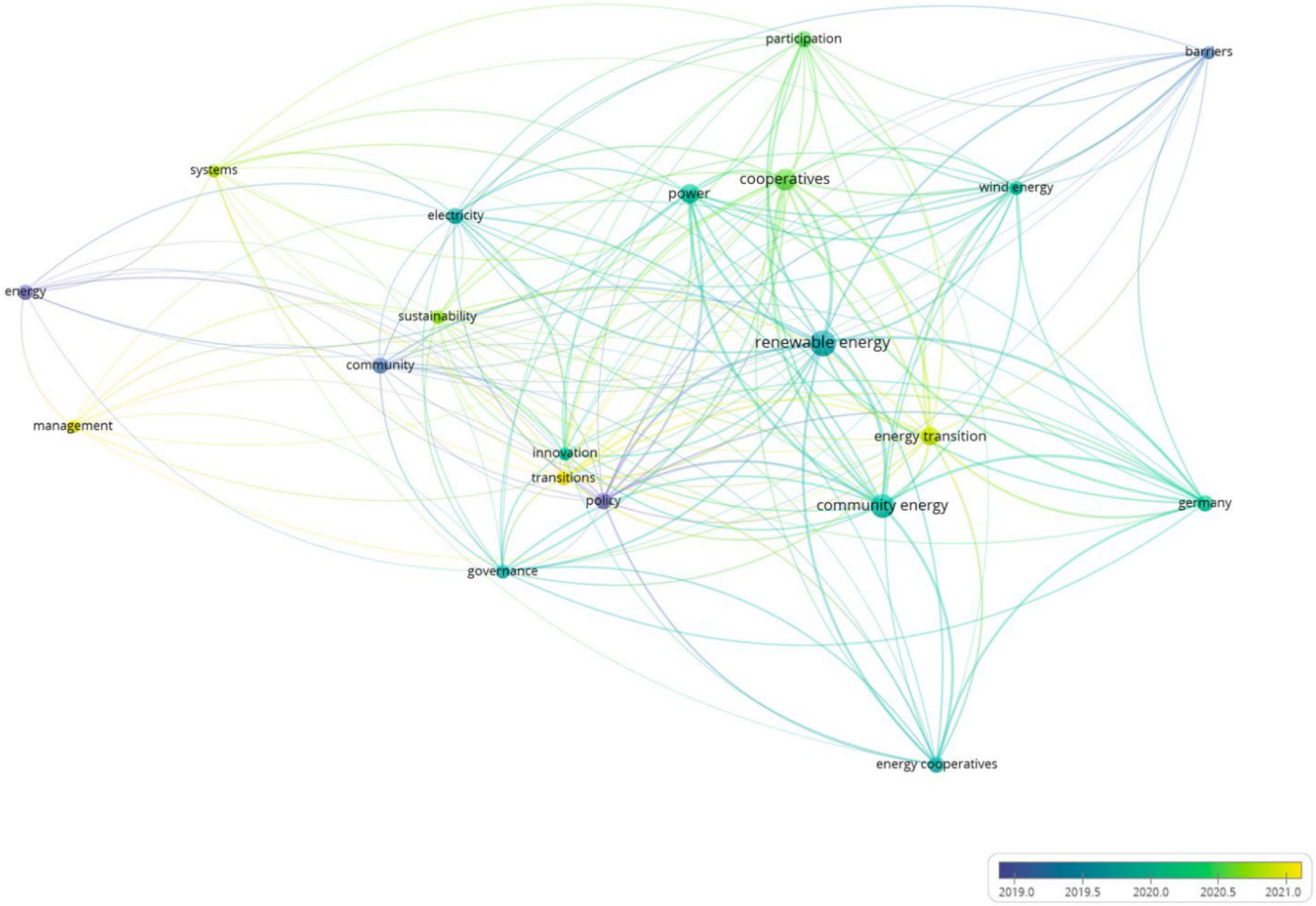

Fig. 6. Keyword co-occurrence analysis
Source: Authors based on Web of Science results and VOSviewer.

from community members.

The keyword "cooperatives" has strong ties with "renewable energy," "community energy," and "participation," underscoring the role of cooperative models in fostering community-based renewable energy initiatives. The linkages indicate that cooperatives are a prevalent organizational form in energy communities. "Energy transition" is connected to "policy," "innovation," and "governance." These linkages suggest that transitioning to sustainable energy systems involves not only technological innovation but also effective governance and supportive policy measures. The presence of "Germany" among the keywords reflects Germany's major contributions to energy transition research and implementation. Its strong position in relation to energy transitions may be on account of its strong policy framework and pioneering renewable energy projects. Other notable keywords include "wind energy," "electricity," and "barriers," which are associated with the technical and practical challenges of implementing community energy projects. The connections between these keywords highlight ongoing discussions about overcoming obstacles and optimizing electricity generation and distribution in community-based systems.

Finally, the emphasis on renewable energy, community involvement, cooperative models, and supportive policies underscores the inclusive approach needed to encourage energy communities and cooperatives. These findings provide valuable insights into the key themes driving academic discussions and highlight the interdependencies between topics in the literature on energy communities and cooperatives.

The keyword co-occurrence network in Fig. 6 also highlights the changes in research themes over time. The color gradient in the bottom right corner is used to indicate different years. The color gradient ranges from purple for studies from earlier years (2019) to yellow for more recent studies (2021). The purple and blue hues dominate the keywords "renewable energy," "community energy," and "cooperatives," suggesting that these topics have been central to research discussions since at least 2019. This finding indicates that there has been a consistent focus on these foundational themes over the past few years. Conversely, keywords with green to yellow shades, such as "policy," "energy transition," "innovation," and "governance," are those from more recent research interests and emerging topics. The yellow keywords suggest that the scholarly community is increasingly focusing on the policy frameworks, governance structures, and innovative approaches required to support energy transitions and community energy initiatives.

In summary, the color gradient in the network map indicates a chronological progression of research themes. The steady focus on renewable energy and community-based initiatives is complemented by increasing attention on the governance, policy, and innovation aspects needed to sustain and grow these efforts.

Discussion

This study provides a multifaceted understanding of the dynamics of energy communities and cooperatives. Researchers have long emphasized the critical role of renewable energy in achieving sustainability goals (Fatima et al., 2021). In this regard, the integration of renewable energy sources, such as solar and wind power, into community-based initiatives not only furthers attempts to meet environmental objectives such as the Sustainable Development Goals (SDGs) but also enhances local energy security and resilience (Diaz-Sarachaga et al., 2018). Thus, these initiatives are closely aligned with the broader sustainability discourse, which advocates a reduction in carbon footprints and an

increase in clean energy solutions (Grist, 2008; Scrase & Ockwell, 2010).

Similarly, local involvement and community-based approaches are pivotal to the success of energy projects (Woo et al., 2019). Theories of social capital and collective action explain the importance of strong social networks and community participation in driving these initiatives, as elucidated by Loukopoulos et al. (2024) and Ahmad and Islam (2024). Active engagement from community members ensures that energy projects are tailored to local needs and preferences, thereby increasing their acceptance and effectiveness. This engagement is particularly important because it is aligned with one of the principles of cooperatives (Majee & Hoyt, 2011). Such engagement is often encouraged by cooperative models, which provide a democratic and inclusive framework for managing shared resources (Kustepeli et al., 2023).

In addition, cooperative structures are particularly effective in organizing and managing community energy initiatives. For example, pooling resources and sharing risks enables cooperatives to undertake larger and more ambitious projects than would be possible individually (Walker, 2008). The transaction cost economics framework supports this approach, suggesting that cooperatives can reduce costs and improve efficiency in the management of communal resources (Trejo-Pech et al., 2023). Moreover, the cooperative model ensures that the benefits of energy projects are equitably distributed among community members, thereby enhancing social equity and cohesion (Becker et al., 2017).

According to Bauwens and Devine-Wright (2018), the transition from traditional energy systems to sustainable, renewable sources is a complex process that requires more than just technological innovation. Effective policy measures and governance structures are essential to support this transition (Inês et al., 2020). Sociotechnical transition theories highlight the need for an integrated approach that includes technological advances, regulatory support, and social acceptance (Wirth, 2014). As a result, policymakers play a crucial role in creating a conducive environment for energy transitions through actions such as providing incentives, removing barriers, and facilitating stakeholder collaboration (Emshoff & Freeman, 2023).

Accordingly, governance and participation are critical factors in the development and success of energy communities. Decentralized and participatory governance frameworks can enhance transparency, accountability, and democratic decision-making processes, which ultimately contribute to the legitimacy and sustainability of cooperative models (Viardot, 2013). Theories of participatory governance suggest that involving community members in decision making not only draws on local knowledge and resources but also fosters a sense of ownership and commitment to the project. This concept is closely linked to the focus on sustainability in energy communities, as reflected by the emphasis on renewable energy, emissions reductions, and community engagement (Van der Schoor et al., 2016). Sustainable development theories advocate a holistic approach that addresses environmental, economic, and social dimensions to achieve long-term sustainability (Akbari et al., 2023). Energy communities embody this approach by simultaneously addressing environmental goals, economic resilience, and social inclusion, as stated by Feng et al. (2023).

Table 5
Future research directions in energy communities and cooperatives.

Theme	Description	Main objectives	Future research questions
Renewable energy	Integration of renewable sources	o Increase the use of renewable energy in community projects o Enhance energy security and sustainability	o How can renewable energy sources be optimally integrated into existing community energy systems? o What are the barriers to large-scale adoption of renewable energy in cooperatives? o How does renewable energy affect the long-term sustainability of energy communities?
Community energy	Local and community-based energy initiatives	o Foster local engagement and ownership of energy projects o Promote decentralized energy generation and management	o What are the best practices for increasing community participation in energy projects? o How do community energy projects influence local economies? o What factors contribute to the success or failure of community energy initiatives?
Energy transition	Shift to sustainable energy systems	o Facilitate the transition from fossil fuels to renewable energy o Develop resilient and adaptive energy infrastructures	o What are the most effective policy measures to support energy transitions at the community level? o How can energy transitions be managed to ensure equitable access to clean energy? o What role do technological innovations play in accelerating energy transitions?
Energy cooperatives	Cooperative models in energy sector	o Promote democratic governance and shared ownership in energy projects o Enhance economic viability and social equity	o How do cooperative models affect the economic sustainability of energy projects? o What governance structures are most effective in energy cooperatives? o How can cooperatives ensure equitable distribution of benefits among members?
Policy and participation	Role of policy and community engagement	o Develop supportive policies and regulatory frameworks o Increase community participation and stakeholder engagement	o What policy frameworks are most conducive to the growth of energy communities? o How can policy interventions increase community participation in energy projects? o What are the impacts of community engagement on policy development for energy initiatives?
Governance	Governance structures and frameworks	o Ensure transparent, accountable, and democratic decision making o Foster effective management and operational practices	o What governance models are most effective in managing energy cooperatives? o How does governance affect the success and sustainability of energy projects? o What are the challenges in implementing democratic governance in large-scale energy cooperatives?
Innovation	Technological and organizational innovations	o Promote the adoption of innovative technologies and practices o Enhance the efficiency and effectiveness of energy systems	o How can technological innovations be leveraged to improve energy efficiency in communities? o What are the organizational challenges in adopting new technologies in energy cooperatives? o How does innovation contribute to the competitiveness of energy communities?

Source: Authors.

Future research directions

Future lines of research in the field of energy communities and cooperatives are proposed to build on this study. Table 5 presents a structured overview of these research themes, offering brief descriptions, key objectives, and suggested research questions. The goal of this table is to guide future academic inquiry and highlight the critical areas where further investigation can enhance the understanding and implementation of energy communities and cooperatives. The selection of these future research themes was based on an extensive review of the current literature, focusing on gaps and emerging trends in the field. The criteria for selection were relevance to ongoing energy transitions, potential impact on policy and practice, and the need to address both technological and social dimensions of energy communities. Themes were chosen to reflect interdisciplinary perspectives and thus ensure a comprehensive approach that addresses environmental, economic, and governance dimensions, building on the insights from the bibliometric analysis.

These proposed research directions emphasize the need for a comprehensive approach to studying energy communities and cooperatives. Future studies can focus on these areas to explore high-impact strategies for advancing sustainable energy practices. For instance, research into policy frameworks and community participation can provide actionable insights for policymakers and practitioners. Likewise, an examination of governance models could offer guidance for the creation of more equitable and efficient energy systems. Addressing these research questions can contribute in a meaningful way to developing more effective, sustainable, and equitable energy systems. The integration of renewable energy, community involvement, cooperative models, supportive policies, and innovative technologies will be crucial to advance the field and achieve broader sustainability goals.

Conclusions

This study used bibliometric analysis to explore the scientific literature on energy communities and cooperatives. With the help of VOSviewer, the study used bibliographic coupling, co-citation analysis, and keyword co-occurrence to identify key themes and interconnections in this consolidated research field. The findings reveal seven focus areas, namely renewable energy, community energy, energy transition, policy, participation, governance, and innovation. These insights underline the importance of combining technological innovation, community involvement, and cooperative models to advance sustainable energy systems and create knowledge in this research field. This study also proposes 14 research objectives and 21 research questions to act as a guide for further academic inquiry and to create knowledge in this field.

RQ1 in this study was as follows: *What are the characteristics of cooperative energy communities, and how do they influence the evolution of traditional cooperatives?* The analysis indicates that cooperative energy communities emphasize the use of renewable energy sources, democratic governance, and community participation. These characteristics foster a collaborative environment that enhances the economic viability and social equity of energy communities. The findings show that the cooperative model's democratic nature and the principle of shared ownership are crucial for the success of energy communities. Hence, energy communities have the potential to contribute to sustainable energy transitions and consolidate the traditional cooperative model. For example, these insights underscore the need for policymakers to recognize the value of cooperative structures in the broader energy transition strategy. Implementing supportive policies, through measures such as financial incentives and regulatory frameworks for cooperative energy models, can significantly enhance their scalability and impact. On a larger scale, such measures could facilitate the replication of successful energy community models across different regions, fostering a more widespread shift toward sustainable energy practices. Additionally, these findings offer guidance for community organizers and practitioners when designing more effective and inclusive energy projects by emphasizing democratic governance and community ownership.

The study's bibliometric analysis further reveals that the volume of research on energy communities and cooperatives has increased considerably over the past few decades. This growth reflects growing academic interest in sustainable energy practices and the role of cooperative models in achieving the associated goals. The identification of three primary clusters in the co-citation network underscores the interdisciplinary nature of energy communities. When studying energy communities, it is important to integrate insights from environmental studies, economics, and social sciences to create knowledge in this research area. This finding highlights the need for a holistic approach to studying the implementation of energy communities by incorporating diverse perspectives and expertise.

The keyword co-occurrence analysis reveals the emphasis on practical aspects such as policy frameworks and community participation, indicating that these areas are critical for the implementation and success of energy communities. The interconnection between keywords such as "renewable energy," "policy," and "participation" suggests that effective energy transitions require not only technological advances but also robust policy support and active community engagement. This alignment of academic research with practical implementation underscores the relevance of this study's findings for both advancing theory and enabling real-world applications for energy communities.

Theoretical implications

The findings of this study provide several theoretical insights into the development and impact of energy communities and cooperatives. The integration of renewable energy in community projects is supported by sociotechnical transition theories. Such theories focus on systemic changes involving technological, regulatory, and social dimensions to achieve sustainability goals. The research questions related to renewable energy, such as optimal integration into community systems and overcoming adoption barriers, are aligned with these theories in that they address both technological and social challenges.

Also, the emphasis on community energy and local engagement underscores the importance of social capital and collective action theories. As previously mentioned, these theories suggest that strong community networks and active participation are essential for the success of local initiatives. Also, fostering local ownership and promoting decentralized energy generation reinforce the idea that community involvement is crucial for the sustainability and resilience of energy projects. This notion is aligned with the theory that local engagement enhances the legitimacy and effectiveness of community energy initiatives.

Likewise, the energy cooperatives highlighted in this study resonate with theories of cooperative economics and democratic governance. These theories advocate collective ownership and participatory decision making as a means to enhance economic viability and social equity. Furthermore, the focus on policy and participation is supported by theories of participatory governance and policy innovation, reflecting the need for inclusive and supportive policy frameworks that foster energy communities.

Finally, technological and organizational innovation is a key theme aligned with theories of innovation diffusion and organizational change. The study's emphasis on promoting innovative technologies and practices to enhance energy efficiency and system effectiveness underscores the theoretical understanding that innovation is crucial for the competitiveness and sustainability of energy communities. Collectively, these theoretical implications offer valuable insights to support the future research proposed in Table 5. They can offer guidance for the exploration of new theoretical developments and practical applications in the field of energy communities and cooperatives.

Practical implications

In terms of its practical implications, this study shows that policymakers, practitioners, and community leaders involved in the development and management of energy communities are directly linked. The emphasis on renewable energy and community engagement suggests that successful energy projects require supportive policy frameworks and active community participation. Policymakers can use these findings to design incentives and regulatory measures that promote the adoption of renewable energy and cooperative models, ensuring that policies match local needs and foster sustainable practices.

Practitioners can use the identified themes to develop strategies that enhance community involvement and ensure an equitable distribution of benefits. For example, implementing participatory governance structures can foster greater ownership and commitment from community members, leading to more resilient and effective energy projects. One way of doing so would be to organize community meetings, workshops, and collaborative decision-making processes that actively involve local stakeholders in project planning and implementation. Practitioners can also embrace innovative technologies such as smart grids and renewable energy storage solutions to optimize energy production and consumption within communities. Additionally, adopting best practices in management and operational practices can improve the overall performance and sustainability of energy cooperatives. For instance, integrating advanced monitoring and evaluation tools can help with the tracking of project progress and can enable data-driven decisions.

Policymakers should consider flexible regulatory frameworks that accommodate the diverse needs of energy communities. Tailored incentives such as subsidies or tax breaks can make projects more accessible and financially viable. This approach ensures that policies are adaptable, reflecting the unique characteristics of each community's resources and challenges. In the same way, community organizers play a key role in building trust and facilitating dialogue between stakeholders. Therefore, involving residents in educational campaigns and workshops can increase awareness and foster a culture of sustainability. This engagement will empower individuals and strengthen community commitment to local energy projects.

Likewise, the focus on policy and participation underscores the need for robust policy support and active stakeholder engagement. Policymakers can create an enabling environment by developing policies that support energy communities and provide financial incentives for cooperative models. Simplified permitting processes and feed-in tariffs can reduce barriers and make renewable energy projects more attractive. Public consultation and feedback mechanisms can ensure that projects reflect community preferences and needs. In this context, equity should be a priority. Policies should include provisions that ensure that underrepresented groups benefit from renewable energy projects. Community organizers can reach out to the community to involve these groups in decision making, thereby promoting a fair and inclusive distribution of resources. Finally, by addressing these areas, policymakers and practitioners can enhance the development and sustainability of energy communities and cooperatives, contributing to broader environmental and social goals.

Limitations

In this exploratory study, several limitations should be acknowledged. First, the reliance on bibliometric data from WoS may have led to the exclusion of relevant studies from other sources. This potential omission of relevant studies could lead to an incomplete representation of the research landscape on energy communities and cooperatives. Although the focus on specific keywords and categories ensured the relevance of the publications included in the analysis, it may have led to the exclusion of other pertinent themes and emerging areas of research. Additionally, the quantitative methods of bibliographic coupling, co-citation analysis, and keyword co-occurrence may not have fully captured the qualitative and contextual differences across studies. Finally, the interpretation of clusters and themes is inherently subjective and is influenced by researchers' views on the literature. Hence, conclusions may vary depending on the subjective interpretation of the literature. Future research should address these limitations by incorporating a broader range of sources, keywords, and empirical and analytical methods to provide a more comprehensive understanding of the research landscape for energy communities and cooperatives.

CRediT authorship contribution statement

Hua Depeng: Writing – original draft, Supervision, Project administration, Methodology, Investigation, Conceptualization. **Fracisco Javier S. Lacarcel:** Writing – original draft, Project administration, Investigation, Conceptualization. **Virginia Simón-Moya:** Supervision, Investigation, Conceptualization.

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