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Energy Communities in the Transition to Renewable Sources: Innovative Models of Energy Self-Sufficiency Through Organic Waste

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Abstract: The paper examines the evolution and crucial role of energy communities in the context of the transition to renewable energy sources. Such communities are presented as an innovative and resilient response to the challenges posed by climate change. Their importance emerges from their ability to decentralise energy production, increasing local security and reducing dependence on non-renewable energy sources and external suppliers. However, despite the obvious benefits, the contribution highlights several challenges, such as the need for significant upfront investment and the presence of regulatory barriers that may hinder the integration of these solutions into existing energy systems. A detailed bibliometric analysis is used, focusing on specific research areas and using tools to map the most relevant keywords and emerging trends. The results of the bibliometric analysis highlight how energy communities are emerging as key players in the sustainability landscape, capable of addressing and overcoming contemporary environmental challenges. The research reaffirms the transformative potential of energy communities in promoting a more sustainable and resilient future.

Keywords: energy communities; organic waste; energy self-sufficiency; renewable energy; sustainable development

1. Introduction

The transition to a sustainable energy system is imperative and amplified by the growing scientific evidence linking, the intensive use of fossil fuels to global warming and climate change [1,2]. The energy transition is not only an environmental goal, but is of strategic importance to ensure a sustainable global future. However, this process is characterised by considerable challenges, including the volatile nature of renewables [3].

In this context, energy communities emerge as significant players, not only as a decentralised model of energy production and consumption, but also as an example of energy resilience of local communities, exploiting local resources and promoting sustainability. According to the International Energy Agency's report (2021) [4], the growing production of organic waste on a global scale, estimated at more than 2 billion tonnes per year, poses a significant environmental challenge but also offers a unique opportunity for renewable energy production. Waste, if not properly managed, can cause environmental problems related to greenhouse gas emissions, soil and water pollution, and loss of potentially recyclable resources. The use of appropriate technologies, such as anaerobic digestion, gasification or pyrolysis, is important to convert organic waste into biogas, thermal or electrical energy and promote sustainable development.

Organic waste-based energy communities contribute to the reduction of greenhouse gas emissions, improve waste management and increase local energy security, resulting in less dependence on external suppliers and fossil fuels. This leads to greater energy autonomy and

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increased resilience of local communities to external energy shocks. However, despite the benefits, the full integration of biowaste-based energy communities into national and global energy systems is hindered by several challenges, such as initial investment and infrastructure needs, regulatory barriers, equitable access to technologies and the development of technical skills at the local level. There is also a need for cultural and societal change that recognises the value of waste as an energy resource. Overcoming these challenges requires transversal collaboration between different actors, including governments, the private sector, the scientific community and civil society. Public policies can play a crucial role in facilitating this process through economic incentives, support for research and development, and the creation of favourable regulatory frameworks. Integrating biowaste-based energy communities into national and international energy planning can accelerate the transition to a more sustainable, resilient and inclusive energy system.

1.1. The role of energy communities in the energy transition

In Germany, energy communities have successfully integrated renewables into their local energy mix, positively influencing national energy policies [5]. However, although they represent a sustainable and autonomous model of energy production, their implementation and operation are not without difficulties [6]. Affordability is one of the main challenges, in addition to the high cost of installing the necessary infrastructure. According to the World Bank's 2018 [7] report, the initial investments required for the implementation of medium-sized biogas plants are substantial, varying from $1 million to $3 million. This highlights the need for sustainable financial strategies, such as government subsidies, tax incentives or innovative financing models, to make these initiatives more affordable and feasible.

Developing rural energy communities, for example, face difficulties related to the maintenance and operation of biogas plants [8]. The shortage of skilled labour can hinder not only the efficiency but also the long-term sustainability of these projects, indicating the importance of investing in training and local skills development.

The sustainability aspect is crucial to ensure that the use of organic waste as an energy source is beneficial in the long run. Approximately 30% of energy communities faced increased costs associated with the collection and transport of organic waste. This situation underlines the importance of careful waste planning and management to ensure that the practices adopted remain sustainable and economically beneficial [9]. Table 1 shows the factors that hinder the adoption of energy communities.

Table 1. Barriers to the implementation of energy communities. Sources: [7-9].

Factor	Description	Data or Statistics
Initial investment	Start-up cost for biogas plants	$1 - $3 million per medium-sized plant
Skilled labour	Need for technical personnel for operation and maintenance	40% of rural communities have skills shortages
Waste Management	Costs and logistics associated with the collection and transport of organic waste	30% of the communities increased management costs

Organic waste-based energy communities therefore offer a promising prospect for energy sustainability. Only through a coordinated effort between governments, non-governmental organisations, the private sector and local communities will it be possible to overcome the obstacles and exploit the full potential of these sustainable energy initiatives. Holistically addressing financial viability, availability of technical expertise and environmental sustainability can help maximise the benefits of bio-waste-based energy communities.

2. Materials and Methods

The methodology employed employed a detailed bibliometric analysis on two separate platforms: Scopus and Web of Science. The search focused on specific research areas, which were

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subsequently highlighted and motivated. We then proceeded by mapping the most relevant keywords to isolate emerging trends, using VOSviewer software.

2.1. Scopus

For the search on the Scopus platform, the string <"Energy Community"> was used. An increase from 2018 emerges, showing an increasing interest over the years with a total of 2645 publications. The trend is shown in Figure 2.

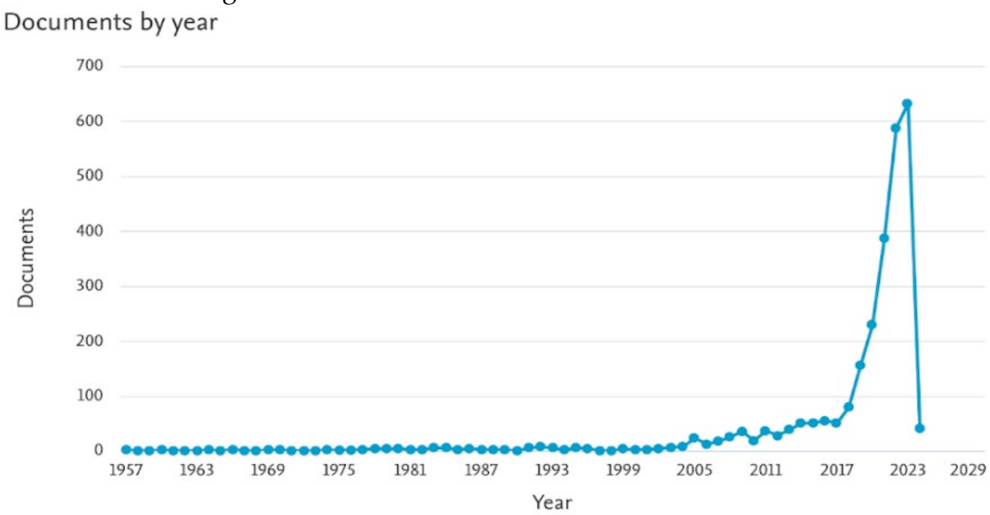

Figure 2. Projection of published articles and conference papers. Source: Scopus.

Italy stands out as a leader in academic research on this topic, with a significant number of publications in this area (Figure 3).

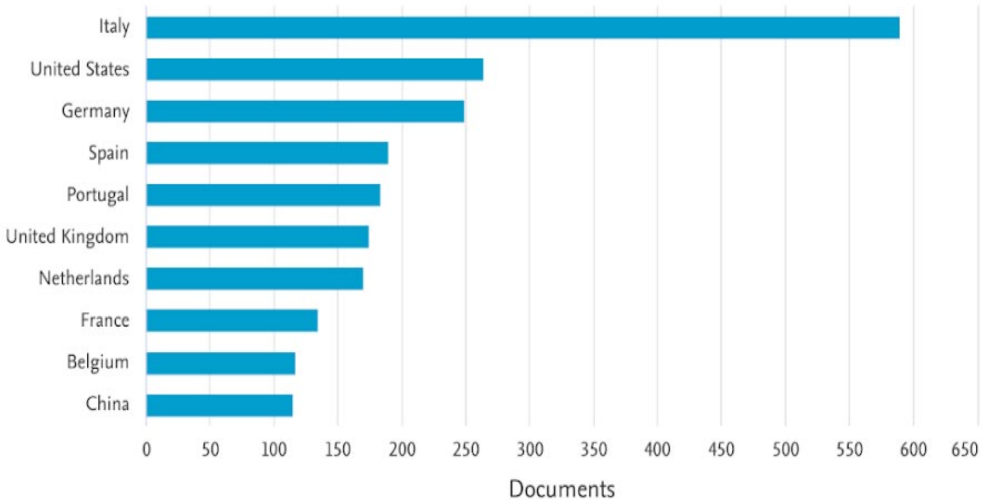

Figure 3. Countries with most research activity in the 'Energy Community' theme. Source: Scopus.

The survey was restricted to the following areas: Energy, Social Sciences, Business, Management and Accounting, Environmental Science, Economics, Econometrics and Finance. The decision not to include other areas, such as Engineering and Agricultural and Biological Sciences, was motivated by the sectorial specificity of these topics, which were considered irrelevant to the research objectives. This sectoriality emerged from the results of the literature search. The type of document investigated was restricted to articles and conference papers, as these were sources subject to the peer-review process. This selective phase generated a total of 1558 titles.

The role of Horizon in this context is particularly relevant, as it has established itself as the main sponsor of this line of research, supporting 317 publications. Horizon, as part of the European research and innovation programme 'Horizon 2020' and later 'Horizon Europe', played a key role in funding projects to promote innovation and scientific research at European level. The figures are shown in Figure 4.

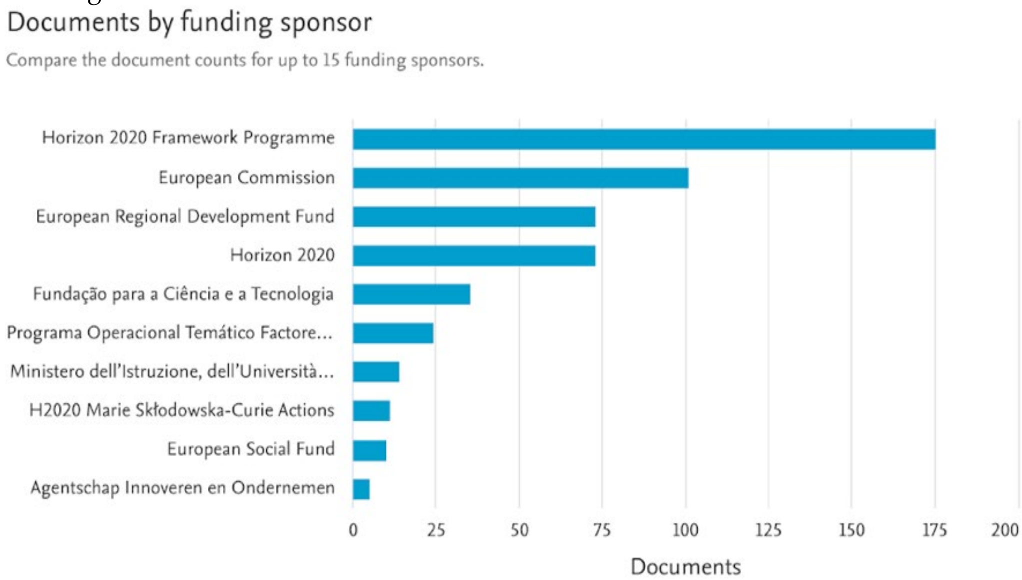

Figure 4. Major research sponsors. Source: Scopus.

Horizon's financial support has enabled the development of advanced research and deepening of crucial topics within the 'Energy Community'. Its initiatives have provided crucial resources to explore new perspectives, advance our understanding of sustainable energy dynamics and promote innovative solutions to emerging energy challenges. The presence of Horizon as a main sponsor underlines the strategic importance recognised in this research area, contributing not only to scientific progress, but also to the definition of energy policies and strategies for a more sustainable future.

2.2 Web of Science

On the WoS platform, the topic of 'Energy Communities' has a total of 121,698 publications. This figure reflects a steady interest over the years, as shown by the increase in publications over the last six years (2018-2023), which reached 60290. This upward trend underlines the increasing importance attached to research and understanding the dynamics of energy communities in the context of environmental sustainability and development. The trend of publications is shown in Figure 5.

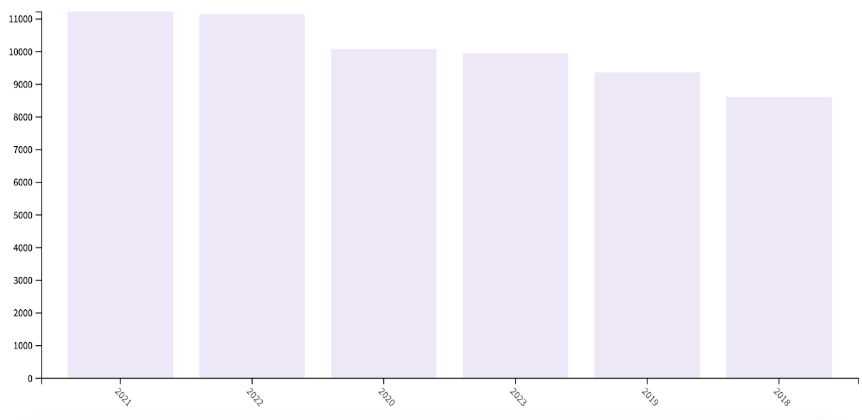

Figure 5. Projection of articles published in the period 2018-2023. Source: Web of Science.

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The search was restricted to Environmental Sciences; Green Sustainable Science Technology; Environmental Studies; Energy Fuels; Ecology; Economics. This choice was guided by the desire to maintain consistency with previous research on Scopus, excluding specific areas deemed not relevant to the subject of investigation. Furthermore, the analysis was limited to articles only. This selective step resulted in a total of 18656 articles identified as relevant for analysis.

The analysis conducted on WoS clearly indicated the European Community, with particular emphasis on the Horizon project, as the main promoter and funder of research in the field of energy communities. This figure reveals the European Community's far-reaching and incisive commitment to fostering development and innovation in the energy sector. Among the numerous papers reviewed, as many as 950 were identified as particularly relevant to our study. These documents, supported by European Community funding through the Horizon project, constitute a significant body of work in the field of energy communities. The identification of these articles underlines the importance and impact of EC policies and investments in promoting energy research and sustainable development.

2.3. Bibliometric keyword analysis from SCOPUS

VOSviewer, a software widely used in bibliometrics, supports the visualisation and analysis of bibliographies and datasets containing bibliographic information such as title, author, keywords, etc. [10,11]. Its versatility makes it possible to capture the trends, impact and evolution of topics through the recurrence of citations [12]. In the scientific research landscape, VOSviewer emerges as a valuable tool for visualising bibliometric data [13], revealing research opportunities in specific fields and identifying the most frequently used references [14].

The software focuses on aggregate-level analysis in the context of cluster analysis [15]. This tool was employed to examine and visualise the relationships between keywords; in particular, the VOS clustering method was applied to keyword occurrences, assigning each cluster a distinctive colour [16]. The interpretation of this approach is as follows: the size of the circles reflects the frequency of use, while the colours identify the clusters [17]. It should be noted that the x- and y-axes have no special significance; therefore, the maps can be freely rotated and flipped [17]. The results obtained from Scopus were exported in .CSV format to make them compatible with the Vosviewer software. Subsequently, a map was generated based on the bibliographic results, using both author and indexed keywords. In order to ensure meaningful representation, a minimum threshold of three occurrences was set to filter the keywords. This methodology aimed to identify the most relevant keywords in the field of study, thus providing a comprehensive and accurate overview of the key concepts emerging from the scientific literature.

In the context of the topic 'Energy Community' on Scopus, the relationships between central keywords, such as 'electric energy storage', highlight their cross-cutting relevance in various research contexts. It is a term that highlights the importance of electrical energy storage technologies, a key aspect in addressing the challenges related to the variability of renewable energy sources and ensuring a continuous and reliable supply of electricity.

The publications associated with this keyword drive the exploration and development of innovative solutions to store electricity efficiently and sustainably. This may include the study of different storage technologies, such as advanced batteries, thermal storage systems, mechanical storage, and other emerging technologies. Figure 6 shows the analysis conducted using Vosviewer for the results on Scopus.

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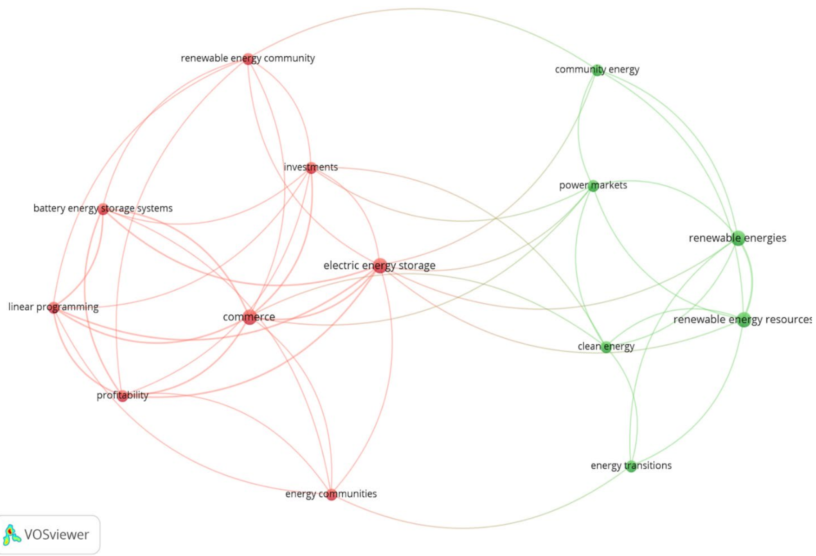

Figure 6. Bibliometric keyword analysis of articles and conference papers. Source: Scopus.

Interest in 'electric energy storage' spans several research areas, including optimising the performance of storage systems, assessing their environmental sustainability, integration into electricity grids, and practical application in sustainable energy communities. The analysis of publications and connections within the 'Energy Community' context shows how this keyword plays a transversal role, acting as a node between various other keywords and topics of relevance. Its centrality in research shows how the scientific community recognises the fundamental importance of electricity storage in promoting the transition to a more sustainable and resilient energy system.

In the right-hand section of the mapping (Figure 6), a perspective oriented towards a more sustainable and ecological approach clearly emerges, in which the keywords 'renewable energies' and 'renewable energy resource' are identified as paramount. This evidence translates into a significant commitment to research aimed at exploring, developing and optimising renewable energy sources. The presence of the construct 'renewable energies' emphasises the centrality of sustainable energy sources, such as solar, wind, hydropower and others. In parallel, the focus on 'renewable energy resource' emphasises the need to specifically investigate the natural resources used to generate renewable energy. This approach aims to understand the availability, variability and potential of these resources, helping to outline more effective strategies for the utilisation of renewable sources. These are correlated with other keywords such as 'community energy', 'power markets', 'clean energy' and 'energy transitions', thus outlining the direction of research towards current issues of crucial environmental importance. In particular, energy communities, represented by the keyword "community energy," indicates a paradigm of active participation and decentralisation in the production, distribution and sharing of energy. This concept emphasises the importance of local involvement and collaborative management of energy resources, pushing towards a more inclusive and responsible view of energy consumption.

In the context of the keyword 'power markets' (Figure 6), the presence of commercial mechanisms regulating the buying and selling of energy emerges. These markets provide energy communities with the opportunity to participate directly in energy production and consumption decisions, creating a dynamic environment where informed choices actively influence the local energy landscape. The keyword 'clean energy' emphasises the shift towards clean energy sources and low environmental impact technologies. In energy communities, this implies the adoption of renewable energy sources, such as solar and wind power, and the integration of technological solutions that promote environmental sustainability, thus helping to mitigate negative impacts on the ecosystem. Instead, the transition to new energy models is associated with the keyword "energy transitions." This concept denotes the transition from traditional systems to more modern, decentralised models based on renewable energy sources. In energy communities, "energy transitions" embody a significant change, moving energy practices towards sustainability and reducing dependence on polluting sources. In the left-hand section of Figure 6, the focus is on the more practical aspect, through keywords such as 'investments' and 'commerce', highlighting the economic and commercial aspect of energy communities. Interestingly, other keywords reflect the concept of energy communities and the need for a holistic approach to their full implementation. Among these, 'energy communities', 'renewable energy community', 'battery energy storage systems', 'linear programming', and 'profitability' stand out, each with a strategic role in research.

Energy Communities represent an innovative paradigm where local groups actively collaborate to generate, consume and share energy. These communities play a crucial role in the creation of a sustainable, decentralised and participatory energy model, promoting a transition to more energy-conscious practices. The keyword "Renewable Energy Communities" deepens this vision, focusing exclusively on the use of renewable energy sources. In this context, the keyword 'Battery Energy Storage Systems' represents a strategic theme. These energy storage systems, mainly batteries, optimise the storage phase of electricity when it is abundant, to make it available later when it is needed. This contributes to a more efficient and flexible management of energy resources. The analysis and application of 'Linear Programming' models emerge as fundamental tools for planning and optimising energy resources within communities. This advanced mathematical approach aims to maximise energy efficiency and minimise costs, promoting rational and economic management of available resources. Profitability plays a key role in the long-term sustainability of energy communities. Profitability analysis assesses whether community energy initiatives are economically viable over time, ensuring the autonomy and growth of the communities themselves. Ultimately, these keywords paint a complete picture of the dynamics and goals of modern energy communities. Furthermore, note how the keywords reflect the diversity of aspects considered in energy communities, from renewable energy production to intelligent resource management to financial optimisation. The combination of these components contributes to sustainable, resilient and technologically and economically advanced energy community models.

2.4 Bibliometric Keyword Analysis from Web of Science

The results obtained from Web of Science were exported in .txt format to be suitable for import into the Vosviewer software. Next, a visualisation was created based on the bibliographic results, using both authors' keywords and those indexed by the platform. In order to obtain a meaningful representation, a minimum threshold of three occurrences was set to filter the keywords. Figure 7 shows the analysis conducted via Vosviewer for the WoS results.

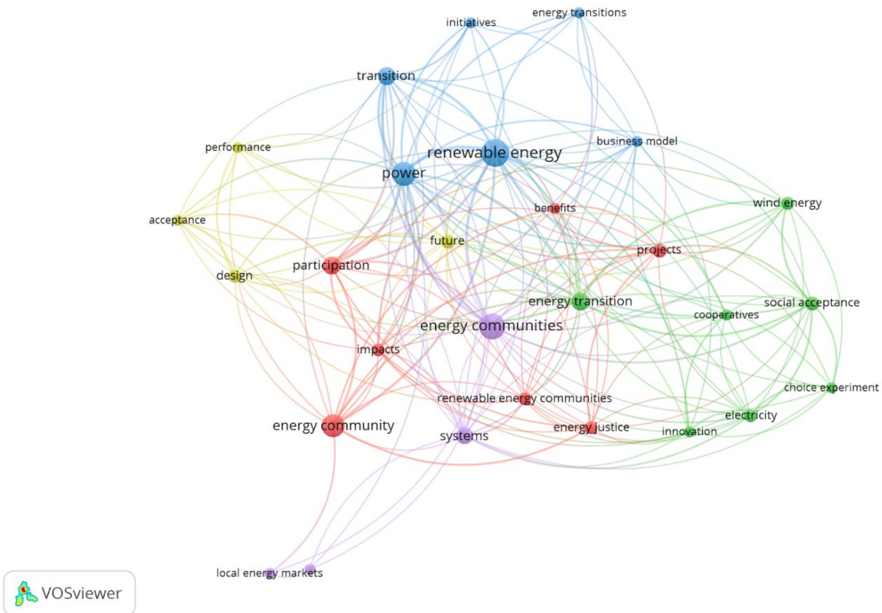

Figure 7. Bibliometric analysis of article keywords. Source: Web of Science.

Replicating the procedure already described, this time on the WoS results, two keywords emerge: "energy communities" and "renewable energy", which represent fundamental pillars of the scientific and social debate on the energy future. Energy communities are local groups that work together to manage and share energy in a sustainable and inclusive manner, promoting the adoption of decentralised and participatory practices. Renewable energy' refers to renewable energy sources, such as sun and wind, which are essential for reducing greenhouse gas emissions and promoting sustainable energy development. Several thematic areas are developed in the mapping in an articulated manner. The first area, which concerns energy transition, is structured around keywords such as 'power', 'transition', 'initiatives', 'energy transitions', and 'business model'. Each term has a precise meaning and impact: "Power" represents the driving force behind our energy system, while "Transition" indicates the fundamental change we are experiencing towards cleaner and more sustainable energy sources. Both highlight the importance of adopting new perspectives and approaches to energy use. Initiatives' highlights the concrete action of communities and actors involved in the energy transition, while 'Energy transitions' embodies the transformational path we must take to adapt to the environmental and energy challenges of our time. Finally, the 'Business model' represents the financial basis on which energy initiatives are built, highlighting the need for economic sustainability to ensure the longevity and effectiveness of energy projects.

It is then possible to identify a section that can be traced back to social aspects, thus "benefits", "projects", "participation", "impacts", "renewable energy communities", "energy justice", "local energy". These keywords share a common focus on the social, participatory and fair aspect of the energy transition.

"Benefits" refers to the advantages of adopting sustainable energy practices, such as economic savings, improved air quality and job creation in the renewable energy sector. "Projects" represents initiatives and interventions aimed at implementing innovative and sustainable energy solutions, involving both public and private entities, and aiming to improve energy efficiency and promote the adoption of renewable energy sources. "Participation" emphasises the active involvement of local communities in decisions concerning energy management and production, promoting a democratic and inclusive approach that values citizens' opinions and needs. "Impacts" indicates the effects, positive or negative, that energy policies and infrastructure projects may have on local communities, including environmental, social and economic aspects. "Renewable energy communities" represents the convergence of the renewable energy and community concept, highlighting the potential of community initiatives in promoting the adoption of sustainable energy sources and fostering local development. "Energy justice" recalls the importance of fair and equitable access to energy for all people, regardless of socio-economic or geographical status, and promotes inclusive energy policies that take into account the needs of all members of society. 'Local energy' refers to the production and consumption of energy at the local level, promoting decentralisation and diversification of energy sources to foster the security and resilience of the energy system. A further section deals with energy perspectives, conveying keywords such as 'acceptance', 'performance', 'future' and 'design', a comprehensive picture of energy transformation and its implications emerges.

"Acceptance" recalls the importance of social acceptance, indicating that energy policies must be accepted and supported by the community to ensure a successful transition. "Performance" highlights the need for efficient performance in energy systems, emphasising the importance of constantly evaluating and improving performance to maximise efficiency. "Future" indicates the need to consider the long-term impacts of current energy decisions and to adopt strategies that promote a sustainable and resilient future. "Design" draws attention to purposeful design, emphasising the importance of an integrated design approach in defining energy solutions. These elements converge to emphasise the urgent need for a holistic approach to energy transformation. In the rightmost section, key aspects contributing to shaping the future of energy emerge, highlighted by the following keywords: "energy transition", "cooperatives", "innovation", "electricity", "social acceptance", and "choice experiment". "Energy transition" represents the shift from conventional to renewable and sustainable energy sources, highlighting the need for a structural change in the energy sector to address environmental challenges. "Cooperatives" refers to energy cooperatives, which involve citizens and local communities in the production and distribution of renewable energy, promoting democratic participation and sustainability. "Innovation" indicates the importance of technological and social innovation in the energy sector, which is needed to develop more efficient, clean and affordable solutions. "Electricity" emphasises the crucial role of electricity as a primary source of energy in the modern world, highlighting the need for resilient management of electricity grids. 'Social acceptance' again reflects the importance of social acceptance of energy policies and infrastructure, highlighting the need to actively involve communities. "Choice experiment" refers to research methodologies used to assess the preferences and decisions of individuals regarding energy policies, enabling a better understanding of the dynamics of choice and the adaptation of energy transition strategies to the needs of the population. These keywords reflect a complex picture of energy transition, emphasising the importance of democratic participation, technological and social innovation, and adaptation to societal needs and preferences in shaping the future of energy.

3. Results

The bibliographic analysis conducted analysed the top 20 most cited articles, shown in Table 8, which revealed the state of the art of Energy Communities

Table 8. State-of-the-art analysis of energy communities. Source: Web of Science/ Scopus [18-37].

Title	Authors	Year	Database	Cit
Peer-to-peer energy sharing through a two-stage aggregated battery control in a community Microgrid	Long, C; Wu, JZ; (...); Jenkins, N	2018	WOS	317
Air temperature optima of vegetation productivity across global biomes	Huang, MT; Piao, SL; (...); Janssens, IA	2019	WOS	300
Renewable energy communities under the 2019 European Clean Energy Package - Governance model for the energy clusters of the future?	Lowitzsch, J., Hoicka, C.E., van Tulder, F.J.	2020	Scopus	294
Regulatory challenges and opportunities for collective renewable energy prosumers in the EU	Inês, C., Guilherme, P.L., Esther, M.-G., ...Stephen, H., Lars, H.	2020	Scopus	256
Local electricity market designs for peer-to-peer trading: The role of battery flexibility	Lüth, A; Zepter, JM; (...); Egging, R	2018	WOS	254
Carbon-concentration and carbon-climate feedbacks in CMIP6 models and their comparison to CMIP5 models	Arora, VK; Katavouta, A; (...); Ziehn, T	2020	WOS	226
BioTIME: A database of biodiversity time series for the Anthropocene	Dornelas, M; Antao, LH; (...); Zettler, ML	2018	WOS	223
Local Energy Markets: Paving the Path Toward Fully Transactive Energy Systems	Lezama, F., Soares, J., Hernandez-Leal, P., ...Pinto, T., Vale, Z.	2018	Scopus	220
Microbial carbon limitation: The need for integrating microorganisms into our understanding of ecosystem carbon cycling	Soong, JL; Fuchslueger, L; (...); Richter, A	2020	WOS	218
Regional climate downscaling over Europe: perspectives from the EURO-CORDEX community	Jacob, D; Teichmann, C; (...); Wulfmeyer, V	2020	WOS	212
Local flexibility market design for aggregators providing multiple flexibility services at distribution network level	Olivella-Rosell, P., Lloret-Gallego, P., Munné-Collado, Í.Rajasekharan, J., Bremdal, B.A.	2018	Scopus	179
Prosumer integration in wholesale electricity markets: synergies of peer-to-peer trade residential storage	Zepter, JM; Lüth, A; (...); Egging, R	2019	WOS	139

Designing local renewable energy communities to increase social acceptance: Evidence from a choice experiment in Austria, Germany, Italy, and Switzerland	Azarova, V., Cohen, J., Friedl, C., Reichl, J.	2019	Scopus	113
Implementing a just renewable energy transition: Policy advice for transposing the new European rules for renewable energy communities	Hoicka, C.E., Lowitzsch, J., Brisbois, M.C., Kumar, A., Ramirez Camargo, L.	2021	Scopus	103
Circular Economy Strategies in Eight Historic Port Cities: Criteria and Indicators Towards a Circular City Assessment Framework	Gravagnuolo, A; Angrisano, M and Girard, LF	2019	WOS	91
Day-Ahead Scheduling of a Local Energy Community: An Alternating Direction Method of Multipliers Approach	Lilla, S., Orozco, C., Borghetti, A., Napolitano, F., Tossani, F.	2020	Scopus	87
Empowering vulnerable consumers to join renewable energy communities-towards an inclusive design of the clean energy package	Hanke, F., Lowitzsch, J.	2020	Scopus	65
PV sharing in local communities: Peer-to-peer trading under consideration of the prosumers' willingness-to-pay	Perger, T., Wachter, L., Fleischhacker, A., Auer, H.	2021	Scopus	57
Collective action and social innovation in the energy sector: A mobilisation model perspective	Gregg, J.S., Nyborg, S., Hansen, M., ...Sciullo, A., Padovan, D.	2020	Scopus	51
Overview of emerging regulatory frameworks on collective self-consumption and energy communities in Europe	Frieden, D., Roberts, J., Gubina, A.F.	2019	Scopus	48

Energy communities represent fertile ground for innovation and transformation in the energy sector, demonstrating how collaboration and adoption of new technologies can lead to more sustainable and democratic energy systems [38]. These communities are emerging as key players in Europe and other parts of the world, highlighting a conjunction of regulatory challenges and innovative governance with benefits ranging from saving money to increasing social cohesion [36].

At the technological level, innovation is a key pillar for energy communities, with the adoption of advanced solutions such as energy storage systems, electric vehicles, the use of Digital Twin and machine learning algorithms [22]. These technologies not only optimise energy consumption and distribution, but also enable community members to participate actively and with greater awareness in the management of energy resources [29,34]. Key aspects include peer-to-peer energy sharing, which allows users to exchange energy, without the mediation of large suppliers. This is often facilitated through advanced battery management systems and community microgrids [18].

From a governance perspective, energy communities explore various models that may include cooperative, state and market elements. These models must effectively balance participatory democracy and operational efficiency to facilitate not only the growth and scalability of the communities themselves, but also to ensure a fair distribution of economic and social benefits among their members [20]. Regulation plays a crucial role, with the European legislative framework still evolving to provide consistent support for energy communities. The absence of a uniform legal definition and different interpretations of what constitutes an energy community show the need for greater clarity and harmonisation at the policy level to facilitate the expansion of these initiatives [21,31].

Finally, the educational and awareness-raising role that institutions are beginning to play is crucial in promoting understanding and support for energy communities [29]. This awareness-raising is essential to promote greater adoption and to educate citizens who are aware of the energy and environmental implications of their daily choices [36].

4. Discussion

The study emphasises the key role of energy communities in using waste to improve energy self-sufficiency and promote sustainability [39]. The results reveal that these communities effectively manage waste and exploit it as a significant energy resource, contributing to the reduction of greenhouse gas emissions and dependence on non-renewable energy sources [40]. This is in line with existing research, such as the study by Nolden (2013) [5] and reports by the International Energy Agency, which highlight the transformative potential of decentralised energy models in promoting landscapes to sustainable energy models.

The implications of our findings go beyond the operational successes of individual communities, suggesting broader impacts on sustainability practices and environmental policy. This research supports policy interventions that facilitate the expansion of similar initiatives [41]. It suggests that incentives for technology investment and regulatory support for renewable energy projects could significantly improve the scalability of community energy systems [42, 43].

Despite these promising results, our study identifies several challenges. The implementation of energy solutions is often hampered by technological barriers, upfront financial costs and regulatory complexities [44].

Future research should explore the integration of alternative and technologically advanced systems within community energy models. Longitudinal studies could provide insights into the long-term sustainability and economic viability of these systems. In addition, comparative research in various geographical and socio-economic contexts would help delineate the conditions under which community energy systems can flourish.

In conclusion, our study reaffirms the critical role of community-based energy systems in promoting renewable energy and mitigating climate change [45]. Active participation of communities, supported by favourable policies and educational initiatives, is essential for the success and sustainability of these models [46]. As the world continues to face environmental challenges, energy communities offer a promising path towards a more sustainable and resilient energy future [34].

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