Exploring the academic landscape of energy communities in Europe: A systematic literature review

Exploring the academic landscape of Energy Communities in Europe: a Systematic Literature Review

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Abstract

Over the past few years, energy communities initiatives have gained traction in Europe as a means to achieve energy transition goals, allowing citizen involvement in energy production, consumption, and distribution. Following the 2018 European directive RED II, these projects have rapidly increased across the continent, showcasing their potential for creating sustainable local energy systems. While studies highlight economic, environmental, and social benefits, barriers such as regulatory challenges, finance access, and low public awareness remain. This paper presents the results of a systematic literature review that explores the state-of-the-art of the academic research on energy communities. The study adopts a systematic approach to examine the body of literature on the topic to provide a comprehensive analysis of the phenomenon on the basis of rigorous and replicable research criteria. The reviewed material consists of 140 articles collected through the Scopus database, evaluated using specific structural dimensions to group the literature into analytical categories. The analysis of scientific papers published between 2018-2022 shows a growing attention towards Renewable Energy Communities, particularly those based on solar energy for electricity production, often combined with storage systems and heat pumps, whereas attention towards energy communities based on thermal energy production is still limited. Furthermore, most scholars focused on analysing specific territorial contexts; comparisons between different regions allows to highlight common features and elements characterizing each model. It emerged that the development of energy communities depends mainly on regulatory, financial, and managerial barriers that require an adequate institutional and legal framework capable of promoting their diffusion. Most studies address the topic from an economic perspective, often in association with incentivizing community models. However, a social perspective should be included by introducing the concept of energy sharing and methodologies for its distribution among all members of the community. The scientific community is called upon to continue investigating and supporting the development of community energy initiatives by providing evidence-based recommendations to policymakers, industry stakeholders, and local communities. This can help to overcome existing barriers and facilitate the diffusion of energy communities models, contributing to the achievement of sustainable and inclusive energy transition goals.

Keywords: Renewable Energy Community, Citizen Energy Community, Collective Self Consumption, Systematic literature review, Sustainability, Energy transition

Nomenclature

BEP	Break Even Point	MILP	Mixed Integer Linear Programming
BESS	Battery Energy Storage System	MOO	Multi Objective Optimization
BIPV	Building Integrated Photovoltaic System	MPC	Model Predictive Control
CEC	Citizen Energy Community	NPV	Net Present Value
CEP	Clean Energy Package	PCR	Percentage Cost Reduction
CRE	Community Owned Renewable Energy	PtG	Power to Gas
CSC	Collective Self Consumption	PV	Photovoltaic
CS	Cooling System	REC	Renewable Energy Community
DPP	Discounted Payback Period	RED	Renewable Energy Directive
DR	Demand Response	RPV	Rooftop Photovoltaic
EAC	Equivalent Annual Cost	SG	Smart Grid
EC	Energy Community	SOO	Single Objective Optimization
EV	Electric Vehicle	SPP	Simple Payback Period
ICES	Integrated Community Energy System	SWH	Solar Water Heater
IEMD	Internal Electricity Market Directive	TEC	Thermal Energy Community
IRR	Internal Rate of Return	TES	Thermal Energy Storage
LP	Linear Programming	WPP	Wind Power Plant
MES	Multi Energy System		

1. Introduction

In recent years, the global energy landscape is undergoing profound changes, since the growing impact of fossil fuels as the main energy source is giving way to new clean energy solutions, paving the way to a worldwide energy transition. Over the past few years researchers have widely addressed the issue relating the global changes in the energy system. (Sovacool, 2016) investigated the temporal issue in energy transitions, highlighting how transitions are long and protracted events, (Cherp et al., 2018) conceptualized national energy transitions through three types of systems: energy markets, energy technologies and energy policies. (Rogge et al., 2017) underlined the great magnitude of energy policies in order to overcome the multiple obstacles that hinder the energy transition. The development energy policies oriented to environmental sustainability is crucial; in several countries, governments have been engaged in the establishment of policies and regulation to promote the production and consumption of renewable energy. Scholars have analysed how the approach to energy transition may vary in different countries: (Lu et al., 2020) reviewed articles aimed at promoting energy policy development in the USA, Germany, the United Kingdom, Denmark, and China; (Brown, 2001) highlighted the importance of policies in the USA to support research into future scenarios for clean energy; (Chen et al., 2014) reviewed the development of renewable energy policies and roadmaps in Japan, Korea and Taiwan; (Liu et al., 2013) highlighted the importance of policies and governments to decarbonise the energy sector in China, (Winkler, 2007) in South Africa, (Griffiths, 2017) in West and North Africa and (Peyerl et al., 2022) in South America. There are many studies dealing with the evolution of energy policies in Europe; (Kitzing et al., 2012; Klessmann et al., 2011) investigated how supporting policies were applied in European Union (EU) member states between 2000-2010, comparing them with what was required to achieve the goals in 2020.More recently, (Kulovesi and Oberthür, 2020) provided a comprehensive overview of the changes in EU climate and energy legislation as a result of the 2030 policy framework. The path to energy transition can therefore take different forms, depending on how countries interpret the energy transition. In addition to the development of renewable energy sources and the improvement of energy efficiency, a key element is the role of different components of society in contributing to this change, through the development of new methods for sustainable generation, transmission, storage, and consumption of energy. One element of the energy transformation is the shift from centralized energy systems based on fossil fuels to decentralized energy systems based on renewable energy sources(Gielen et al., 2019). Therefore, it is necessary to improve the control of flexible assets in distribution networks in order to defer network reinforcement and avoid overloading of substations and low-voltage cables, as well as voltage violations (Gonzalez Venegas et al., 2021; Sudhoff et al., 2022). In this context, several energy communities (ECs) and collective self-consumption (CSC) projects have emerged (Minas, 2020).

Energy communities are playing an important role in the transition from a traditionally centralized energy market dominated by fossil fuels to a more decentralized and democratized one (Brisbois, 2020; Mucha-Kuś et al., 2021), enabling citizens to be the main actors of energy transition. New governance models have been created in Europe as a result of EC projects, offering an "enabling framework" to compare these models to those of other market participants and to encourage and support their growth. In 2016, through the formalization of the "Clean Energy Package for all Europeans", the European Commission recognized initiatives aimed at promoting collective self-consumption and the creation of energy communities (European Commission. Clean energy for all European packages). After two years, this package was finalized and the concept of Energy Community and Self-Consumers acting Collectively were formalized in two European directives: the EU Renewable Energy Directive 2018/2001 (RED II) of 11 December 2018 (Directive(EU)2018/2001), and the EU Internal Electricity Market directive 2019/944 (IEMD) of 5 June 2019 (Directive(EU)2019/944). The RED II gave a generic overview in article 2, where the concepts of "Renewable Self-Consumer" and "Renewable Energy Community" were introduced, then defined respectively in article 21 and 22. The

IEMD, on the other hand, provided an overview in the article 2 in which the concept of "Citizen Energy Community" was introduced, then defined in article 16.The 27 Member States (28 before the Brexit) should have transposed the RED II into national legislation by 21 June 2021. From that moment, prosumers have the right to consume, store or sell the energy produced on their premises also through agreements of buying and selling renewable electricity.

The implementation of these global rules requires the creation of a regulatory environment and a support framework, as well as the creation of new business models aimed at encouraging consumer participation in the in order to allow co-investments of different types of actors, aimed at promoting the diffusion of ECs in the market. Considering the multiplicity of concepts, the factors influencing the transition to ECs in Europe have been approached and studied from different perspectives and with different priorities. In this context, this paper presents the results of a systematic literature review that explores the state-of-the-art of scientific community on ECs. A more detailed explanation is presented in Section 2, which introduces the aim of the review, formulates the research questions, and defines its contribution to EC research. Then, Section 3 describes the research methodology used; Section 4 focuses on how the material was gathered to perform the review. Section 5 presents the bibliometric evaluation and descriptive analysis of the results; Section 6 firstly describes how the structural dimensions and analytical categories were identified, secondly it presents the evaluation of the results; Section 7 includes the discussion and the limitations of this study, proposing future lines of research.

2. Aim of the review and the formulation of research questions

Several studies reviewed scientific publications on energy communities. The emergence of EC does not occur to the same extent or at the same speed in all countries; (Lode et al., 2022) examined the factors influencing the emergence of EC and proposed way for future research to aid in their dissemination. Other studies aimed to identify the concepts and definitions relating to Energy Communities and Collective Self-Consumption: (Bauwens et al., 2022) analyzed 183 definitions codified through three specific focuses regarding meaning, activity and purpose of the community, (Gruber et al., 2021) proposed an analysis of the presence of EC concept in the literature, while (de São José et al., 2021) showed that there are many overlapping concepts and definitions of the energy community, creating confusion among researchers.

Other studies addressed specific issue of ECs: (Fouladvand et al., 2022; Papatsounis et al., 2022) analyzed the emergence of Thermal ECs (TEC), (F. Ceglia et al., 2022; Trivedi et al., 2022) examined recent literature on Smart ECs, (Lazdins et al., 2021) analyzed the political, economic and social aspects of PV ECs, (Berka and Creamer, 2018) identified the approaches needed to understand the local effects of community-owned renewable energy (CRE), (Koirala et al., 2016) examined energy trends that shape the development of integrated community energy systems (ICES).

Other studies focused more on government and policy aspects: (Busch et al., 2021; Leonhardt et al., 2022), (Sousa et al., 2019) analyzed the new P2P markets based on a consumer-centric perspective in relation to the concept of energy sharing, (Gjorgievski et al., 2021) analyzed the technical design's aspects of local energy systems by the economic, environmental, and social impacts of ECs.

Other studies had a specific geographical focus: (Di Silvestre et al., 2021) deals with the development of Energy Communities in Italy, (Ambole et al., 2021) in Africa, (Klein and Coffey, 2016) in USA, while (van der Schoor and Scholtens, 2019) pointed out that EU energy research has only recently become active and that it mainly looks at "developed" countries, with a particular focus on United Kingdom, United States, Germany, and the Netherlands. Other studies focused on the European context: (Hewitt et al., 2019) collected, described, and mapped EC initiatives from Belgium, France, Germany, Italy, Poland, Spain, Sweden and United Kingdom, (F.G. Reis et al., 2021) analyzed the business models of existing and emerging EC by analyzing projects across Europe, (Busch et al., 2021) conducted a review of the scientific literature on Energy Communities in Europe through a policy lens, while (Wuebben et al., 2020) focused on the Citizen Energy Community (CEC) introduced by the IEMD.

The aforementioned papers are collected in Appendix A in Table 1 that shows the main features of literature reviews on energy communities published in recent years, performed with a systematic approach based on rigorous and reproducible search criteria. In this framework, the present paper aims at providing an exhaustive and comprehensive overview of academic studies on RECs, CECs, and CSCs in the European context, identifying barriers and gaps in order to provide future research directions on the topic.

Therefore, the study addresses the following research question: how does the academic world approach the study of these new subjects introduced by European directives? From these Research Questions arise additional inquiries. Firstly, which disciplinary perspectives and methodologies are employed to study the topic? Secondly, what are the current and future technologies, energy sources, and management strategies for energy communities? Compared to previous reviews, the present paper contains several innovations that add value to a better understanding of the topic. Firstly, a clearly defined perimeter was established for analyzing the scientific literature pertaining to the three forms of energy communities introduced by the European directives of 2018 and

2019. To this purpose, approximately 200 documents written from 2018 to the present day were collected for analysis, focusing on those that encompass Renewable Energy Community (REC), Citizen Energy Community (CEC), and Collective Self Consumption (CSC). In order to address the main questions concerning ECs, structural dimensions and analytical categories have been defined, allowing for an effective and systematic organization of the existing literature. Specifically, structural dimensions are the main elements that guide the organization and analysis of scientific works within a specific context. The present work focuses on various aspects such as energy resources, technologies, methodology and geographical focus. Analytical categories represent subcategories that allow for a detailed breakdown within each structural dimension. For instance, analytical categories for energy resources can include biogas, solar, hydrogen, wind, etc. These categories provide greater specificity in analyzing data and information in scientific literature.

3.Materials and Methods

The methodology used to perform the systematic literature review follows the guidelines of (Denyer and Tranfield, 2009) and (Mayring and Brunner, 2007) in order to integrate a qualitative and quantitative analysis investigating a specific topic (Brewerton and Millward, 2001), reducing the potential constraints of narrative reviews (Tranfield et al., 2003). (Kitchenham, 2004) defined systematic literature review as a study whose purpose is to 'identify, evaluate, and interpret all available research related to a particular topic, research question, or phenomenon of interest'. With respect to individual studies or primary studies, this is a form of secondary study that collects, group and evaluate research previously performed by scholars (Brereton et al., 2007). This approach, that can be considered as a content analysis, provides a transparent and repeatable process for the selection and reporting of research previously conducted on a given topic, setting specific steps starting with the formulation of research questions. Next, material collection and descriptive analysis are provided to give a first categorization of the results. The third step is to define topic-specific structural dimensions and their related analytical categories. Finally, the collected material is assessed following the structural dimensions and analytical categories and relevant evaluations are made with respect to the research questions formulated at the beginning of the process (Seuring and Gold, 2012). The review process was divided into five main phases, summarized in Figure 1. This approach has been widely employed to perform review in the field of supply chain management (Seuring and Müller, 2008; Singh and Khaire, n.d.) and sustainability studies (Brandenburg et al., 2014; Karatzoglou, 2013; Merli et al., 2020). Methodologies and categories used for the evaluation process, carried out according to the abovementioned phases, are presented in the following sections

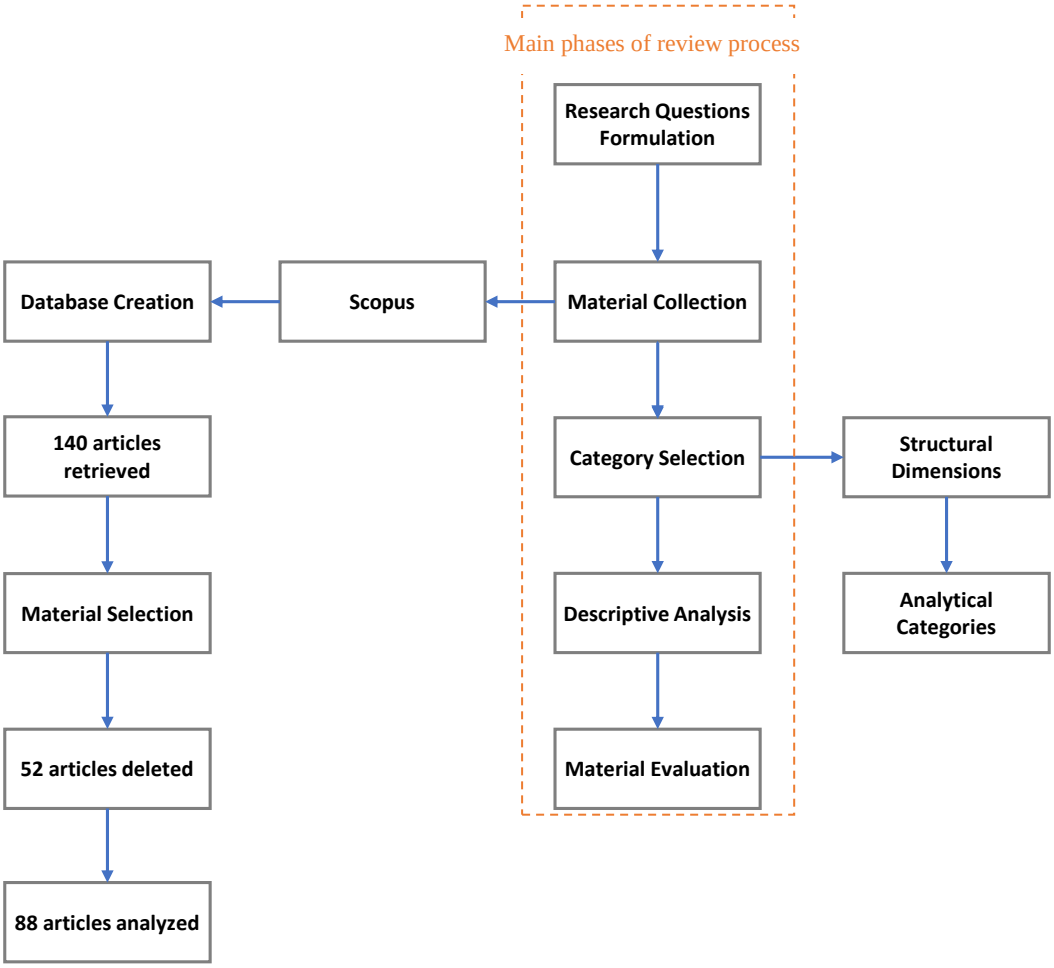

Figure 1. Summary of the review process

3.1 Material Collection

The material was collected through the use of Scopus as a scientific database. Elsevier introduced Scopus to the information market in 2004, and it is one of the largest multidisciplinary scientific literature databases (Chadegani et al., 2013); moreover, Scopus exhibits a high degree of singularity, this feature is of particular interest when selecting information sources for future research (Sánchez et al., 2017). According to (Díaz-García et al., 2015; Salim et al., 2019), Scopus is the database with the greatest data coverage with respect to the ISI database and has more stringent methodological criteria for database coverage. In the review process, the unit of analysis was defined as the single research article. Generally, the results were limited to articles and reviews published in academic journals by setting specific field search criteria of title, abstract and keywords, as well as setting a specific chronological limitation and including only EU member countries. The query returned 140 results; subsequently, these results were critically evaluated in order to select the studies that were coherent with the scope of the review. The following is the query employed for the Scopus research:(TITLE-ABS-KEY("Renewable Energy Community") OR TITLE-ABS-KEY("Citizen Energy Community") OR TITLE-ABS-KEY("Collective Self Consumption") OR TITLE-ABS-KEY("Collettive Self Consumption") AND PUBYEAR > 2017 AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "re")) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (SRCTYPE, "j")) AND (LIMIT-TO (AFFILCOUNTRY, "Country xxx") OR LIMIT-TO (AFFILCOUNTRY, "Country xxx"). With the aim of ensuring relevance to our research objective, an initial file selection has been performed based on abstract readings. Afterward, for those necessitating more rigorous examination, the complete articles were thoroughly assessed. A total of 52 articles were rejected due to their primary focus not aligning with any of the three forms of ECs introduced by the EU directives. For example, (Barbour et al., 2018) included *renewable energy communities* among the keywords, but since it was published in early 2018, it did not address the ECs European forms; (Azarova et al., 2019) published an article in 2019 on local energy communities but analyzed

data from a survey conducted between November and December 2017; (Iskandarova et al., 2022) mentioned *collective self-consumption* in the keywords but the description does not match with the definition introduced by the REDII.

3.2 Categories Selection

According to the research questions formulated in the introduction, the structural dimensions and the analytical categories were chosen (Mayring and Brunner, 2007; Shukla and Jharkharia, 2013). This phase was characterised by a concept-centric approach to the analysis of the literature (Webster and Watson, n.d.) that employs an iterative process with a deductive approach to identify analytical categories used in previous literature. Regarding the research questions introduced in Section 2, Figure 2 illustrates how categories were chosen and materials were evaluated. The feedback loop represents the ongoing process of refining the structural dimension and analytic categories as the literature review progresses. This framework facilitated an iterative approach that began with a deductive method, using the analytic categories found in prior research. Once the analytic categories were identified, a preliminary scan of the collected material were conducted. Subsequently, with an inductive process those analytical categories not suitable for the review were discarded and, when necessary, new ones were created (Mayring and Brunner, 2007; Shukla and Jharkharia, 2013). ECs topic was analysed through the selected structural dimensions and the related analytical categories listed in Table 2.

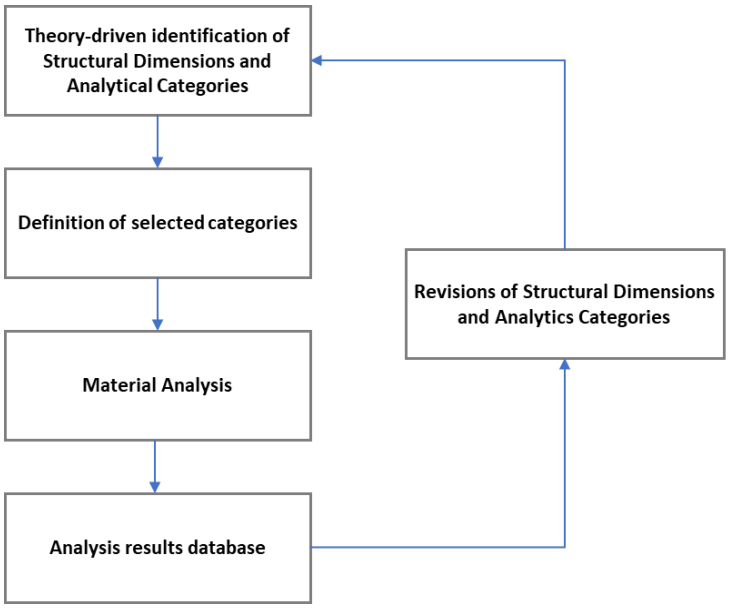

Figure 2. Research process of a structured review analysis

Table 1. Structural dimensions and analytical categories

Structural dimensions	Analytical categories
Energy resource	• Biogas • Biomass • Fossil Fuel • Geothermal • Hydro • Hydrogen* • Solar • Wind
Energy technologies	• CHP • CS • DHN • HP • PV • PtG

	• SHW • BESS • EV • WPP
Geographical focus	• Comparative analysis • Geographical area • Single country
Legislative framework	• CEC • CSC • REC • Directive transposition • National regulation
Management and control	• Benefit sharing • Control strategy • Demand response
Research methodology	• Case study • Modelling and simulation • Real data • Review • Survey • Theoretical and conceptual
Subject area	• Business and management • Computer science • Economic and finance • Innovation • Policy and legislation • Social science • Strategy management • Technologies
Sustainability	• Economic • Environmental • Social

* hydrogen is commonly recognized as an energy vector rather than a primary resource, for the convenience of categorization within the context of energy resources, it is included due to its substantial utilization as a viable energy source within communities."

4. Results

4.1 Descriptive Analysis

In order to study the correlation between the geographical location of the authors' affiliation of the papers analysed and the research topic, CiteSpace (Chen et al., 2010), that is a freely available Java application for analysing literature data, was used. As a first step, nodes of the network were created based on the country origin of each paper in the analysed database. Then, the clustering algorithm was adopted in order to partition the network and identify clusters in the database. In particular, the clustering algorithm identifies in the same group nodes with strong connections and assign loosely connected nodes to different clusters (Chen et al., 2010). Once the clustering operation was performed, the cluster labels were selected using the Automatic Cluster Labelling (Chen et al., 2010) based on the noun phrases extracted from the titles of the paper. In particular, labels were chosen using a ranking algorithm based on the log-likelihood ratio (LLR) test (Dunning, 1993). The resulting network diagram together with clusters labels is reported in Figure 3.

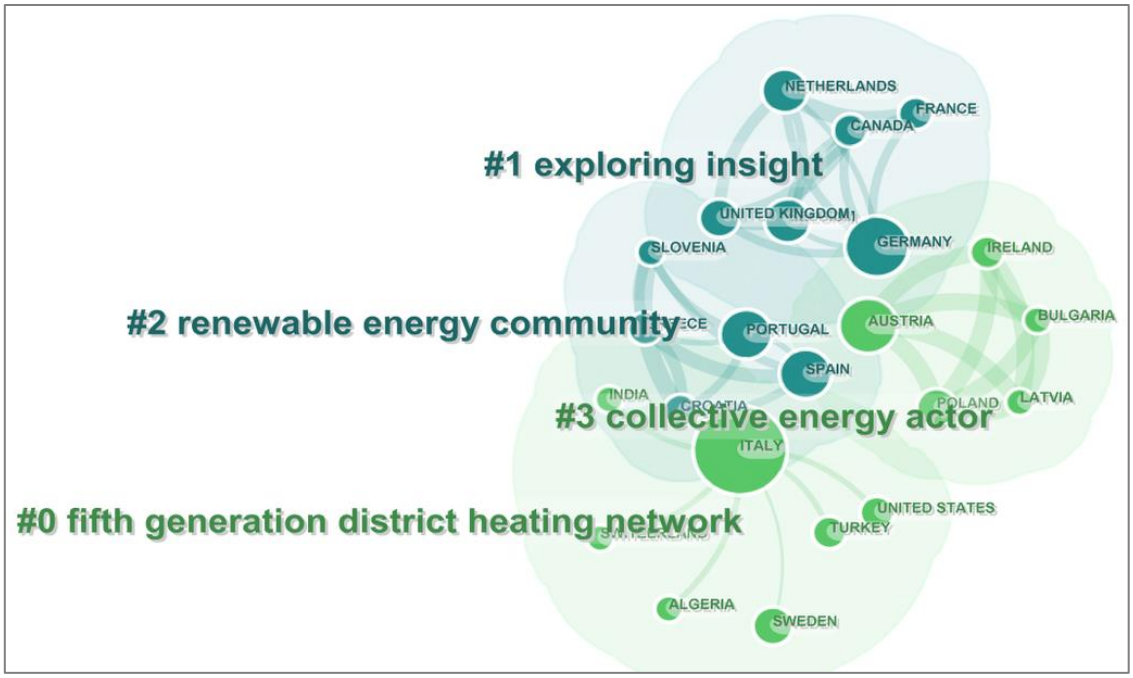

Figure 3. Network diagram: country is used to create the nodes while titles of papers is used to create the clusters

As it can be seen from Figure 3, the clustering algorithm adopted identified 4 clusters:

- Fifth generation district heating network
- Exploring insight
- Renewable energy community
- Collective energy actor

It is interesting to observe that largest cluster identified is “Fifth generation district heating network”, indicating that a connection exists between the concept of EC and the one of exchanging thermal energy between buildings. This fact may suggest that in the future the energy exchange concept may occur not only in terms of electric energy, but also in terms of thermal energy. Furthermore, it is also interesting to notice that the most cited country in this cluster is Italy, indicating an active research interest on the topics of EC and district heating. Moreover, focussing on the clusters location in the network, strong connections seem to exist between the “Fifth generation district heating network” and the “Renewable energy community” clusters, indicating that papers within these two groups are significantly correlated. Regarding the geographical location of the authors’ affiliation, Figure 3 shows that institutions in different countries are dealing with the research topic of Energy Communities focussing on different aspects. In particular, it appears that countries located in the cluster ”exploring insights” are very few connected to those that belong to the cluster “Fifth generation district heating network”. This fact suggests that research interests are different and that institutions are concentrating their research efforts on different aspects, even if all related to the EC research topic.

4.2 Material Analysis

Methodology

Firstly, the structural dimension "Research methodology" was used for the review of the documents which was covered by supply chain management studies dealing with sustainability issues (Hassini et al., 2012; Seuring and Müller, 2008). The dimension includes five methodological approaches to research (analytical categories):Case Study, Modelling and simulation, Review, Survey, Theoretical and conceptual. To better identify studies that explore the development of Energy Communities using real consumption data, a new category specifically dedicated to this topic (i.e., “Real data”) was create. Real consumption data refer to operational energy loads, directly monitored at the end users or collected in data set. They reflect variations and fluctuations in consumption that occur over time due to a high acquisition frequency (e.g., 15 minutes), thus providing an accurate representation of end-user behaviour and enabling to perform data-driven simulations. For example, (Barreto et al., 2022) used real data for end-users’ consumption and generation monitored through IoT devices with 15 min resolution; (Francesca Ceglia et al., 2022) used real building energy load imported from an energy distributor dataset; (Ghiani et al., 2022) performed an

analysis based on real data recorded with smart meter installed at end users' premises. Figure 4 shows the partition of articles according to research methodologies. The categories most employed are "Modelling and simulation" and "Case Study" with respectively 51 and 53 papers, showing that researchers may have adopted an experimental approach to explore the potentials and limitations of the new ECs models, by testing and simulating different scenarios in different national regulatory contexts, seeking to understand the main novelties introduced by EU directives. The methods and modelling approaches most used by scholars for the development of Energy Communities are summarized in Table 3. Many articles deal with case studies of a single country, while other scholars make a comparative analysis between Netherlands and Denmark (Neska and Kowalska-Pyzalska, 2022), France and Germany (Wainer et al., 2022). Other studies adopted a "Theoretical and conceptual" approach and "Survey", that could be related to the need to clarify the complexity of these models, given the involvement of multiple actors and stakeholders, such as producers, consumers, local authorities, and network operators. In addition, the "Survey" includes interviews as well, serving as another valuable method to collect specific data and information regarding energy communities. Interviews, much like surveys, enable the gathering of insights on experiences, opinions, perceptions, or approaches. For example, (Coenen and Hoppe, 2022) used empirical data from the EU's REScoop Plus project, which includes expert interviews and surveys among RECs to evaluate the effectiveness of energy-saving actions; (Kojonsaari and Palm, 2021) conducted a case study on the planning process of a sustainable city district in Sweden by utilizing participatory interviews with relevant stakeholders; (Spasova and Braungardt, 2021) combined a literature review with expert interviews gathering information to provide scientific evidence to support the development of a policy framework for REC in Eastern European Member States. Moreover, the regulation and governance of such ECs require an integrated and multi-disciplinary approach that considers both technical and economic aspects, as well as social and environmental ones. In particular, (Bernadette Fina et al., 2022) presented a framework for the impact of large-scale introduction of RECs, (Iazzolino et al., 2022) focused on factors influencing business models for energy sharing, (Hanke et al., 2021), through the analysis of data from 71 RECs investigated the social role they play, (Inês et al., 2020) compared the regulatory framework of 9 European countries. (Heldeweg and Séverine Saintier, 2020) analysed the role of RECs in light of the goals of democratization and energy decentralization. The analytical category with less contribution is "Review" (only 5 of the articles are reviews): this is somehow expected, since nowadays academic research is still ongoing, and the topic is continuously evolving.

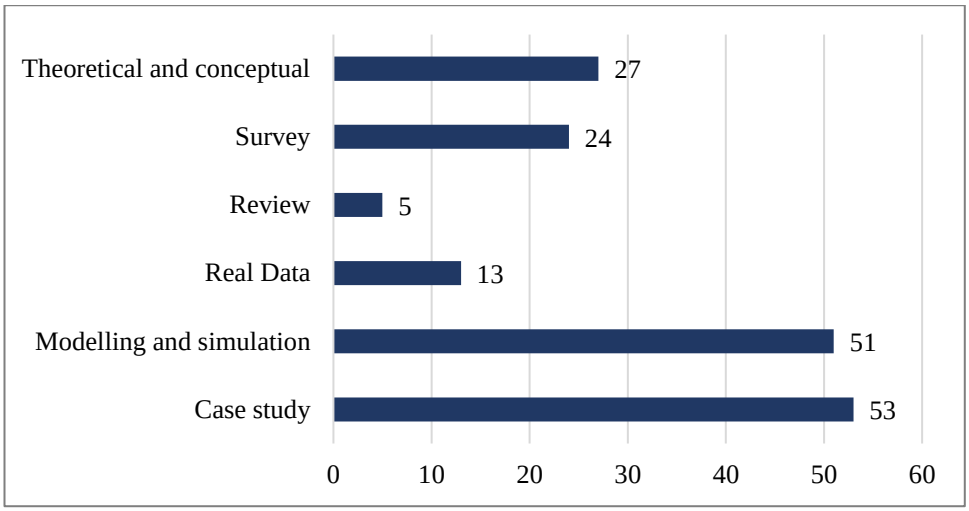

Figure 4. Distribution of analytical categories related to research methodology

Table 2. Method and modelling approaches

Authors	Model Features	Software/Environment
(Volpato et al., 2022) (Cosic et al., 2021) (Cielo et al., 2021) (Talluri et al., 2021) (Rossi et al., 2021)	MILP	Gurobi, Python
(Negri et al., 2022)	MPC	HomerPRO
(Golla et al., 2022) (Secchi et al., 2021)	MOO	Borg MOEA, OpenDSS

(B. Fina et al., 2022) (Weckesser et al., 2021) (Stroink et al., 2022)	LP	Pyomo, IBM (CPlex)

Subject Area and Sustainability

Figures 5 and 6 show the repartition of studies between the analytical categories related to the structural dimensions Subject Area and Sustainability. Through the analysis of various scenarios in different national regulatory contexts, scholars have deeply investigated the "Economic and finance" aspect, consisting of 47 research papers. Moreover, they have extensively researched the "Policy and legislation" of ECs, which has garnered significant attention with 40 papers. This attention is particularly crucial as policies play a crucial role in establishing a regulatory framework that encourages the involvement of different stakeholders in the generation and distribution of renewable energy at the community level. Several studies focused on specific national regulation, (Eichman et al., 2022) provided a review of policy framework in Spain, (Di Silvestre et al., 2021) in Italy, (Spasova and Braungardt, 2021) in Bulgaria and Germany, while (Hoicka et al., 2021) highlighted the benefits and main challenges for the development of the RECs in the process of transposition by EU members. Other studies analysed the ECs from a social point of view: (Hanke et al., 2021) exploited the energy justice framework to examine how ECs actively contribute to promoting social equity by enabling the participation of marginalized groups; (Efthymiou et al., 2022) introduced a tool to facilitate decisional process about developing REC in Crete (Greece); (Laes and Bombaerts, 2022) examined through Foucault's theory of governance the compatibility between the ideals of the energy community and neoliberalism, which has guided EU energy policy for the last four decades; (Conradie et al., 2021) conducted a study in Belgium to investigate how people's attitudes, subjective norms, and perceived behavioural control affect their intentions to participate in a REC.

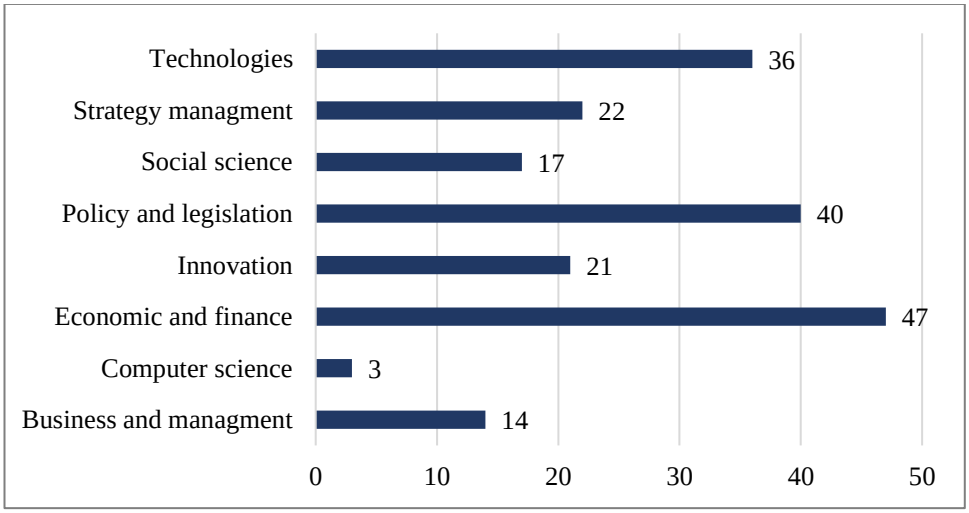

Figure 5. Distribution of analytical categories related to subject area

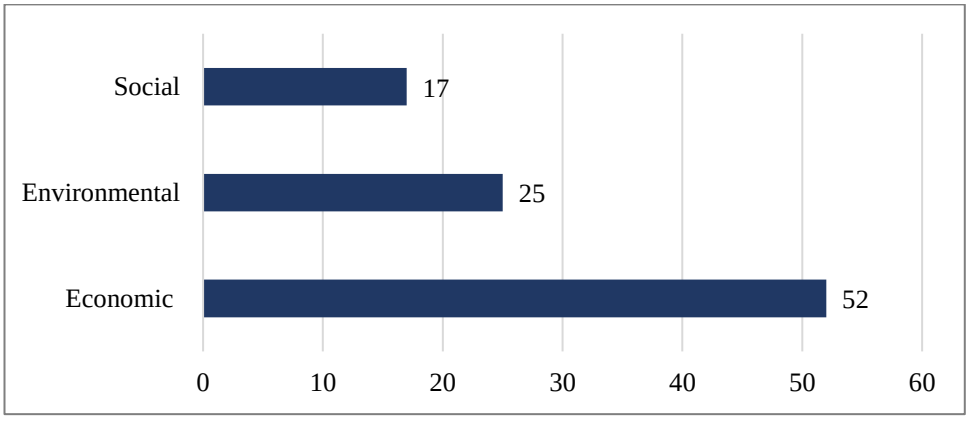

Figure 6. Distribution of analytical categories related to sustainability

Some studies focused on assessing the profitability of renewable energy projects and managing the risks associated with investing in this field. The stakeholders involved in these activities must consider various factors, including project costs, construction timelines, energy prices, financing availability, and potential regulatory barriers. Table 4 shows some of the most employed economic indicators by scholars to evaluate the development of ECs reviewed in the present work. The NPV is the most used indicator to evaluate the profitability of investment in the ECs considering the time cash value. Another indicator widely used by scholars is the payback period, some studies use the Simple Payback Period (SPP) without considering the time value of money or the discount rate while others use the Discounted Payback Period (DPP) which does. Other scholars employed less commonly used economic indicators such as the Break Even Point (BEP), used in cost and revenue analysis to determine the point at which a community generates enough revenue to cover all its costs or the Percentage Cost Reduction(PCR), used to evaluate the operational efficiency of a community or the concept of Equivalent Annual Cost (EAC), used in to determine the annualized cost of an investment or project over its entire lifespan, allowing for comparison with alternative investment options.

Table 3. Economic indicators used to quantify the impacts of Energy Communities

Authors	BEP	DPP	EAC	IRR	NPV	PCR	SPP
(Ancona et al., 2022)					✓		
(Bahret and Eltrop, 2021)					✓		
(Canova et al., 2022)		✓		✓	✓	✓	
(Francesca Ceglia et al., 2022)					✓		✓
(D'Adamo et al., 2022)	✓		✓		✓		
(Radl et al., 2020)			✓		✓		
(Secchi et al., 2021)		✓		✓	✓		
(Talluri et al., 2021)					✓		
(Vivian et al., 2022)							✓

Energy technologies and resource

Figures 7 and 8 show that several articles investigate the energy technology dimension, which is often the starting point of the analysis. In most cases, this focus on energy technologies is associated with photovoltaic systems (46) and energy storage technologies (20). The analysis shows that few articles deal with the use of integrated systems or multi-energy systems (MES), in which electricity, heat, cooling, fuels, transportation, etc. interact optimally with each other at various levels (Mancarella, 2014). The main focus of the literature is explicitly on electrical ECs, few scholars deal with thermal ECs or the connection between RECs and DHN or PTG. The integration of photovoltaics, heat pumps and absorption chillers has been studied by (Ancona et al., 2022) in order to decarbonise a district heating network, while (Ceglia et al., 2022) integrate a biomass-based organic Rankine cycle cogeneration plant, a mini-hydro plant, and a distributed photovoltaic plant into an Energy Community. As for energy resources, the most frequent is the solar (46), while few papers deal with hydrogen resource; in particular, (Pastore et al., 2022) increased physical self-consumption by introducing hydrogen into the local gas network using it as a storage system, furthermore, the new European directives promote the exploitation of solid biomass, biofuels and biogas for district heating in connection with RECs (Ceglia et al., 2022; Volpe et al., 2022). Wind energy is the most widespread renewable energy source in Europe ("Eurostat," n.d.) yet this energy source is not very present in the literature in the field of ECs; this can be due to the fact that these technologies require a more complex installation than PV, which can represent not only a technical but also an economic barrier for homeowners and in general for members of the energy communities. However, there are many initiatives in Europe that are promoting the use of wind energy at a residential level, such as the installation of small wind turbines in urban parks or private ground (Loganathan et al., 2019).

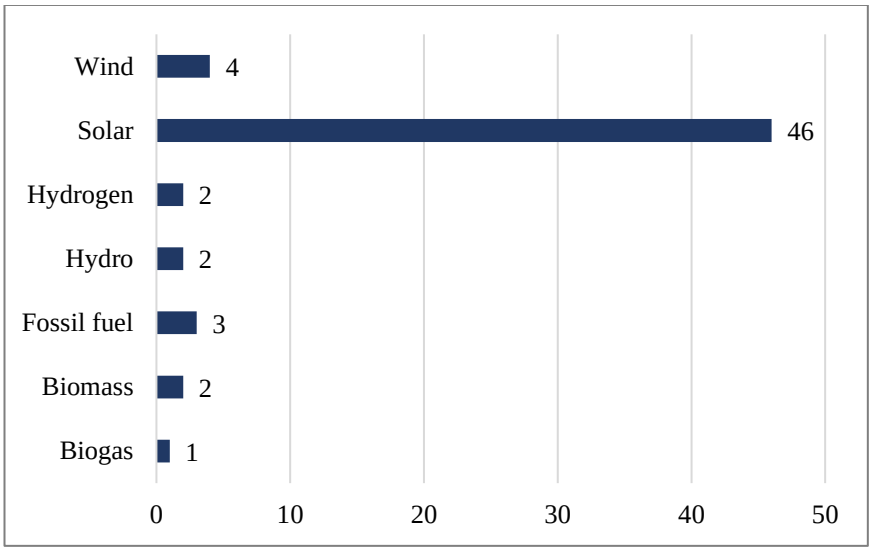

Figure 7. Distribution of analytical categories related to energy resource

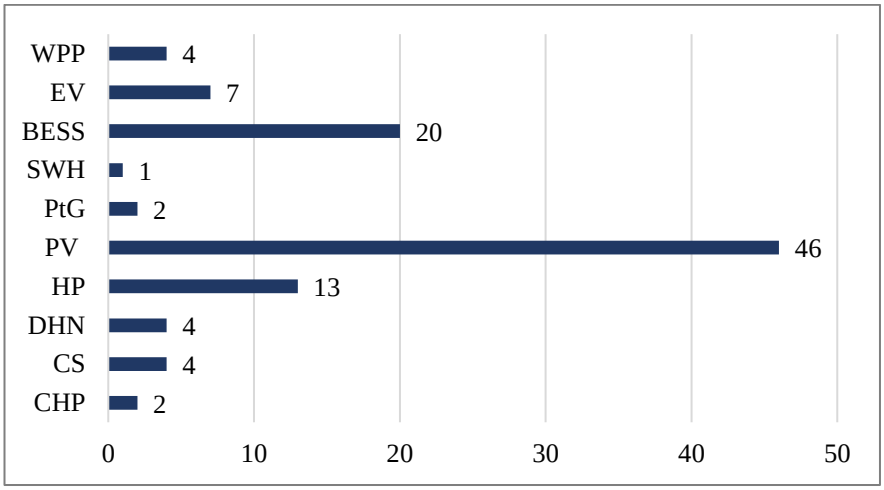

Figure 8. Distribution of analytical categories related to energy technologies

Focusing on photovoltaic, which is a versatile and modular technology suitable for various applications and integrations with other technologies to maximize electricity production, Table 5 shows the most common integrated technologies (e.g., storages, heat pumps, electric vehicles)and applications for studies on ECs. Moreover, the PV can be easily integrated into various application such as building facades, roofs or on the ground.

Table 4. Integrated PV technologies and applications for ECs

Authors	MES	PV System	Sector
(Canova et al., 2022)(Pinto et al., 2020)	PV+ HP	RPV	Residential
(Cosic et al., 2021)(Cielo et al., 2021)	PV+BESS	RPV PV	Commercial, Public service, residential
(Pastore et al.,	PV+BESS + HP	PV RPV	Residential

2022)(Mutani and Usta, 2022)			
(Felice et al., 2022)	PV + BESS + HP + EV	RPV, BPV	Residential
(Sudhoff et al., 2022)			

Legislative Framework

The next phase of the analysis is the categorization of the documents according to the ECs legal entity and the state of transposition of the European directives on the EC. Figure 9 shows that most of the papers deal with the subject Renewable Energy Communities (65), followed by the Citizen Energy Communities (21) and finally the Collective Self-Consumption initiatives (14). By June 2021, EU Member States had to transpose the RED II directive in order to develop an enabling framework to promote RECs: some scholars discussed the main developments in the transposition of EU directives and show how national approaches are in very different stages (Frieden et al., 2021; Sokołowski, 2020); others limited their area of investigation to specific Member States, as (Spasova and Braungardt, 2021), who compared the regulatory framework in Bulgaria and Germany, or (Krug et al., 2022) who analyzed Germany and Italy. Other studies have focused more on the different aspects that influence the REC operating phase, (Casalicchio et al., 2022) implemented a linear optimization model in order to address 3 different aspects of a REC regarding the best technology mix, the role of demand response and the method of sharing the benefits among the participants, the latter being a topic addressed also from (B. Fina et al., 2022).

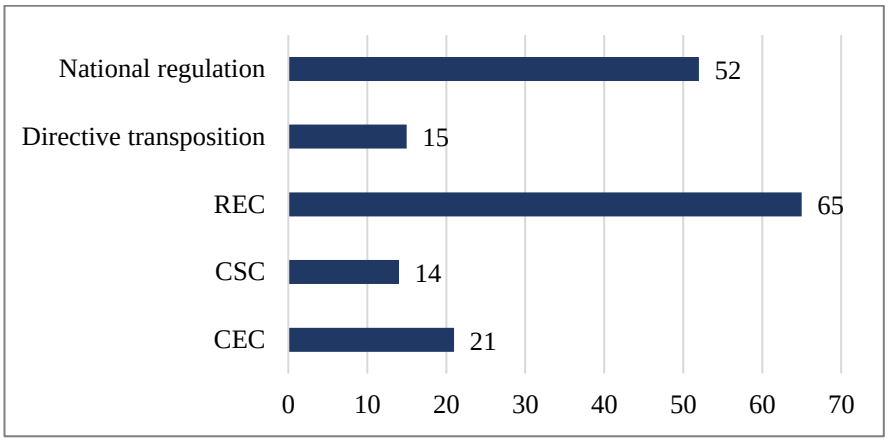

Figure 9. Distribution of analytical categories related to legislative framework

Geographic Focus

This structural dimension investigated the geographical focus of the analyzed studies. Figure 10 shows that researchers have distinct approaches and perspectives about EC initiatives in Europe. Most of the studies reffered to a single country analysis (54): (Canova et al., 2022) analyzed different scenario for the simulation of a CSC initiative under the Italian regulation framework, (Lucas and Carvalhosa, 2022) introduced a methodology for pairing consumers tested in a specific region of Porto in accordance with Portuguese regulations, (Luttenberger Marić et al., 2022) proposed a case study of 20 residential buildings situated on the island of Krk, Croatia, (Kojonsaari and Palm, 2021; Palm, 2021) analyzed case studies under the regulation framework of Sweden, (Botsaris et al., 2021) developeda virtual REC in Greece located nearby Kimmeria, (Grève et al., 2020) presented data analytics tools designed to assist community members tested in a case study of Belgium, (Cabarcos et al., 2020) analyzed the factors that influence investment in a rural CER project, in line with the Spanish government's strategic direction, (Heldeweg and Séverine Saintier, 2020; Inês et al., 2020) have their geographical focus on the UK prior to Brexit. Other scholars

make a comparative analysis between different countries (14): (Dóci, 2021) conducted a comparative evaluation of case studies carried out in Germany and the Netherlands, (Lowitzsch et al., 2020) made a comparative analysis between six countries among wich Spain, Czech Republic, France, Netherlands, Italy and United Kindgdom.According to Figure 11, Italy is the most frequently mentioned country in the literature (36),followed by Germany (11), Austria (10), and Spain (9). Notably, some European Union countries including Cyprus, Estonia, Lithuania, Luxembourg, Malta, Romania, Slovakia, and Hungary are not investigated by the scientific literature.

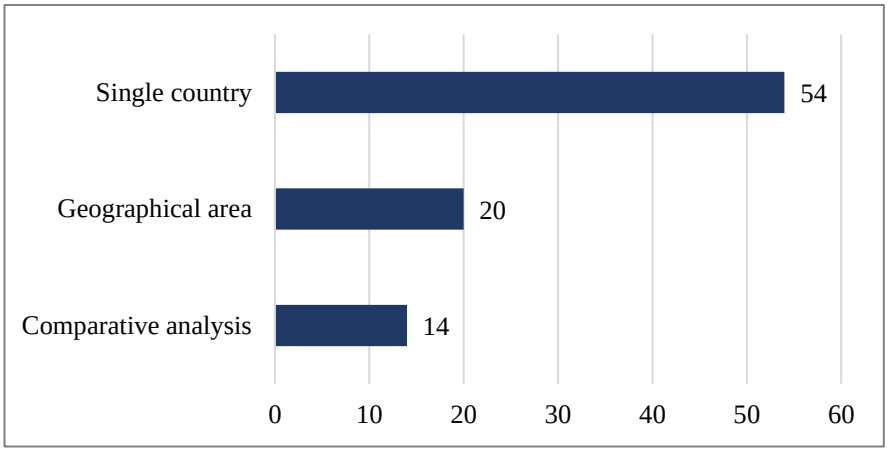

Figure 10. Distribution of analytical categories related to geographical focus

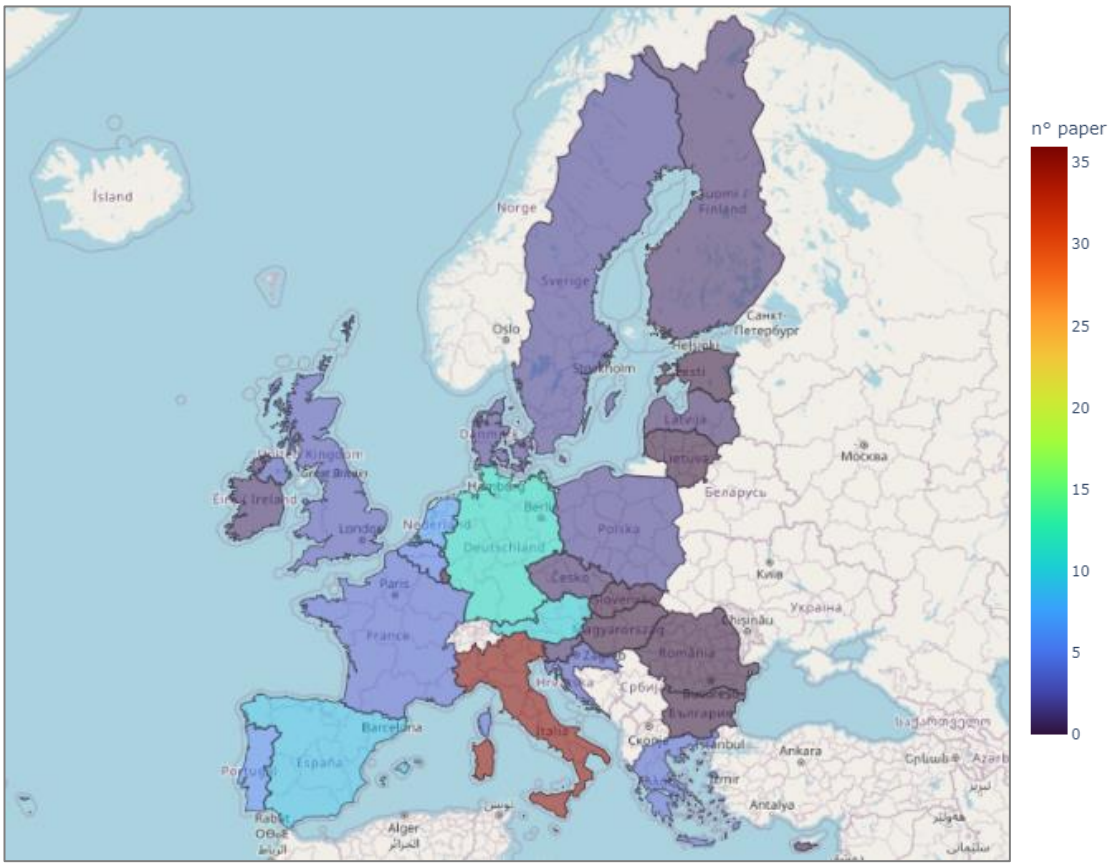

Figure 11 Distribution of papers citing EU Member States (and the UK)

Management and control

The last structural dimension investigates the "Management and control" of EC through different analytics categories. A significant focus for ECs is to tackle the challenge of implementing a fair and justified approach to allocating costs and revenues among their members, thereby ensuring an equitable distribution of energy. This concern is further evidenced by the attention given to the study of "sharing mechanisms" by numerous scholars, as depicted in Figure 12. In particular (Minuto and Lanzini, 2022) proposed three sharing algorithms to distribute the profits resulting from renewable energy production and consumption among the members of the energy community, (De Villena et al., 2022) presented a modelling solution for the distribution of renewable electricity generation in a REC, (Casalicchio et al., 2022) defined a fair method for allocating benefit among REC participants, (Volpato et al., 2022) applied a new cost allocation criterion and price-based demand-response programs to different community configurations. This last aspect has also been explored by other scholars; utilizing Demand Response (DR) programs could play a crucial role in maximizing the advantages of aggregation in ECs and allows the demand for electricity to be managed intelligently and sustainably. Thanks to its use, it is possible to avoid consumption peaks, reduce energy costs and decrease the environmental impact in the EC; (Luttenberger Marić et al., 2022) focused on increasing flexibility system through demand response program, while (Barreto et al., 2022) suggested a new approach to incorporating demand response (DR) participation in a CEC.

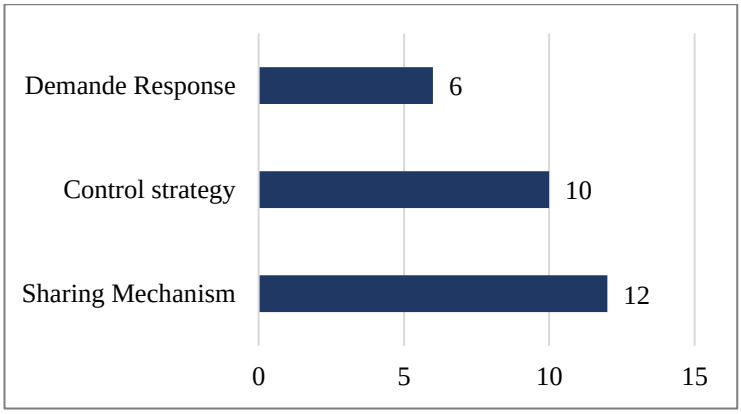

Figure 12. Distribution of analytical categories related to management and control

5. Discussion

The most important findings of the study are discussed in this final section, highlighting the key trends in academic research on ECs. Following that, the main limitations of the study are listed, providing the baseline for possible future investigations and implications.

5.1 Key research outcome

- Researchers primarily use an experimental approach through case studies' simulation

Researchers primarily employ an experimental approach through case study simulations to explore the potentials and limitations of ECs models. This approach allows them to examine different scenarios within different national regulatory contexts and gain a deeper understanding of the main novelties introduced by EU directives. By testing and simulating these scenarios, the researchers aim to evaluate the effectiveness and applicability of the new models in practice.

- Economic and financial aspects, driven by policy regulations, are the most researched areas in ECs studies

Researchers have extensively explored economic and financial aspects in ECs studies, strongly influenced by policy regulations. They have devoted extensive attention to these aspects due to their critical role in addressing global challenges such as inequality, energy poverty, climate change, and sustainable development. The emergence of new models for ECs emphasizes the importance of financial incentives as a significant driver for their growth, particularly as these initiatives are required to compete in the

energy market. Additionally, considerable emphasis has been placed on analyzing the policies and regulations surrounding ECs. This focus is anticipated, considering that policies play a vital role in establishing a regulatory framework that encourages the participation of different stakeholders in the production and distribution of renewable energy at the community level.

- Photovoltaic systems represent the prevalent technology in the ECs studies
- Novelty of ECs stems more from a political and social perspective rather than technological advancements.

Photovoltaic systems are the widely adopted technology in ECs studies. This can be due to two factors: 1) the geographical location of the studies, which mainly focused on countries with high solar radiation level e.g., Italy and Spain ("joint research centre.ec.europa.eu," n.d.) 2) the final use of RES, where the use of PV systems in residential settings is the primary driving force behind the renewable energy sector (De Boeck et al., 2016), the gradual transformation of energy systems in the decarbonization pathway, characterized by lower final consumption and a growing share of electrification. In addition, ECs are mainly addressed in literature from an electrical perspective, as current national legislative frameworks have always incentivized the electrical sector over the thermal sector

- The Renewable Energy Community (REC) is the most studied form of ECs by scholars

The Renewable Energy Community (REC) is the most studied form of EC by scholars in the literature. The greater development of studies on RECs can be due to the fact that the RED II came out a year earlier (2018) than the IEM (2019), anticipating the studies on RECs by the scholars; moreover, RECs are more often related to incentive systems as they are bounded exclusively to the production of energy from renewable sources, whereas CECs may include alternative energy sources. The lower frequency in literature of CSC projects can be due to the fact that, being limited to a single building, academic interest may be lower compared to a potential energy community that integrates a plurality of members in different potential scenarios.

- The majority of studies on ECs refer to the national regulation of the country analysed

The 28 EU Member States have been given a deadline until June 2021 to incorporate the RED II into their respective national legislations (Lowitzsch et al., 2020). Since ECs forms represent new concept, national regulations assume crucial role in providing guidelines and structures for their implementation. Consequently, many researchers have addressed this topic by referencing national legislation as it allows for a better understanding of the context in which ECs operate, including the specific obstacles and opportunities in each country. Some scholars have further discussed the main developments in the transposition of EU directives, highlighting the variations in national approaches at different stages (Frieden et al., 2021; Sokołowski, 2020).

- Italy is the most mentioned country in the literature on ECs

Italy is by far the most prominently referenced country in literature, followed by Germany, Austria, and Spain. This prominence can be attributed to Italy's favourable legal framework, which grants scholars the freedom to explore various scenarios related to ECs through well-defined regulations and incentives for renewable shared energy. In fact, Italian legislation, on 28 February 2020, promoted the development of REC and CSC through an experimental framework anticipating the definitive transposition of the RED II directive. Specifically, this framework started through Article 42-bis of Decree-Law 162/19 and was afterwards implemented by Conversion Law No. 8/2020 (*Decreto Legge 162/19 (articolo 42bis)*, n.d.). Since that moment the regulations introduced the opportunity to share renewable energy production, with end users who are part of a community through the existing networks. Additionally, incentives available for shared energy, making these new regulatory frameworks economically appealing (Canova et al., 2022; Trevisan et al., 2023).

- The management of ECs involves the development of mechanisms for sharing benefits among its members

Several countries have adopted a virtual scheme for local energy sharing in ECs, often incentivized by national legislation with premium tariffs for shared energy. Many management aspects concern the distribution of shared energy and economic gains, often handled internally resulting in different configurations depending on the type of generation systems, users, and community purposes. A major challenge for ECs is determining a justifiable method for dividing costs and revenues among all members, while ensuring fair and equitable energy distribution. The development of sharing mechanisms has been studied by many scholars; this can be related to the fact that an equitable distribution of benefits among community members can help create a sense of solidarity and collaboration, promoting the active involvement of citizens in the energy transition. In this way, ECs can become not only an opportunity to reduce energy costs, but also a mean to strengthen social cohesion and the active participation

of citizens in community life. Specifically, policymakers and researchers are focused on two key component of energy sharing: internal guidelines for distributing benefits and costs within the EC (Casalicchio et al., 2022), and external regulations that institute the general regulation framework (Gjorgievski et al., 2023).

5.2 Implications, limitations, and future research

The primary objective of this paper is to provide an overview of how researchers approach the topic of EC European models. Main findings and information gathered in this review could offer valuable assistance or guidance to various stakeholders – such as scholars, policymakers, citizens, community organizations, and professionals – in making informed decisions and actions, shaping policies, or gaining a deeper understanding of the dynamics in ECs. As for the academic community, the review critically examines the literature and directs scholars towards specific thematic areas within this research field that warrant further investigation. Data-driven simulations of ECs and the methods highlighted in the structural dimension "Research methodology", for example, can guide toward an easier access to operational data on energy consumptions, useful to perform robust technical-economic feasibility studies. By examining and comparing different countries, the paper enables a clearer understanding of the benefits, challenges, and best practices associated with energy communities. It includes the financial support mechanisms and their characteristics e.g. duration and scale of the incentive to ensure competitiveness in the market, correlation to energy prices, etc. This comprehensive analysis allows policymakers to develop well-informed policies and strategies that promote the development and widespread adoption of energy communities. e.g., regulatory frameworks, community engagement initiatives, financial support mechanisms, grid integration strategies, etc. With respect to professionals, the review offers an overview of best practices, challenges, and opportunities faced in the implementation and management of energy communities. This can assist industry stakeholders in making more informed decisions, adopting effective investment strategies, and implementing innovative solutions for the establishment and management of ECs. Finally, findings empower citizens to make informed decisions regarding their participation in ECs or the promotion of similar initiatives within their own communities, by understanding the concept and by assessing benefits and risks, legal and regulatory insights, financial implications, and community impact. Furthermore, it can contribute to raising the awareness among citizens regarding the importance of sustainable energy and the role they can play in promoting it through participation in energy communities. The study is not without limitations, primarily due to its qualitative nature. Firstly, the researcher's biases inevitably influence the categorization of information, despite transparent documentation of the research process. To effectively address this issue, the work provides a comprehensive description of the structural dimensions and analytical categories employed. Secondly, the limited review of journal articles in this study may impact validity, as the scientific literature on this subject is still developing, and potentially valuable contributions from grey literature were not included (Mahood et al., 2014). Due to synthesis needs, not all articles for each selected analytic category were cited. However, a few notable examples were provided for each category to assist the reader. The limitations of the study can serve as a foundation to enhance and stimulate future research on the topic. The scope of research on new models of ECs in Europe can be expanded to include grey literature to gain a more comprehensive and applied perspective. Researchers are increasingly recognizing cases where it seems necessary to expand the search for evidence beyond the boundaries of academic journals to incorporate "grey literature" (Adams et al., 2016; Sharma et al., 2015). In fact, grey literature provides valuable and complementary information that may be missing from "white literature". It encompasses reports, theses, unpublished documents, and practical materials, offering real data, practical experiences, and insights into the challenges and opportunities in implementing ECs. Future developments may consider further analyzes of the structural dimensions, in order to outline a more detailed framework of the context in which energy communities operate. For example, a greater focus could be placed on the main motivations that push photovoltaics to be the predominant renewable technology within these models, or possible partnerships could be analyzed in order to explore how ECs can collaborate with other types of actors, such as utilities, industries, or public authorities, for the development of shared projects. The knowledge of ECs could also be deepened by examining specific cases, through the factors that contributed to the success of some projects and those that limited their performance. Understanding the dynamics and interactions between different stakeholders, including citizens, public authorities, network operators, and investors, is crucial for the success of ECs. Furthermore, future investigations should focus on the reasons why ECs are studied mainly from an electrical and not thermal perspective (Papatsounis et al., 2022), despite EU directives opening up to all forms of renewable energy. Deepening studies on thermal energy communities can lead to a better understanding of local dynamics, the interactions between various energy sectors, and the socio-economic and cultural nuances that influence the adoption of sustainable thermal solutions. This can promote more effective design and implementation of policies and incentives for energy communities.

6. Conclusions

How do scholars approach the energy communities in Europe? The paper presented a systematic literature review on ECs in the European Union (RECs, CECs, and CSCs) that was conducted to explore how the scientific community approaches these new models for energy sharing. The aim is to provide information and stimuli for academics and policy makers, in order to deepen the knowledge already available and fill any gaps that still exist. Focusing on different areas and levels of investigation, the study highlighted strengths and limitations for an overall comprehension of ECs, a complex topic that requires the support of both European and national policies for its effective implementation. This was achieved through the development of a framework to categorize the academic literature through the analysis of more than 100 scientific papers, published in journals employing Scopus as search engine. The framework for the analysis, that includes a list of structural dimensions and analytical categories, allowed the authors to analyse the evolution and the main features of ECs studies. From the review emerges a complex and diversified framework that highlights some trends and consolidated knowledge, but also gaps and challenges that require further study and research. The articles, that were analyzed in the timeframe between 2018-2022, showed how the most of studies concern ECs based on renewable energy sources, with solar power being the predominant source. Consequently, the most employed technologies are those related to the production of electricity from photovoltaics often combined with batteries and heat pumps. Conversely, studies on communities based on the production of thermal energy are still very limited. Most studies focused on individual countries, although comparative studies between different geographical areas are important to understand common characteristics and differences between different types of ECs. In this case, the creation of these models at the national level is conditioned by regulatory, financial, and managerial challenges that require an adequate legal and institutional framework to promote the ECs' development. In this respect, the provisional reception of EU directives by Italy has supported scholars to refer to a defined regulatory framework and test its potential before other European countries, obtaining the highest number of works focusing on this specific country. Among the models introduced by the EU directives, RECs are the most explored in literature, being more closely linked to the incentive system settled by many EU member states. Indeed, many studies analyze ECs implementation from an economic perspective, in order to understand the benefits deriving from energy sharing among community members. In general, results show a great heterogeneity in the choice of energy sources, technologies, geographical level, and research method, as well as in disciplines including technology, economics, policy, and social sciences, which allowed to identify the most relevant findings and define future developments of research on this topic. At present, energy communities represent a new socio-economic paradigm in the management and sharing of energy from renewable sources, aligning with the decarbonization goals set by the European Union by 2050. By embracing the principles of local empowerment, participation, and renewable energy integration, energy communities have the potential to revolutionize the way we produce, consume, and distribute energy, leading us towards a more sustainable and decarbonized future.

Appendix A

Table 5. Literature reviews on EC with systematic approach

Focus	Authors	Databases	Investigated years	Keywords	Numbers of reviewed papers	Source
Thermal Energy Community	(Papatsounis et al., 2022)	Google Scholar; Scopus	2000-2022	Local energy community, Local production, Thermal energy	135	Energies
Emergence of ECs	(Lode et al., 2022)	Web of science	2012-2021	Drivers, Energy communities, Energy transition, Multy-level	75	Renewable and Sustainable Energy Reviews
Government s instrument	(Leonhardt et al., 2022)	Scopus	2000-2020	Community energy; Energy t ransition; Government instru ments	108	Energy Research & Social Science
Community based initiatives for heating and cooling	(Fouladvand et al., 2022)	Web of knowledge; Scopus	Up to 2020	Energy community; Institutio nal analysis and development; Renewable energy technologies; Thermal energy community; Thermal energy system	134	Energy Research & Social Science
Smart Energy Community	(F. Ceglia et al., 2022)	Scopus; Science Direct; Web of Science	2018-2022	prosumer; REDII; renewable energy community; smart ene rgy communities; smart ener gy system	78	Energies
Conceptuali zing community in energy system	(Bauwens et al., 2022)	Scopus	Up to 2019	Community renewable energ y;Decentralized energy resou rces; Local energy systems; Low-carbon transition; Peer-to-peer energy market; Prosume rs	405	Renewable and Sustainable Energy Reviews
PV EC	(Lazdins et al., 2021)	Web of science; Scopus; Science Direct; IEEE Xplore	2015-2021	Consumer; local energy com munities; Photovoltaic comm unities; PV; Renewable energ y	64	Energies
Classify existing literature of EC	(Gruber et al., 2021)	Google Scholar; Science Direct; Semantic Scholar	2000-2021	community energy; distributed generation; energy communities; renewable energy	67	Elektrotechnik &Informations technik
Business model for ECs	(F.G. Reis et al., 2021)	Web of Science ; Scopus ; Science Direct; Google Scholar; IEEE Xplore	Up to 2021	Business model canvas; Business models archetypes; Energy communities; Lean canvas;	99	Renewable and Sustainable Energy Reviews
Italy, ECs,	(Di Silvestre et al., 2021)	Scopus	Up to 2021	Business models; Energy communities; Prosumers; Sel f-consumption	100	Renewable and Sustainable Energy Reviews
Smart ECs	(de São José et al., 2021)	SciELO; Web of Science ; Science Direct; DOJA; IEEE Xplore; ACM	Up to 2021	Integrated community energy system; Prosumer community; Smart energy community; Smart grid community	103	Energy Strategy Reviews
Policy challenge in EU	(Busch et al., 2021)	Web of Science	2007-2019	Community energy; Directionality; Energ y policy; Renewable energy; Transition challenges	99	Renewable and Sustainable Energy Reviews
Sub-Sahara Africa, ECs	(Ambole et al., 2021)	Scopus	2010-2020	Energy communities; Energy democracy; Stakeholder engagement;	77	Sustainability
Community energy Research	(van der Schoor and Scholtens, 2019)	Scopus	1997-2018		263	Current Opinion in Environmental Sustainability

Integrated community energy system	(Koirala et al., 2016)	Scopus	2004-2013	Distributed energy resources; Energy systems integration; Local energy systems; Self-organized energy communities; Smart grids	1258	Renewable and Sustainable Energy Reviews

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