Sustainable Business Models for Renewable Energy Communities: A Comprehensive Framework

Abstract. The "Clean Energy for All Europeans" legislative framework introduced the concept of Renewable Energy Communities (RECs) to empower citizens by granting them greater decision-making authority and control over their energy consumption. As a result, the number of implemented energy communities has been increasing since 2019, leading to a growing interest in the design of business models (BMs) that enable their development and long-term viability. While several studies classify and describe BM for RECs, most lack a structured typology definition and fail to assess their broader sustainability implications. Framing RECs within the circular economy (CE) highlights their role in resource and eco-efficiency, local loop closing, and the socio-technical integration of clean energy solution in cities, a shared and validated understanding of sustainable business model (SBM) typologies is needed to guide their effective implementation, facilitate policy alignment, and enhance social acceptance. This study combines a systematic literature review with participatory validation to define and analyse nine SBM-REC typologies. Each typology is characterised using an extended sustainable business model canvas SBMC framework that integrates governance and sustainability dimensions. Results show that SBM-REC typologies differ significantly in their contributions to social, economic, and environmental sustainability, influenced by their governance model, and local ownership structures. The framework that integrates key dimensions of the BM (value creation, delivery and capture) as well as governance and sustainability aspects enables: (i) the structured classification and comparison of SBM-REC; (ii) the identification of value management patterns; (iii) the analysis of variation in governance logics; and (iv) a qualitative assessment of sustainability (social, environmental, economic) outcomes across typologies.

Keywords. Circular Economy; Renewable Energy Sources; Sustainable Energy Transition; Renewable Energy Communities; Sustainability assessment; Sustainable Business Model

Abbreviations:

REC: Renewable Energy Community

RE: Renewable Energy

CE: Circular Economy

SBM: Sustainable Business Model

SBM-REC: Sustainable Business Model for Renewable Energy Community

SBMC: Sustainable Business Model Canvas

BMC: Business Model Canvas

ECBM: Energy Community Business Model

BM: Business Model

TBL: Triple Bottom Line

1 Introduction

The transition to sustainable energy is one of today's most pressing challenges. Conventional and highly polluting energy production has been identified as one of the main sources of climate change [1,2], globally, the energy sector accounts for nearly three-quarters of greenhouse gas emissions [3]. In addition, excessive dependence on fossil fuels for energy generation exposes citizens to volatile price fluctuations in international markets [4], as seen during the 2021–2022 energy crisis [5]. In this context, various measures have been implemented to accelerate the energy transition, with an emphasis on decarbonization and energy efficiency [6].

The European Union (EU) aims for 42.5% Renewable Energy (RE) in its total energy mix by 2030 and carbon neutrality by 2050 [7,8], via the Green Deal [9], and RED II [10]. Additionally, the European Climate Law [11] and the "Fit for 55" package [12] aim to reduce greenhouse gas emissions by 55% by 2030 and enhance energy efficiency to lower overall energy consumption [13,14].

A significant aspect of the sustainable energy transition is the establishment of Renewable Energy Communities (REC), where citizens actively contribute to energy self-sufficiency [15]. This initiative aligns with the EU Clean Energy Package, promoting a secure, sustainable, and affordable energy supply for all EU consumers [16]. The EU classifies energy communities as citizen-led initiatives [10], that coordinate various energy-related activities [17] with the main aim of promoting RE solutions and bringing economic, social and environmental benefits to the communities [18], these benefits align with circular economy (CE) principles of resource efficiency and local loop closing.

The first definition of an energy community was provided under Directive (EU) 2018/2001 [10], emphasizing RECs as legal entities characterized by voluntary participation and local control, focused on benefiting members rather than generating profit [10,19]. Additionally, Directive (EU) 2019/944 [20], introduced the concept of Citizen Energy Communities (CECs), which involve citizen-led electricity initiatives encompassing generation, distribution, and related services [6,20]. While both RECs and CECs encourage citizen involvement and operate as non-commercial entities, they differ in geographical scope, technology eligibility, and membership conditions [10,20]. RECs necessitate close geographical proximity and reliance on renewable sources, while CECs permit a wider participation spectrum and are technology-neutral [10,20–22].

Despite these definitions, the literature still reflects a wide range of terminology to describe similar initiatives, including REC [23], Energy Community Business Models (ECBMs), Renewable Electricity Business Models (REBMs) [24], Community-Owned Renewable Energy (CORE) [25], and Social Innovation in Energy (SIE) [26], among others. As these terms differ in legal status and conceptual scope, this study adopts RECs as the most suitable category for the analysis. Table 1 in section S1 of the Supplementary File (SF) summarises the definitions of REC, CEC, REBM, CORE, SIE and ECBM as they appear in the literature.

Economically, RECs promote local employment, business growth, investment, and reduced energy costs by diminishing fossil fuel dependency [27–29]. Social benefits include community engagement in clean energy projects, citizen empowerment, support for local businesses, and enhanced regional economic resilience [30–32]. Environmentally, RECs play a crucial role in reduction of emission and accelerating renewable energy transitions, aligning with global climate goals [27].

However, significant economic, financial and organizational challenges [27], impede RECs growth in the energy sector [33], with only 12% of identified energy communities in Spain operating an active project, largely due to bureaucratic barriers and lack of experience [34]. Stakeholders including municipalities and civil society, often lack expertise in renewable technologies, legal frameworks, and governance models [23]. Addressing these challenges requires greater legal clarity, simplified processes, and development of innovative business models. Capacity-building initiatives are essential for the effective implementation and sustainability of RECs, ensuring that their potential impact is realized in the energy landscape [35].

Understanding Business Models (BMs) is crucial for the design and management of RECs. Research indicates that the organization of value creation, governance, and resource flows in RECs significantly influences their ability to generate social, environmental, and economic benefits [36–38]. RECs are viewed as sustainable business models (SBMs), focusing on a value proposition that aligns various stakeholders' interests [39], emphasizing sustainability over mere profit [40]. This includes a commitment to participatory governance and inclusive practices, advancing eco-efficiency and resilience within a CE perspective [41]. This approach has a people- and planet-oriented perspective [42], and RECs emphasize sustainability-driven value creation, delivery, and capture, and promote inclusive, participatory governance models [43].

A preliminary literature review conducted on October 16th, 2024, using SCOPUS (without time or geographical filters) shows a rising interest in energy communities, particularly from 2019 (Fig 1.). This trend aligns with the launch of the "Clean Energy for All Europeans" package [15], which emphasizes the role of energy communities in the transition to clean energy. However, when incorporating the concept BM into the search, the results narrow significantly. Specifically, a search combining the terms ("energy communities" OR "renewable energy communities") AND, "business model" AND, ("sustainable" OR "sustainability") resulted in only 23 journal papers, which demonstrate the scarce literature available linking sustainability to energy community BM (see fig. 1).

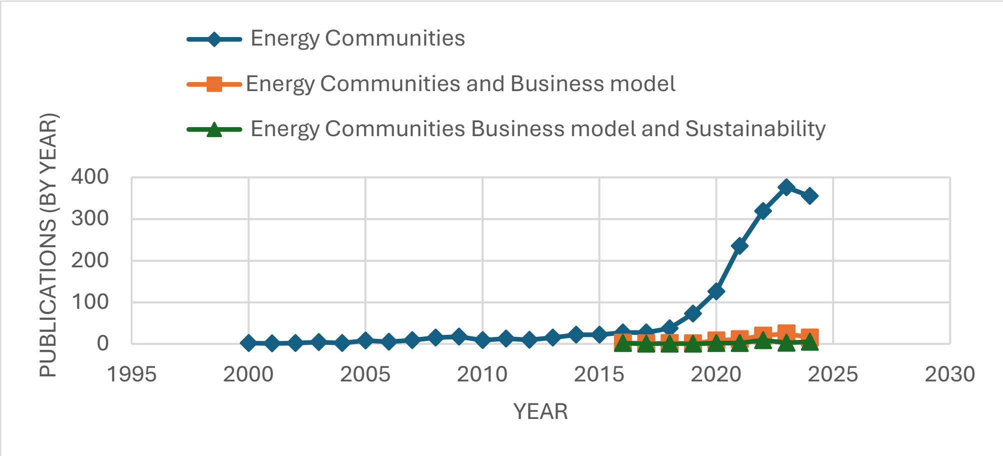

Fig. 1 Annual scientific publications on Energy Communities, Business Models, and Sustainability

Despite this limited focus on sustainability-oriented BM, current academic research explores a broad array of topics such as cost-benefit allocation [44], stakeholder engagement [45], citizen participation [46], and integration with electricity markets and distribution networks [47,48] for RECs. While most studies adopt qualitative approaches, particularly case studies, interviews, and reviews [43,49,50], there is also growing interest in simulation-based and quantitative modelling to assess specific technical or economic aspects (e.g., Sarfarazi et al.; Casalicchio et al.,[51,52]). In addition, several typologies and frameworks have been proposed to categorise REC BMs [53,54], often reflecting the influence of national contexts, policy environments, and community configurations. Collectively, these studies highlight the diversity of BM configurations being explored and the complexity of aligning technical, regulatory, economic, and social objectives within REC initiatives.

While these contributions reflect increasing academic attention to REC BMs, several critical gaps remain that limit the ability to compare and evaluate these BM in practice.

The first issue that gives rise to these gaps is the wide variation in how REC BMs are conceptualised across studies, each using different terminology, levels of abstraction, and analytical lenses. This fragmentation hinders comparability and limits the cumulative development of knowledge [55]. Several studies propose BM typologies for RECs, often using inconsistent terminology to describe similar configurations [43,49,54]. This lack of systematization complicates comparisons and impedes the consolidation of knowledge in this field [56,57]. While some works provide broad categorizations (e.g Reis et al [43], Herbes et al [58], Rossetto et al [59]) others conduct detailed case studies within specific national contexts (e.g.,Vernay et al; [49] for France, Wu et al across ten EU countries [56]), making cross-country comparisons difficult. For this reason, adopting a typology-based synthesis is appropriate. It consolidates dispersed BM configurations into coherent groups and provides a structured basis for comparing how RECs organise value creation, delivery, and capture and facilitate knowledge development [59]. Among the reviewed studies, the work by Reis et al [43] provides the most comprehensive analysis of BMs for REC to date. The authors present a set of BM typologies based on an extensive review of online databases (including Web of Science, Scopus, Science Direct, Google Scholar and IEEE Xplore) as well as project reports up to 2021.

Second, there is a predominance of profit-driven frameworks in BM characterisation [39]. When defining BMs for RECs, researchers adopt different approaches. Some focus on economic feasibility and financial mechanisms [43,54], while others emphasize community participation and governance structures [25,49]. Although these perspectives provide valuable insights, they often lack a detailed breakdown of the specific BMs used by RECs. Most studies that thoroughly characterise BM for REC rely on Osterwalder's Business Model Canvas (BMC) [37], as it offers a structured and detailed framework to analyse value creation, delivery, and capture in profit-driven businesses [39]. However, the BMC has limitations in capturing key aspects of BM for RECs, which are often based on collaborative, non-profit, and community-driven initiatives [30,60]. Integrating governance more explicitly into the BM architecture is therefore essential for understanding REC dynamics. This is because governance mechanisms strongly influence participation, ownership, benefit-sharing, and local acceptance, elements directly linked to sustainability outcomes [61].

Third, there is a limited integration of sustainability considerations in REC BMs. Most studies do not incorporate sustainability assessments into their methodological frameworks for classifying RECs [43,62]. Even studies that address sustainability often focus on specific aspects, failing to provide a complete evaluation of environmental, social, and economic impacts [63,64]. Moreover, existing sustainability analyses rarely quantify the prevalence of different BMs or evaluate their real-world adoption and effectiveness. This gap is particularly relevant, as the absence of integrated sustainability frameworks may hinder not only the assessment of REC performance but also broader societal acceptance and the scalability of these initiatives across different contexts [65,66]. Hence, embedding a sustainability lens directly within the BM structure is necessary to systematically analyse the extent to which different BM configurations contribute to sustainability objectives.

To address the abovementioned gaps, this study presents a comprehensive characterisation of SBM for REC, contributing to the reduction of the current lack of standardised classification in the literature. Specifically, it examines how existing BM typologies, particularly those proposed by Reis et al. [43], align with the configurations documented in recent REC studies. While Reis et al. [43], Vernay & Sebi [49] and Rossetto et al [59] provide important conceptual and institutional perspectives on RECs BMs, their frameworks tend to be descriptive, highly context-specific, or focused on regulatory arrangements, with limited attention paid to the internal configuration of the BM.

Rather than proposing entirely new categories, the study builds upon established typologies to quantify their prevalence, refine them through comparative analysis, and identify additional configurations when needed, Section 2 details the methodology. Furthermore, to overcome the limitations of profit-oriented frameworks and in response to the limited incorporation of sustainability in current research, the study extends the conventional BMC [37] by integrating a governance dimension to better capture decision-making structures and embedding sustainability lens directly within the canvas structure. This enhancement provides clearer operational guidance for characterising how RECs create, deliver and capture value. It offers a more systematic and comparable understanding of their sustainability potential than the frameworks currently reported in the literature (Section 3). By doing so, this work provides a structured framework that directly addresses the main gaps limiting the development and comparability of RECs typologies. The study contributes theoretically by consolidating dispersed REC BM alternatives into a coherent typology. It extends the conventional BMC to include governance and sustainability and strengthens it through participatory validation. Practically, the framework offers an operational tool for systematically characterising REC configurations and supports practitioners and policymakers in evaluating, designing and scaling REC initiatives.

2 Methodology

A four-step methodology was applied to identify, categorise, and characterise the SBM for REC (Fig 2). The procedure was built upon the methodological approaches adopted in previous studies to define and analyse BM for REC [43,63] and systemise SBM typologies [28,64,67]. It combines a systematic literature review [68], structured classification and characterisation using an extended BMC, and validation through Participatory Action Research (PAR) [69,70], with key stakeholders.

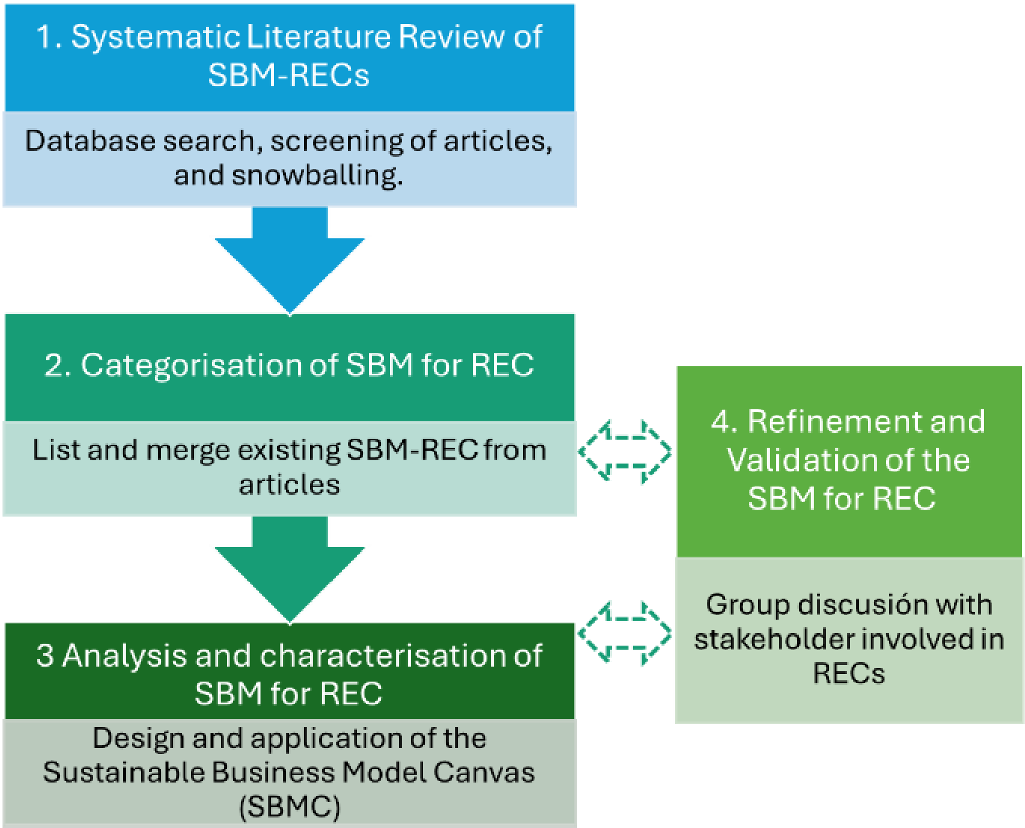

Fig. 2 Research methodology. Acronyms: SBM-REC (Sustainable Business Model for Renewable Energy Community)

2.1. Systematic Literature review of SBM-REC

A systematic literature review was conducted to define BM categories for RECs, using the approach of Bocken et al [38] to extract typologies based on patterns in sectoral studies [38]. The initial data collection was carried out in March 2024 using Scopus as the primary database, due to its comprehensive coverage of interdisciplinary research, energy and sustainability journals [71,72]. Scopus was selected due to its broad coverage of peer-reviewed journals in energy policy, sustainability transitions, and socio-technical systems. As reliance on a single database may introduce publication bias, the search strategy incorporated additional measures to ensure completeness. The corpus was cross-checked against key review papers (e.g., Reis et al.[43]; Rossetto et al [59]) and we verified that the core journals indexed in Web of Science and IEEE Xplore were also present in Scopus. In addition, the PAR process provided complementary insights from practitioners, not widely represented in indexed literature.

Four search strings were used combining keywords related to sustainable energy, BMs, energy communities, and BM typologies (see Table 1). The search initially retrieved 87 documents, of which 51 met the inclusion criteria after filtering for peer-reviewed journal articles or review papers published in English between 2015 and 2025. This timeframe corresponds to the period in which the concept of REC gained policy recognition and conceptual maturity. The foundations were laid from 2015 onwards, with preparatory work that ultimately led to the formal definitions of RECs and CECs in the Clean Energy for All Europeans Package [15] (see Fig1). Earlier academic contributions rarely use the REC concept in its current sense, making 2015 an appropriate starting point for capturing the evolution of the field. The end date (2025) corresponds to the time of data collection. To ensure the coverage of the most up-to-date research, the search was updated in February 2025 to incorporate newly published studies, however, no additional articles meeting the inclusion criteria were identified.

Table 1 Keywords used in the literature review

Search strings	Key words
Sustainable energy	("renewable energ*" OR "clean energy" OR "green energy" OR "sustainable energy" OR "energy efficiency" OR "civic energy" OR "energy transition")
Business models	("business model*" OR "value proposition" OR "value creation" OR "value delivery" OR "value capture" OR "financial model*" OR "governance model*")
Energy communities	("communit*" OR "citizen" OR "prosum*" OR "self-consum*" OR "self-sufficien*")
Typologies	(type* OR "typolog*" OR "taxonom*" OR "pattern*" OR "archetyp*" OR "classification*" OR "topolog*")

This review was limited to peer-reviewed academic literature to ensure analytical rigor, methodological transparency, and terminological consistency in the identification and classification of SBM typologies. Although grey literature can provide valuable contextual information, the often-heterogeneous formats and lack of systematic characterisation of BM render it less suitable for comparative analysis [73]. Nonetheless, practitioner insights were incorporated during the validation phase through PAR (see Section 2.4), enhancing the applicability and robustness of the findings.

To ensure the relevance of the final sample, all 51 identified articles were subsequently reviewed in detail to retain only those that provided a comprehensive characterisation of BMs for RECs. Given that RECs represent an emerging field, special attention was paid to works offering in-depth descriptions of the full set of BM components. In this context, analytical frameworks such as "complete pattern frameworks" [36], and "BMC" [37], were used as references, to check whether each article described key elements of the BM, such as value creation, delivery, and capture. These frameworks supported the identification of articles that offered a sufficiently complete picture of how RECs operate [74]. From this process, 28 articles were identified that did not fit these criteria as they lacked focus on detailed BMs [75] or REC [76]. In addition, 20 articles were identified using the snowball technique [68,77], leading to a final sample of 43 articles for content analysis (Fig. *3)*. A detailed list of the articles analysed can be found in S1 of the SF.

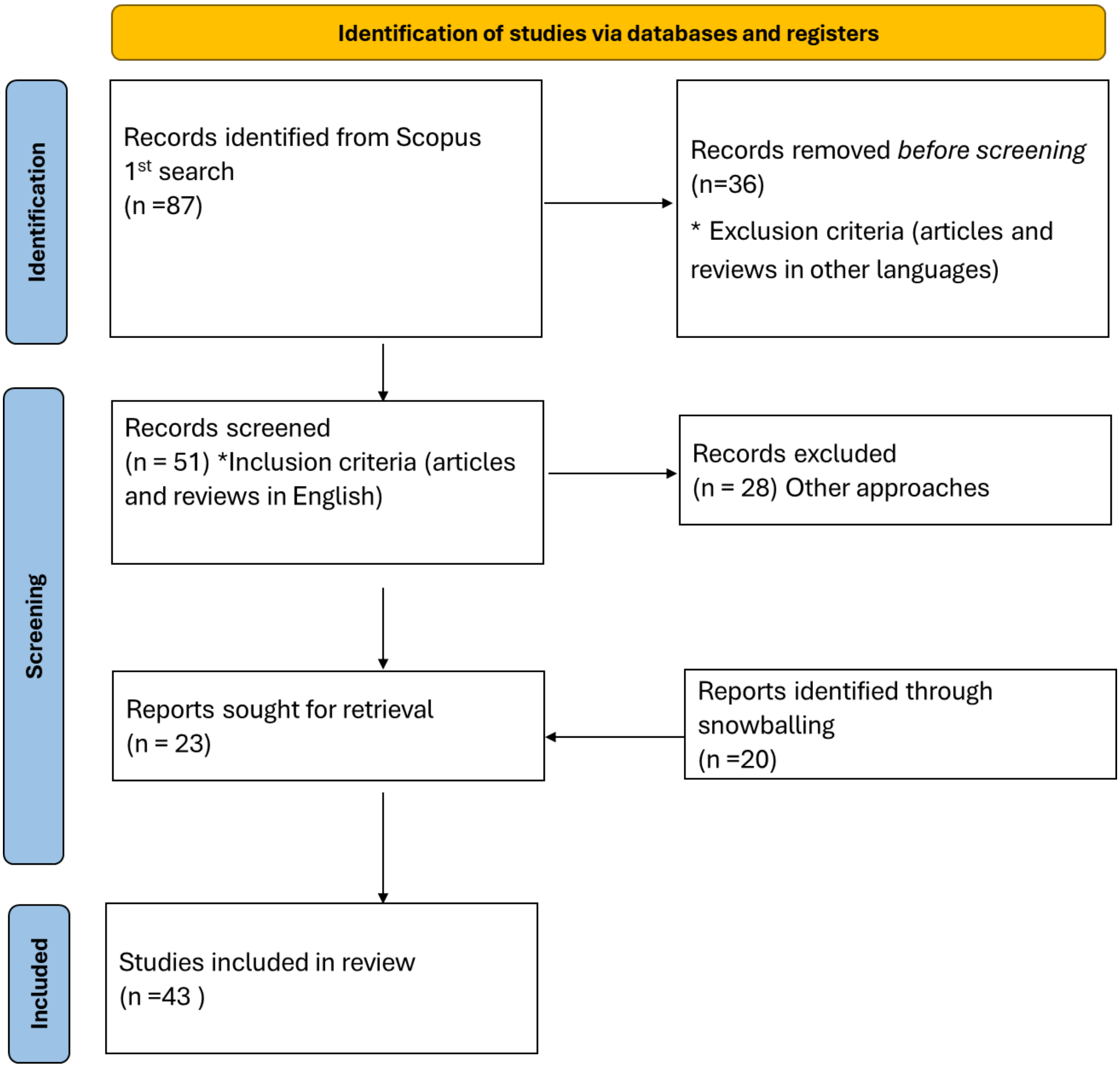

Fig. 3 Systematic literature review procedure and outcomes. Based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram [78]

2.2. Categorisation of SBM for REC

Following the systematic literature review and selection of relevant publications, each document in the final sample was analysed using a structured coding framework to identify existing and potential SBMs for REC. For further details, see S2 of the SF. It should be noted that the 43 analysed articles do not share consistent terminology when referring to energy communities, particularly in relation to SBM for REC. Moreover, many of the identified SBMs, although labelled differently, refer to the same type of SBM configuration or share many common characteristics [75]. For instance, SBMs characterised by community ownership and local energy generation were described under various labels such as "citizen energy groups", "cooperative energy supply", "renewable microgrids", or "community-based RES initiatives".

As a result, the initial list included a total of 193 SBM alternatives for REC, encompassing similar, overlapping, and duplicate SBMs (see S3 of the SF). These were compared in pairs to eliminate identical entries and merge similar SBMs [64]. To guide this process, the classification framework developed by Reis et al [43] was used as a reference model for grouping SBMs and establishing an organised starting point for the systematisation of SBMs for REC. Several iterations of refinement were carried out, combining insights from this framework with the specific definitions and contextual descriptions provided in the reviewed articles. The final set of SBMs assigned to each of the nine typologies is presented in Section 3.1.

2.3 Analysis and characterisation of SBMs for REC

The final set of SBM typologies was analysed and characterised using a structured Sustainable Business Model Canvas (SBMC**)** developed for this study**.** This tool builds on the conventional BMC [37], which was the most frequently used framework in the reviewed. It appeared in at least 20 out of the 43 analysed articles either directly or in combination with other modelling approaches such as such as Ad Hoc graphical representations [79], Strategic Business Model Ontology [80], and Causal Loop Diagram [81]. In addition, the Lean Canvas (LC) proposed by Reis et al [43] as well as the Energy Community Business Model (ECBM), framework by Vernay and Sebi [33],] were also reviewed to ensure conceptual alignment and to inform the development of a more comprehensive analytical tool.

However, these existing frameworks primarily focus on profit-oriented businesses and lack dedicated structures to assess essential SBM-REC dimensions, such as governance structures [82–84]**,** and social and environmental aspects [85], and their potential contribution to CE strategies in energy systems [86,87]. To address these gaps, the SBMC developed in this study synthesises insights from the most relevant SBM literature (e.g. [16,57,74,88]). It extends the original BMC by incorporating two additional dimensions that are critical for the characterisation of sustainability-oriented and community-driven BMs: the governance model and the Triple Bottom Line (TBL) aspects. Table 2 presents a detailed description of the SBMC dimensions and related building blocks.

The governance model involves both the coordination and management of key BM elements, including the offer, the distribution and organisation of activities and resources, and the mechanisms for generating and distributing value, as well as the organisational form of the BM [89]. As such, BM may involve either a single organisation or a network of interdependent companies working together to deliver a service or product [90]. This can encompass a range of legal forms, with varying levels of public, private, and civil society governance [82–84].Thus, the governance model dimension is characterised by considering the four elements described in Table 2.

The dimensions of value proposition, value delivery, value creation, and value capture are described following the nine building blocks outlined by Osterwalder [38,91], as defined in Table 2. These dimensions are crucial for creating and capturing value in firms, particularly in knowledge management processes [92]. Finally, the TBL aspects encompass a sustainability-oriented perspective by addressing social [93], economic and environmental blocks of the SBM for REC, see the Table 2.

Table 2 Sustainable business model canvas for RECs (SBMC-REC). Acronyms: TBL: (Triple bottom line).

Building block	Information	Definition	Source
Governance model	Promoter	Who initiated and promoted the project	[82–84]
	Focal firm	Who runs the business	
	Governance structure	How is the business managed, how is ownership defined, how are responsibilities shared, how are agreements and decisions made	
	Legal form	SL, S. Coop, etc	
Value proposition	Need/problem addressed	Value proposition refers to the value or utility of the goods and services that an organization or network provides to the customer.	[39,94]
	Offer (good and/or service)		
	Organisations' meaning of existence		
Value delivery	Customer segment	The customer interface covers all subsequent customer-related interactions including the customer's relationship with supplier organizations in terms of marketing, sales and distribution channels, as well as the permanent relationship with the product or service.	[39]
	Key channels (promotion and distribution)		
	Key relationships		

Building block	Information	Definition	Source
Value creation	Key resources (technological, human capital, knowledge)	The distribution of related processes and activities, together with the resources and capabilities involved and the company's internal value chain.	[95]
	Key activities		
	Key partnerships		
Value capture	Financial model (how the model is financed)	Why the business model is financially viable and relates to the revenue model. The financial model constitutes the combination of an organization's capital and operating expenditures with its means of revenue generation. It is linked to the value proposition, in terms of what products and services customers pay for and how revenues are collected and distributed.	[91,95]
	Cost structure (capital and operational costs)		
	Revenue streams (how earnings are obtained)		
TBL aspects	Social (+/-):	Positive or negative potential impacts on local, regional society, lifestyles	[85,93]
	Economic (+/-):	Positive or negative potential impacts on local, regional economic development	
	Environmental (+/-):	Positive or negative potential impacts on natural environment	

2.4. Refinement and validation of the SBM for REC

This study employed the PAR method [96] to refine and validate the results obtained during the process of categorising and characterising the SBM for REC. PAR is a methodological approach that combines research with collective action, actively involving stakeholders in the co-production of knowledge and decision-making processes. [69,70].

The lead author actively participated in monthly meetings of "Ernamuina", a regional working group focused on advancing community energy initiatives in Gipuzkoa (province in northern Spain) [97], held from January 2023 to January 2025.This participatory process involved a multi-actor working group composed of representatives from existing and emerging RECs, energy cooperatives and suppliers, academic and research institutions, private sector organisations, and public bodies. The primary objective of the group was to collaboratively address shared challenges and support the co-design of SBM-REC. Between 2023 and 2025, more than 20 group sessions were conducted monthly, amounting to approximately 44 hours of collective deliberation. Table 3 provides a structured summary of the 27 stakeholder profiles, including their institutional affiliations, roles within the REC ecosystem.

Additionally, the lead author is an active member of a REC. Since the process began in 2022, the author has participated in bi-weekly meetings of approximately 1.5 hours each, accumulating over 100 hours to date. These sessions focus on defining the community's BM and expected sustainability impacts and involve a multidisciplinary team of 12–15 members, including a municipal energy technician, three academic researchers, a university professor, a student of renewable energies, as well as engineers and economists.

Following the logic of the PAR approach [98], initial results were iteratively contrasted and enriched through these two forums. This process involved, i) thematic discussions on governance, legal, financial, and sustainability aspects; ii) case-specific validation of SBMC blocks with real REC configurations; and iii) refinement of typologies through dialogue and feedback loops.

Table 3. Stakeholder profiles involved in the participatory validation process (Ernamuina, 2023–2025)

Stakeholder group	Role	n (Participants)
Renewable Energy Communities (REC)	Community member (citizen in the board of REC, involved in governance or development)	13
Energy cooperatives / suppliers	Facilitator	2
	Technical advisor	
Academic / research institutions	University researchers (SBM & circular economy; economic modelling)	3
	Research and innovation centre (Solar resource assessment	
Private sector & industry	Company (Legal advisor)	3
	Industrial partner (Financial support and project facilitation)	
	Cooperative services provider (Energy procurement expertise and knowledge sharing)	
Institutional / public bodies	Process coordinator	4
	Institutional partner (supporting regional coordination and policy engagement)	
Digital and operational support	Cooperative supporting the development and operational management of REC (Digital infrastructure and software partner)	2
	Energy project developer present of wind project model	

To address potential researcher bias linked to the author's involvement in the REC ecosystem, reflexive practices recommended in recent PAR literature [99,100] were applied throughout the process. These included separating facilitation and analytical roles, documenting interpretive decisions, and discussing emerging insights with co-authors not involved in the PAR activities to maintain analytical distance. Triangulation was ensured by systematically cross-checking PAR insights with the alternative BMs identified in the literature review [101]. Any configuration emerging from PAR sessions required either support in peer-reviewed sources or validation by multiple independent stakeholders before being incorporated into the typology. Finally, all PAR activities followed institutional ethical guidelines and aligned with inclusive research practices recommended for community-based projects [102], including informed participation, confidentiality agreements, and the anonymisation of community-specific details when reporting results.

3 Results and discussion

This section presents the typological framework of nine SBM-REC categories, each characterised using the extended SBMC. Section 3.1 describes the SBMC of SBM typologies for REC. section 3.2 focuses on governance structures section 3.3 compares how different typologies approach value creation, delivery, and capture., while section 3.4 discusses the TBL aspects of each model.

3.1. Categorization and Characterisation of SBM typologies for REC

Table 4 presents the nine SBM-REC typologies identified in this study, based on the analysis and grouping of 193 business model alternatives. The complete characterization and categorization, detailing which SBMs were assigned to each typology, can be found in the S4 and S5 of the SF.

Table 4. SBM typologies for REC. Acronyms: SBM-REC (Sustainable Business Model for Renewable Energy Community); TBL: (Triple Bottom Line); RE (Renewable Energy).

Typologies		n (SBM-REC cases)	Core value logic
1	Community-owned	54	Ownership (Collective ownership and local autonomy)
2	Peer-to-peer trading	42	Exchange (Community members exchange energy directly)
3	Localised energy markets	21	Market (Buying and selling energy within the local community)
4	Collective generation	23	Joint generation (Community produces RE on a shared basis.)
5	Externally managed project	39	External management (An external entity manages energy production for the community)
6	Aggregated community	21	Flexibility (Energy is managed flexibly to balance supply and demand)
7	Local energy service companies (ESCOs)	30	Service (Service-based models for efficiency and renewable)
8	Electric mobility cooperative	9	Mobility (Shared e-mobility and cooperative service provision)
9	Technologically enabled	4	Technology (Smart, tech-enabled and modular configurations)

Note. n: number of RECs under that typology:

These nine typologies do not aim to represent mutually exclusive categories, but rather to capture the main organisational and value-creation patterns emerging from the literature and empirical evidence. The classification reflects the predominant business logic and governance mechanisms observed in each case. For example, *P2P trading* (2) and *localised energy markets* (3) may coexist in practice, yet differ in terms of transaction structure, technical infrastructure, and the degree of decentralisation or community ownership involved [57]. An additional group of eight non-standardised cases was excluded from the main typologies.

In terms of prevalence, the typologies most frequently observed were c*ommunity-owned renewable networks* (n=54) and *P2P energy trading* (n=42), which together account for nearly half of the reviewed cases. These reflect the growing interest in citizen ownership [30,60] and decentralised energy exchange mechanisms [51]. In contrast, typologies such as 'Electric mobility cooperatives' (n=9) and 'Sustainable and technologically enabled' (n=4) appear far less frequently, suggesting that these models remain at a more exploratory or pilot stage [45,53]. This distribution highlights both the consolidation of certain BM typologies and the emerging nature of others within the REC landscape. Each typology is characterised in the following sections based on key SBMC components.

3.1.1 Community-owned

Community-owned renewable networks (Table 5), also referred to as *energy cooperatives* [43], are BMs where community members jointly own and manage renewable energy resources. The key feature of this model is ownership, as the community directly owns the RE infrastructure. This approach promotes decentralisation and democratisation of electricity, fostering local autonomy and reducing dependence on external entities [25,53]. Additionally, it enhances citizen participation in ownership and decision-making [26], as these cooperatives are typically based on voluntary and open membership, democratic governance (one member, one vote), and the active economic participation of their members [103,104]. It is the most common REC model in Europe, with over 1,500 cooperatives officially registered under REScoop.eu, although it is estimated that the real number may exceed 2,400 initiatives [105] This typology is represented by 54 SBM-RECs in this paper, as detailed in section S6 of the SF.

Table 5 SBMC for community-owned REC. Acronyms: SBMC (Sustainable Business Model Canvas); REC (Renewable Energy Community); TBL: (Triple Bottom Line); RE (Renewable Energy); O&M (Operation and Maintenance).

Community-owned			**Source**
Governance model	Promoter	- Citizen-led and community-driven initiatives	[16,23,25,31,43,59]
	Focal firm	- Cooperative members or representative bodies	
	Governance model	- Participatory, "one member one vote"; shared ownership and collective responsibility.	
	Legal form:	-Cooperative (S. Coop), Association	
Value proposition	Need/problem addressed	- Lack of funding, space constraints, external dependence, need for decentralised and citizen-owned energy systems.	[23,25,26,43,49,58]
	Offer	- Joint investment and ownership in RE infrastructure; promotes energy democracy.	
	Organisations' meaning of existence	- Foster local climate action and social, environmental, and economic benefits. - Member ownership	
Value delivery	Key relationships	- Strong engagement with local community and prosumers.	[16,25,26,31,59,106]
	Key channels	- Events, newsletters, online platforms, local media.	
	Customer segment	- Households, SMEs, public institutions, co-op members.	
Value creation	Key partnerships	- Local authorities, RE tech providers, community groups, financial institutions.	[16,23,25,26,45,53,80,106,107]
	Key activities	- Community ownership of local RE generation and operation - Legal/technical support.	
	Key resources	- Community-owned RE systems, local volunteers, technical expertise. - Renewable assets owned directly by the community.	
Value capture	Cost structure	- Infrastructure, O&M, technical equipment, smart meters	[25,53,88,106,108–110]
	Financial model	- Public grants, local support. . - Community investment: Membership fees and coop funding.	
	Revenue streams:	- Energy sales, - Membership fees, subsidies.	
TBL aspects	Social (+/-)	+ Job creation through local infrastructure and maintenance + Strong community participation and democratic control +Community engagement and environmental education initiatives - + Reduction of energy poverty through collective ownership	[16,25,43,57]
	Economic (+/-)	+ Consumer cost savings through cooperative models + Return on investment for community members + Income streams for local economies via shared ownership ± Community-based financing structures	[16,43,49,81]
	Environmental (+/-)	- Locally owned renewable systems reduce grid dependency and emissions from long-distance transmission - High self-consumption promotes energy savings and encourages more conscious energy use	[24,49]
Cases (Examples)		- French *Enercoop;* - *Argiñola Berener, Ekiherri, Esnargi, Hitzar (D2030 Working Group, 2025)*	*[33,111]*

Note. Full characterization available S6 of the SF

3.1.2 Peer-to-peer trading

Peer-to-Peer (P2P) trading (Table 6), also known as *prosumer trading*, refers to a model where community members produce and exchange energy directly through peer-to-peer platforms. A prosumer is an active energy user who both generates and consumes electricity [112]. The key element is the direct peer-to-peer exchange of energy among participants. allowing prosumers greater flexibility and control over their energy consumption [113]. This model democratises energy markets by enabling participants to choose whom they buy from or sell to [80]. Transactions are facilitated by local grid controllers, with some integrating smart contracts for automation[43]. The typology is based on an analysis of 42 SBM-RECs, as detailed in section S7 of the SF.

Table 6 SBMC for P2P REC. Acronyms: SBMC (Sustainable Business Model Canvas); REC (Renewable Energy Community); P2P (Peer-to-Peer); TBL: (Triple Bottom Line); RE (Renewable Energy).

Prosumers (P2P) trading.			**Source**
Governance model	Promoter	- Prosumers, local authorities - Local citizens, community groups, NGOs	[26,43,58,109,113]
	Focal firm	- Energy cooperatives - Real estate developers, municipalities - P2P platforms	
	Governance model	- Democratic, based on participation and collective decision-making by members - Agreements and decisions are made based on community interests	
	Legal form:	- S. Coop - Organisational, Collaborative, Service governance	
Value proposition	Need/problem addressed	- Lack of incentives and autonomy in traditional markets, limited access to flexibility services.	[43,113,114]
	Offer	- Direct P2P energy exchange with real-time pricing; increased self-sufficiency and transparency.	
	Organisations' meaning of existence	- Empower prosumers to become active market participants and decentralize control.	
Value delivery	Key relationships	- Smart contract–based trust systems; prosumer and DSO collaboration.	[16,26,43,57,80,110,115]
	Key channels	- Digital trading platforms (P2P networks) - Community campaigns, local grid controller.	
	Customer segment	- Residential prosumers, SMEs, and energy-conscious communities.	
Value creation	Key partnerships	- RE tech providers, P2P operators, local authorities	[57,80,106,113]
	Key activities	- Local energy generation, platform development, aggregation of flexibility. - Direct energy trading platforms between prosumers - Development of P2P	
	Key resources	- Solar PV, batteries, digital infrastructure (e.g. smart contracts, VPP), skilled labor.	
Value capture	Cost structure	- Platform maintenance, regulatory compliance.	[53,57,80,81,108,114]
	Financial model	- Subscription models, grid incentives, surplus trading.	
	Revenue streams:	- Revenue from transaction fees in P2P exchanges. - Flexibility services, external energy sales.	
TBL aspects	Social (+/-)	+ Enables active consumer participation in energy trading + Supports social values of decentralization and autonomy +Provides opportunity for citizen involvement in governance -Weak supplier engagement in sustainable practices	[26,30,31,79]
	Economic (+/-)	+ Reduces energy costs for consumers by enabling local transactions - High initial investment and maintenance costs	[49,79]
	Environmental (+/-)	- Real-time trading improves energy efficiency and local balancing of renewable supply and demand - Reduces reliance on centralized infrastructure by distributing generation and consumption	[26,58]
Cases (Examples)		- Svalin community in Denmark - Lumenaza	[31,43,116]

Note. Full characterization available S7 of the SF

3.1.3 Localized energy markets

The *Localized Energy Markets (LEM),* refer to community-based systems where prosumers and consumers trade energy through structured local markets (Table 7). The core element is the establishment of a structured local market with customized pricing agreements, where prosumers and consumers exchange energy under customized pricing agreements. These markets optimize renewable resource utilization through digital platforms and collaboration among local actors, fostering trust and energy efficiency [30] For instance, Reis et al. [43] highlight how these markets offer cheaper and more reliable local energy supply, reducing dependency on external providers through energy trading platforms. Carroll et al [26] and Rieksta et al [115] emphasize the ability of Peer-to-Peer (P2P) platforms to facilitate direct energy exchange among local prosumers, optimizing the use of local renewable resources. Siksnelyte Butkiene et al [57] complements this by noting that P2P platforms require advanced technological infrastructure, including blockchain, to ensure secure and transparent transactions. Additionally, Rossetto et al [59] underscores the crucial role of community participation and collective management in local energy generation and distribution. This typology is based on 21 SBM-RECs, as detailed in section S8 of the SF.

Based on literature data and discussions during the validation process, it was also noted that *P2P trading* can often be part of *LEM*. In practice, many *P2P trading* systems are used within these *LEMs* to manage energy exchange. Therefore, P2P can sometimes be seen not as a separate model but as one of the ways energy is traded in LEMs.

Table 7 SBMC for LEM REC Acronyms: SBMC (Sustainable Business Model Canvas); LEM (Localized Energy Markets); REC (RE Community); TBL: (Triple Bottom Line).

Localized energy markets (LEMs)			**Source**
Governance model	Promoter	- Technology companies - Local community leaders - Organizers	[26,57,59]
	Focal firm	- Community energy managers, digital platform operators. - Actors that coordinate and manage local energy exchanges	
	Governance model	- Platform management with rule-based exchanges. - Collective decision-making by members - Service providers	
	Legal form:	- Platform agreements, service governance	
Value proposition	Need/problem addressed	- High upfront costs, space constraints, and external dependence	[26,43,59]
	Offer	- Local, low-cost energy through smart contracts and localized trading; tailored pricing agreements	
	Organisations' meaning of existence	- Promote energy autonomy - Local resilience via digital innovation	
Value delive	Key relationships	- Ecosystem of prosumers, regulators, utilities, and platform stakeholders.	[57,110,115]
	Key channels	- Trading and community platforms, online campaigns	
	Customer segment	- Local prosumers, SMEs, public institutions	
Value creation	Key partnerships	- Grid operators, regulators, investors, technical partners	[24,26,114]
	Key activities	- Energy production and trading; local coordination	
	Key resources	- Technological platforms (e.g., blockchain) - Local energy infrastructure, human capital, knowledge.	
Value capture	Cost structure	- Infrastructure and platform development, operations.	[57,59,81]
	Financial model	- Transaction fees - Investments from members, public-private partnerships.	
	Revenue streams:	- Prosumers' income from sales - Transaction commissions, long-term contracts.	
TBL aspects	Social (+/-)	+ Community involvement in local energy generation and trading + Improved well-being through reduced local energy costs - Governance often managed by platforms rather than citizens, limiting community empowerment	[26,59]
	Economic (+/-)	+ Lower electricity bills through optimized local exchange + Transaction-based revenue models for prosumers -+ Expands local market for energy services	[26,57,59]
	Environmental (+/-)	+ Facilitates CO_2 reduction via optimized local RE use. +Improves energy efficiency through localized trading - Virtual platforms reduce the need for physical infrastructure, but their environmental impacts (like energy use and e-waste) are not considered	[24,57,59,114]
Cases (Examples)		- Sonnen Community in Germany, Austria, and Italy - Hoog Dalem 2.0	[26,43]

Note. Full characterization available S8 of the SF

3.1.4 Collective generation

Collective generation (Table 8), consists of projects where communities jointly generate RE. The key element is joint generation, with a focus on self-generation and shared consumption [43]. These projects are typically managed by cooperatives or municipal entities [23,30], aiming to enhance energy efficiency and reduce costs through community participation and local investment [59,110]. This typology includes 23 SBM-RECs, as outlined in section S9 of the SF.

Unlike *community-owned RECs*, which are characterised by full community ownership and democratic governance across all business model components*, collective generation RECs* focus specifically on the shared generation and use of energy [49]. These projects are often promoted or managed by municipalities or technical operators, and governance structures may be less participatory [81].

Table 8 SBMC for collective generation REC. Acronyms: SBMC (Sustainable Business Model Canvas); REC (Renewable Energy Community); TBL: (Triple Bottom Line); RE (Renewable Energy); O&M (Operation and Maintenance).

Collective generation			**Source**
Governance model	Promoter	- Local authorities, - Social housing corporations, - Community members and cooperative	[16,49,59,110]
	Focal firm	- Community energy managers - Municipalities. - Sometimes individual prosumers or grid operators.	
	Governance model	- Community-based governance with shared ownership. - Cooperative or municipal management, with democratic decision-making	
	Legal form:	- Cooperative (S. Coop) - Local governance	
Value proposition	Need/problem addressed	- Achieve energy self-sufficiency and reduce dependence on external supply.	[16,43,49,110]
	Offer	- Joint renewable energy generation, shared consumption, and fair cost distribution	
	Organisations' meaning of existence	- Foster collaborative energy management and local cost-effective solutions.	
Value delivery	Key relationships	- Voluntary, long-term cooperative agreements within the community.	[31,57,59,79,88]
	Key channels	- Direct grid connection and long-term power purchase agreements (PPAs).	
	Customer segment	- Tenants, homeowners, SMEs, large commercial clients, public and local community users.	
Value creation	Key partnerships	- Local governments, cooperatives, technology and energy providers.	[23,30,43]
	Key activities	- Renewable energy co-generation and local consumption coordination.	
	Key resources	- Shared installations, pooled investments, and collective technical infrastructure.	
Value capture	Cost structure	- Shared capital, O&M, ICT infrastructure	[31,43,59,80,108]
	Financial model	- Community and cooperative investments, public incentives.	
	Revenue streams:	- Collective energy use savings, surplus energy sales (when applicable)..	
TBL aspects	Social (+/-)	+ Enhances local engagement and awareness of renewable energy benefits + Fosters community self-consumption and shared governance +Strengthens community cohesion and participation	[33,54,59]
	Economic (+/-)	+ Enables revenue from energy self-consumption and grid sales + Encourages cost efficiency through collective investments and long-term savings − Requires high initial CAPEX, though OPEX is manageable	[23,54,79,88]
	Environmental (+/-)	+ Promotes decentralized energy generation, storage, and self-consumption + Reduces environmental burden through optimized distribution	[30,33,54]

Collective generation		Source
Cases (Examples)	- Windkraft Simonsfeld in Austria - Ixotzen (D2030 Working Group, 2025)	[26,43]

Note. Full characterization available S9 of the SF

3.1.5 Externally managed projects

Externally managed projects (Table 9), involve RE projects managed and funded by external entities, rather than by community members themselves [43]. The key element is external management, where an outside company or investor oversees the project [24,88,106]. These large-scale projects are typically funded through customer investments, government programs, or credit schemes, generating revenue through energy sales, power purchase agreements (PPAs), and service fees [26,88,117]. This typology consists of 39 SBM-RECs, as detailed in section S10 of the SF.

A summary of the table shows that these projects encompass various financial models, including crowdfunding-based initiatives [26], leasing schemes [80], development trusts, non-profit organisations that hold and manage community assets for long-term local benefit [118], and large-scale investments by utilities [106]. Externally managed projects usually involve long-term PPAs that provide financial stability for investors while ensuring affordable RE access for consumers [43]. The role of financial institutions and public-private partnerships is crucial in ensuring the viability of these externally managed renewable projects [88], as they often provide dedicated investment funds, grants, or full project financing.

Table 9 SBMC for externally managed renewable projects REC. Acronyms: SBMC (Sustainable Business Model Canvas); REC (Renewable Energy Community); TBL: (Triple Bottom Line); RE (Renewable Energy); O&M (Operation and Maintenance).

Externally managed projects			Source
Governance model	Promoter	-Crowdfunding platforms, energy developers, ESCOs	[26,88]
	Focal firm	- Combination of crowdfunding platforms and project organizers - External service providers manage projects with limited community input	
	Governance model	-Centralised project management with optional investor consultation; defined by service contracts	
	Legal form:	- Varies (LLC, cooperative, PPP)	
Value proposition	Need/problem addressed	-Energy poverty, high upfront costs for community, utility decline, and need for stable long-term contracts	[59,80,117]
	Offer	- Fully financed RE infrastructure and services via PPAs, often including DSM and discounts	
	Organisations' meaning of existence	-Provide affordable, renewable energy via third-party investment	
Value delivery	Key relationships	- Long-term contracts with municipalities - Partnerships with regulatory bodies and transmission system operators for grid integration	[26,119]
	Key channels	-Digital platforms, direct municipal agreements, crowdfunding campaigns	
	Customer segment	-Low-income households, municipalities, commercial/industrial users.	
Value creation	Key partnerships	-Grid operators, financial institutions, RE tech providers, NGOs	[24,88,106]
	Key activities	- Financing, construction, and operation of RE infrastructure.	
	Key resources	- External capital, utility-scale RE systems, legal/technical know-how.	
Value capture	Cost structure	- Capital-intensive infrastructure, O&M, grid integration. - Community reinvestment	[56,120]
	Financial model	- Fully **financed by utilities** - External investors, grants, social enterprises.	
	Revenue streams:	- PPAs, energy sales, ancillary grid services.	
TBL	Social (+/-)	+ Employment generated through infrastructure installation	[24,26,119]

Externally managed projects			Source
		- Decision-making dominated by external platforms - Weak alignment with social values; minimal community empowerment - Limited or no focus on education and participation	
	Economic (+/-)	+Revenue generated by selling energy under long-term contracts +Cost burden mostly assumed by external developer -Little local economic reinvestment or value capture -High operational costs reduce net return for communities *Financially efficient for developers, but with limited direct return for the community.	[23,81,121]
	Environmental (+/-)	+Better use of renewable sources like wind and solar - Lower control over environmental performance due to external management -Involves transmission over long distances, reducing efficiency	[106]
Cases (Examples)		- Ekiola in Spain - Verivox and Check24 in Germany	[113,122]

Note. Full characterization available S10 of the SF

3.1.6 Aggregated community

Aggregated community RECs (Table 10) involve community aggregators pooling energy resources to provide flexibility services to the grid [43]. The key element is flexibility, enabling small consumers to participate in the energy market by balancing supply and demand [30,57]. Aggregators optimize distributed energy resources such as solar panels, storage systems, and electric vehicles, offering grid services like demand response to reduce energy costs for participants [26,59,113]. This model is based on 21 SBM-RECs, as documented in section S11 of the SF. Aggregators are intermediaries that coordinate and combine the flexible capacities of multiple distributed energy resources like household batteries into a single offer that can be traded with grid operators, enabling even small-scale actors to access complex energy markets [80,109,114].

Table 10 SBMC for aggregated community projects REC. Acronyms: SBMC (Sustainable Business Model Canvas); REC (Renewable Energy Community); TBL (Triple Bottom Line); RE (Renewable Energy).

Aggregated community			Source
Governance model	Promoter	-Aggregator companies -Energy companies and grid operators	[57,59,109]
	Focal firm	-Aggregator companies and energy management companies - Primarily managed by entities that coordinate energy generation	
	Governance model	-Managed by aggregators and prosumers. - Local groups are involved, with aggregators	
	Legal form:	-Not specified	
Value proposition	Need/problem addressed	- Barriers for small consumers to participate in flexibility markets; grid balancing needs	[30,43,57,80,114]
	Offer	-Collective demand response (DR) and flexibility services with potential cost savings.	
	Organisations' meaning of existence	- Enable local actors to access high-value grid services while improving system efficiency.	
Value delivery	Key relationships	- Aggregator–participant and aggregator–grid operator interactions.	[80,113,114,123]
	Key channels	- Digital apps, municipal partnerships, targeted outreach	
	Customer segment	- Households, SMEs, and public institutions with flexible consumption or generation	

Aggregated community			Source
Value creation	Key partnerships	- DSOs/TSOs, technology providers, -Aggregator -Licensed supplier	[30,43,57,59,109,113,114,123]
	Key activities	-**Aggregating DERs** - **Managing DR programs** and bidding aggregated capacity -Contract administration for flexible	
	Key resources	-**Software platforms** -Skilled workforce	
Value capture	Cost structure	- Devices, software, customer support, penalties for underperformance	[43,74,80,109,114,123]
	Financial model	- Bilateral contracts with participants; potential reselling to higher-level aggregators	
	Revenue streams:	- **Payments from balancing, reserve, or ancillary markets for aggregated demand flexibility**	
TBL aspects	Social (+/-)	+ Creates local employment for technical support - Focus on aggregation and demand management rather than direct citizen engagement - Benefits small-scale prosumers but lacks social cohesion mechanisms - Limited visibility of community ownership or participation	[57,59,123]
	Economic (+/-)	+Revenue from flexibility services sold to grid operators +Cost savings through collective demand optimization -Requires costly infrastructure for monitoring and aggregation -Technical complexity may limit access to economic benefits	[57,59]
	Environmental (+/-)	+Supports sustainable cities and clean energy goals +Aggregators optimize renewable usage and grid balancing - Requires infrastructure and tech with unclear environmental footprint - Smart metering enhances monitoring but not necessarily reduces consumption	[26,59,74,123]
Cases (Examples)		- Piclo in California (Aggregates local loads to sell flexibility in wholesale markets) - Vandebron Platform in the Netherlands	[57,124]

Note. Full characterization available S11 of the SF

3.1.7 Local energy service companies (ESCOs)

Local Energy Service Companies (ESCOs) (Table 11), provide energy efficiency and RE services at the community level [109,118]. The key element is service, as these companies offer tailored energy solutions to optimize energy use and reduce costs [58,79,80]. This SBM is represented by 30 SBM-RECs, as documented in section S12 of the SF.

Table 11 SBMC for local energy service companies projects REC. Acronyms: SBMC (Sustainable Business Model Canvas); REC (Renewable Energy Community); TBL (Triple Bottom Line); RE (Renewable Energy); O&M (Operation and Maintenance).

Local energy service companies (ESCOs)			Source
Governance model	Promoter	-Private or community-based, co-ops, 3rd sector organizations	[23,57,58,79,109,125]
	Focal firm	-The central company ESCO itself managing key activities, which in this case is the ESCO.	
	Governance	-ESCO in control but possibly involving community input.	
	Legal form:	- Cooperatives are the most typical for community-led projects, while LLCs (limited liability company) are common for private or hybrid management	
Value proposition	Need/problem addressed	- High upfront costs and lack of technical capacity for comprehensive EE/RE projects	[23,58,74,79,80,117]
	Offer	- **Turnkey "energy-as-a-service"** solutions: from audits to system installation and operation.	
	Organisations' meaning of existence	-Promote a fair and affordable energy transition with guaranteed savings - Empower communities through reduced bills, sustainable infrastructure, and shared governance	

Local energy service companies (ESCOs)			Source
Value delivery	Key relationships	- Long-term contracts with clients; coordination with DSOs and suppliers.	[58,79,106,117]
	Key channels	- Municipal initiatives, local events -Digital apps/web portals.	
	Customer segment	- Households, SMEs, public buildings, prosumers.	
Value creation	Key partnerships	-Licensed suppliers - Distribution system operators (DSOs) & Transmission System Operators (TSOs)	[45,58,79,80,117,118]
	Key activities	- Energy Efficiency (EE) services, RE generation O & M -Performance-based contracting	
	Key resources	- Technical know-how, smart systems, financing models (e.g. EPCs).	
Value capture	Cost structure	-Capital for EE measures, solar/heat systems, metering infrastructure - O&M, licensing, support services	[79,109,117,118]
	Financial model	- Upfront financing by ESCO or third parties - Possible synergy with public grants and community share offerings.	
	Revenue streams:	-Selling EE services - Performance-based payments, service fees, energy tariffs	
TBL aspects	Social (+/-)	+Generates jobs in design and implementation +Improves living conditions through reliable energy access -Limited focus on education and empowerment +Provides affordable heating and services to local populations	[23,58,74,81,117]
	Economic (+/-)	+Energy efficiency services reduce customer energy bills + Revenue model based on service performance, not volume - High upfront investment and technical costs ± Financial viability depends on long-term contracts and subsidies	[79,80,106,109,118]
	Environmental (+/-)	+ Reduces emissions by increasing energy efficiency + Promotes renewable heat production + Includes systems for water treatment and grid monitoring - Some infrastructure may be resource intensive	[74,107,109,117]
Cases (Examples)		- Chase Community Solar (The United Kingdom) - Choice Energy in Australia	[108,126]

Note. Full characterization available S12 of the SF

3.1.8 Electric mobility cooperatives

Electric Mobility Cooperatives (Table 12), focus on providing shared electric mobility solutions such as electric vehicle (EV) sharing and charging infrastructure. The key element is mobility, ensuring accessible and sustainable transport options [23,109]. These cooperatives are designed to foster local economic and environmental benefits by enabling car sharing and e-mobility services within communities, often using public or shared infrastructure [59]. This model is based on 9 SBM-RECs, as outlined in section S13 of the SF.

Table 12 SBMC for electric mobility cooperatives projects REC. Acronyms: SBMC (Sustainable Business Model Canvas); REC (Renewable Energy Community); TBL: (Triple Bottom Line); RE (Renewable Energy).

Electric mobility cooperatives			Source
Governance model	Promoter	- Mobility service providers or citizen groups initiate, technology star-ups	[30,59,109,113]
	Focal firm	- Mobility service providers.	
	Governance model	-Local cooperatives managing mobility services	
	Legal form:	-S.coop, LLC or hybrid	

Electric mobility cooperatives			Source
Value proposition	Need/problem addressed	- High EV ownership costs, lack of accessible infrastructure, need for cleaner transport.	[23,59,109,113,115]
	Offer	- Shared e-mobility services (cars, scooters, e-buses); charging infrastructure powered by local RE.	
	Organisations' meaning of existence	- Democratise transport access and reduce transport emissions	
Value delivery	Key relationships	- Cooperative members, local authorities, grid operators (for V2G integration)	[23,43,59]
	Key channels	-Digital platforms & mobile apps -Local engagement: Community events	
	Customer segment	-**Residents lacking personal vehicles** -SMEs, municipalities with transit needs.	
Value creation	Key partnerships	-Vehicle manufacturers & charging providers -Local goverments	[23,43,59,109]
	Key activities	-E-Mobility services -Charging Infrastructure deployment -Potential flexibility services, aggregating EV batteries	
	Key resources	-EV Fleets & charging stations -Digital platforms	
Value capture	Cost structure	-Capital investment: **Purchase/lease of EV fleets** -Infrastructure, maintenance, licensing	[23,43,59,109]
	Financial model	-Community funding -Public-private partnerships	
	Revenue streams:	-Selling e-mobility services: Pay-per-use, subscription, or membership -Charging fees: Payment from users charging	
TBL aspects	Social (+/-)	+ Promotes local employment and procurement + Facilitates access to clean transport for underserved users + Strengthens community ties through shared use and co-responsibility of mobility assets - Limited direct education initiatives identified - Digital platforms enable participation but require digital literacy, which may create barriers for some users	[30,59,109]
	Economic (+/-)	+ Cost savings through shared vehicle use + Revenue from memberships, usage fees and public support - High capital and operating costs - Resource-intensive: fleet, charging infrastructure, software	[23,59,109]
	Environmental (+/-)	+Reduces emissions through shared electric transport +Charging infrastructure often powered by renewables +Lowers private vehicle dependency and mobility-related emissions -Environmental impacts of EV production and infrastructure are not considered in the model	[23,59,115]
Cases (Examples)		- The big lemon in the UK - Plugsurfing, ChargeNow and PlugShare (Apps)	[30,113]

Note. Full characterization available S13 of the SF

3.1.9 Technologically enabled models

Technologically enabled models (Table 13) are RECs that incorporate advanced technologies to improve energy management. The key element is technology, as these models integrate Artificial Intelligence (AI), Wireless Sensor Networks (WSNs), and digital platforms to enhance efficiency, security, and system optimization [115,127]. Additionally, they leverage demand response models to encourage community participation in energy decisions [128].

Importantly, the integration of smart technologies not only improves technical performance but also fosters cooperation and communication among members, helping to attract new participants to collective energy initiatives [53]. Their modular and flexible architecture allows energy communities to adapt to diverse user needs, increasing engagement and long-term commitment [62]. While technology offers significant advantages, maintaining a balance between digitalization and community engagement is crucial. This model is based on 4 SBM-RECs, as documented in section S14 of the SF.

Table 13 Sustainability impact dimension for the technologically enabled models REC. Acronyms: REC (Renewable Energy Community); TBL (Triple Bottom Line).

Technologically enabled RECs			Source
TBL aspects	Social (+/-)	+ Enhances energy awareness through digital tools + Technology increases transparency and potential participation - Risk of eroding social cohesion or excluding non-digital actors	[115,129]
	Economic (+/-)	+ Improved efficiency and optimized energy consumption + Revenue from selling excess energy via smart systems - Requires very high investment in digital and AI infrastructure ± Benefits often realized in the long term, after tech amortization	[26,115,130]
	Environmental (+/-)	+ Enables optimization and energy forecasting with AI systems + Power storage and demand response improve grid integration - High tech systems may lack transparency in environmental costs -Technologies(storage) in energy communities can unintentionally increase emissions when prioritising profit over environmental goals -Large-scale renewable deployments cause biodiversity loss and visual impacts, undermining community-oriented principles	[59,115,127,131,132]

Throughout the review, other SBMs that do not correspond to RECs were identified and excluded from the analysis, such as microgrids, small-scale power systems that can operate independently or connected to the main grid [62], private wire models [30], or energy-as-a-service offerings led by utilities, such as E.ON [106]. These models differ in ownership structures, governance logics, or legal forms, and are documented in section S19 of the SF.

3.2 Governance in SBM for RECs

Governance is a critical design element that shapes not only operational functioning but also the values, legitimacy, and community embeddedness of energy initiatives [82–84]. Building upon the governance-related blocks from the SBMC characterisations, Table 14 provides a comparative overview of the governance models across SBM-REC typologies. It synthesises governance type, decision-making structure, and citizen involvement into a standardised format to enhance cross-typology comparability.

Table 14. Comparative overview of governance features across SBM-REC typologies.

SBM-REC Typology	Bottom-up	Hybrid	Top-down	Democratic decision-making	Community involvement	Legal Form(s)
Community-owned	✓			✓	✓	S. Coop, Association
Prosumers (P2P) trading		✓		± (shared with platform)	✓	Cooperative, Platform operator
Localized energy markets (LEMs)		✓		✗ (platform or market rules)	±	Platform provider, Multi agreements
Collective generation	✓			✓	✓	Cooperative, Municipality
Externally managed project			✓	✗	✗	Utility, ESCO, PPP
Aggregated community			✓	✗ (aggregator-led)	±	Aggregator, ESCO, Supplier
Local energy service companies (ESCOs)		✓	✓	±	±	ESCO, Private company
Electric mobility cooperative	✓		✓	✓	±	S. Coop, Multi-stakeholder
Technologically enabled			✓	✗ (expert or AI-led)	✗	Tech company, Private entity

Note. This synthesis is based on the governance-related components included in the SBMC characterisations for each typology, in Sections 3.1.1–3.1.9. Full references supporting each dimension are included in the respective typology characterisation. "✓" = characteristic clearly present; "±" = partially present or shared; "✗" = not present or marginal.

3.2.1 Citizen-led and cooperative governance (bottom-up)

Typologies such as *community-owned*, *collective generation*, and *electric mobility cooperatives* are rooted in bottom-up governance. They are initiated by citizens, local organisations or cooperatives, and often adopt democratic decision-making mechanisms. Ownership is collective, and strategic decisions are made in participatory forums (e.g., general assemblies, co-creation processes). This model aligns strongly with the foundational principles of RECs; local empowerment, democratic control, and socio-environmental purpose [29,30,43,59].

These governance configurations tend to strengthen community identity, trust, and long-term engagement, and are often more resilient to social acceptance issues [57,59]. However, they can face challenges related to administrative capacity, regulatory complexity, or financial scalability [9].

3.2.2 Hybrid and decentralised platform governance

Models like *P2P trading*, *LEMs*, and *ESCOs* have hybrid governance. Although some originate from community or municipal initiatives, much of the operational and decision-making authority is transferred to external platforms, aggregators, or service intermediaries. These models attempt to balance community-driven principles with market-based efficiency, often via platform-based coordination, shared ownership agreements, or limited co-governance arrangements [43,59,133].

While this structure enables innovation, scalability, and technical sophistication [113], it may dilute participatory control. Without careful design, such models risk drifting from core energy community values toward more autocratic or investor-driven logics [26,57].

3.2.3 Externally led governance (top-down)

Externally managed projects*, aggregated communities*, and *technologically enabled* SBMs largely follow top-down governance. Depending on their specific configuration, some *ESCOs* may also operate under this governance model. Projects are typically led by utilities, companies, or technology providers with centralised management and minimal community involvement. In many cases, citizens are positioned as consumers or passive beneficiaries, rather than active co-creators [57,118]. In technologically enabled models, governance may even be embedded in digital systems (e.g., smart contracts or AI agents), raising concerns about transparency, accountability, and the erosion of collective agency [9,43].

These models can be effective in mobilising capital, reducing deployment times, and ensuring technical reliability [58,79]. However, they may conflict with the normative expectations set by the EU clean energy package, which frames energy communities as participatory, inclusive, and locally anchored initiatives [10,20].

In summary, governance emerges as a key differentiator between SBM-REC typologies. BMs following bottom-up, community-led governance are more consistent with the social mission and democratic values associated with RECs. In contrast, top-down or platform-led governance may compromise those values in favour of efficiency, scale, or digital optimisation. Designing governance models that preserve participation while enabling effective operation is thus central to the long-term legitimacy and sustainability of RECs [29,43,57,59].

3.3 Comparison of the value management mechanisms in SBM for RECs

SBM typologies offer a structured way to classify BMs into distinct types based on recurring patterns, theoretical constructs, or empirical traits [134] This section briefly compares key value delivery. creation, and capture mechanisms across SBM-REC typologies, based on the structured analysis presented in Section 3.1.

Value delivery mechanisms differ notably in how communities interact with the energy services and in the degree of user empowerment. *Community-owned* and *electric mobility cooperatives* prioritise close, trust-based relationships with their members, using physical outreach (e.g., events, workshops) and democratic forums to maintain engagement [16,91]. In contrast, models like *P2P trading* and *LEMs* adopt more digitally mediated delivery channels, apps, platforms, and automated transactions. These offer flexibility and convenience but sometimes reduce community cohesion or direct involvement [63,75]. *Aggregated community* and t*echnologically enabled* SBM rely on high-tech interfaces and grid operator coordination, often treating citizens more as passive participants in automated systems [59,135]. Meanwhile, *ESCOs* deliver value through long-term contracts and tailored services, balancing local trust networks with technical performance metrics.

The creation of value in SBM-REC typologies is primarily shaped by the types of partnerships established and the configuration of key resources and activities. Typologies such as *community-owned* and *collective generation* strongly rely on local partnerships, municipalities, cooperatives, and citizens mobilizing social capital, renewable assets, and local technical expertise to collectively develop energy projects [24,25]. In contrast, *externally managed projects* and *aggregated community* depend more heavily on private companies, financial institutions, and specialised technology providers, with value creation centred on technical infrastructure, grid services, or digital platforms [91,96]. SBMs like *ESCOs* and *P2P trading* emphasise service innovation and technology integration, reflecting a hybrid approach that combines community alignment with commercial viability.

The mechanisms for capturing value reveal important differences in financial structure, revenue models, and cost distribution. *Community-owned* and *collective generation* rely on member contributions, cooperative funding, and public support, with revenues from self-consumption, grid sales, and subsidies, often reinvested locally [136,137]. *P2P trading* and *LEMs* use transaction-based income and fee structures, enabling prosumers to monetise surplus while platforms retain commissions [75,91]. In contrast, *externally managed projects* are usually financed entirely by third parties, with revenue and risk largely externalised, limiting local economic retention [58,105] *ESCO*s and *electric mobility cooperatives* employ hybrid financing (e.g., grants, contracts, and usage fees), with performance-based payments becoming more common. Lastly, *aggregated communities* generate income through grid services and balancing markets but require significant technical infrastructure and carry high operational costs.

These findings demonstrate that SBM-REC typologies are not exclusive but rather exist along a continuum shaped by contextual variables such as regulatory frameworks, technological maturity, and community capacity. Understanding these internal variations is key to aligning the model design with local goals and values.

3.4 TBL aspects analysis of the SBM-REC typologies

To synthesise the TBL aspects emerging from the SBM-REC typology analysis, Table 15 presents a comparative overview of the most frequently cited social, economic and environmental aspects. More details on sustainability can be found in S16 of SF.

Table 15 Most mentioned TBL aspects of SBM-REC typologies.

TBL aspects	
Social	-Community participation and empowerment [26,33,43] -Local job creation and skill development [25,30,119] -Reduction of energy poverty and affordability [33,59,81] -Promotion of social cohesion and trust [59,109]
Economic	- Cost savings through self-consumption and efficiency [23,49,59] - Income generation from energy sales and flexibility markets [26,114] - Financial accessibility and investment models [25,106] - High upfront costs barriers [57,79]
Environmental	- Emission reduction via RE and self-consumption [24,49] - Energy efficiency and optimization [23,123] - Integration of digital and smart grid technologies [57] - Limited attention to biodiversity [74]

Note. This synthesis is based on the analysis conducted through the SBMC in Sections 3.1.1–3.1.9.

3.4.1 Social sustainability

SBM typologies such as *community-owned* and *collective generation* offer the strongest contributions to social sustainability. These models are community-led, support inclusive participation, and frequently promote local ownership, empowerment, and equitable access to RE [25,43,49]. They also address energy poverty [57], by ensuring affordable and secure energy access through collective action and democratic governance structures [26,59]. These trends have been confirmed in the real-life implementation of local energy communities engaged through the PAR approach, such as RECs Argiñola and Ixotzen (D2030, Working group, 2025) [111].

In contrast, *externally managed projects* and *technologically enabled* tend to perform lower on social dimensions. In these SBMs, decision-making is typically driven by external actors, and community involvement is often limited to the role of passive consumers [106,115,129]. Additionally, SBMs such as *aggregated community* and *electric mobility cooperatives* show mixed performance; while they have the potential to empower users, barriers like digital exclusion or limited co-governance structures can reduce their social value [59,109].

3.4.2 Economic sustainability

From an economic perspective, SBM-REC typologies offer a variety of SBMs with different implications for value creation and distribution. *ESCOs*, *P2P trading*, and *aggregated community* generate revenues through services, performance-based savings, and participation in flexible markets [26,59,80]. These approaches support financial innovation and cost savings for end users but often require high initial investments and advanced technological infrastructure [79,114].

Community-owned and *collective generation* demonstrate potential for local reinvestment and long-term cost efficiency, especially when supported by public funding or cooperative financing [25,54]. In contrast, *externally managed projects* are financially robust and scalable but typically generate limited local economic returns, as most profits are captured by third-party investors [106,120]. Similarly, *electric mobility cooperatives* and *technologically enabled RECs* offer innovative revenue streams, but their high initial capital intensity may challenge financial sustainability if not supported by subsidies or strong partnerships [23].

3.4.3 Environmental sustainability

Nearly all SBM-REC typologies contribute to decarbonisation and improved energy efficiency by integrating distributed RE systems [24,33]. *LEMs*, *P2P trading*, and *aggregated community* enhance system efficiency through real-time balancing and resource optimisation, reducing emissions associated with centralised generation [30,54,57]. These models also reduce energy losses by promoting proximity generation and smart grid integration. C*ommunity-owned* and *collective generation RECs* also demonstrate a clear link to emission reduction via localised self-consumption and the use of simple infrastructures. However, some typologies, particularly those heavily reliant on digital infrastructure, have prompted concerns about the environmental footprint of enabling technologies (e.g., EV platforms, blockchain, AI-based systems), which are often not assessed in existing studies [74,106,115].

In summary, the comparative analysis highlights that no single typology excels across all sustainability dimensions. Trade-offs are evident, and the most appropriate SBM-REC configuration depends on the local context, goals, and capacities of each community. Models led by citizens and cooperatives, such as community-owned renewable networks and collective generation, tend to deliver stronger social outcomes, fostering democratic governance and local empowerment [29,30,43]. Moreover, decentralised configurations that enable active participation and shared ownership are particularly aligned with the principles of a just and inclusive energy transition [26,59]. As such, SBM-RECs make a tangible contribution toward the objectives of SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action), by promoting renewable, decentralised, and socially grounded energy systems [9]. They also align with CE principles by fostering resource efficiency and local value circulation

Given the inherent purpose of RECs to address social, environmental, and economic goals, it would be reasonable to expect all typologies to show contributions across these three dimensions. However, performance outcomes are strongly influenced by the selection of evaluation criteria. For example, economic impact may be assessed through indicators focused on citizen cost savings or investor returns, leading to different interpretations [138]. Moreover, for typology comparisons to be fully representative, the assessment would ideally be applied to the same local context. Since each typology analysed here is based on literature from diverse settings, contextual differences inevitably influence how each model performs in practice [119].

Building on these limitations and contextual differences, the relative strengths of the nine typologies can be further understood through a comparative reading of the evidence available in the literature. Citizen and cooperative led models such as *community-owned* and *collective generation* (typologies 1 and 4) consistently show the strongest social contributions, with studies highlighting their effects on participation, empowerment and energy poverty alleviation [16,25,43,49,108]. In contrast, market-oriented configuration including *P2P trading* and *aggregated community* (typologies 2 and 6) demonstrate clearer economic performance through cost savings, participation in flexibility markets and additional revenue streams [24,30,57,59]. Environmental contributions tend to be strongest in decentralised renewable generation and efficiency-oriented models. This is particularly evident in *LEMs*, collective generation schemes, ESCO-type configuration, and electric mobility cooperatives (typologies 3, 4, 7 and 8), which combine renewable production, proximity-based energy sharing, and demand-side optimisation [30,59,107,115]. These tendencies are synthesised in Table 16, which presents a qualitative performance matrix of the relative TBL performance of each typology based on the detailed sustainability coding in section S16 of the SF.

Table 16 Qualitative assessment of TBL performance across SBM-REC typologies

SBM-REC Typology	Social	Economic	Environmental	Key references
Community-owned	++	+	++	[16,25,43,49,108]
Prosumers (P2P) trading	+	++	++	[24,26,30,57,59]
Localized energy markets (LEMs)	+	++	++	[56,57,59,62,118]
Collective generation	++	+	++	[23,43,49,54,107]
Externally managed project	0	+	++	[23,58,59,79,106]
Aggregated community	+	++	++	[59,114,115,121,123]
Local energy service companies (ESCOs)	+	++	+	[23,79,81,107]
Electric mobility cooperative	++	+	++	[23,59,109,115]
Technologically enabled	0	+	+	[74,113–115,132]

Note. "++" = strong contribution; "+" = moderate contribution; "0" = weak or limited evidence. Based in Supplementary File (SF, S16).

While this study offers a structured, qualitative assessment of the social, environmental, and economic impact of each SBM-REC typology, the findings also highlight the importance of moving towards more quantitative evaluation frameworks. Several methodological avenues could support this effort. For instance, the LocalRES project proposes a KPI-based system covering technical, environmental, social, and economic dimensions including indicators such as energy self-production, minimised CO_2 emissions, citizen engagement levels, and investment in RE infrastructure [139]. Similarly, the Smart City Indicators framework offers sub-indicators on urban sustainability that could be tailored to local REC contexts [140], while the SDG 7 targets and indicators provide internationally recognised benchmarks for clean energy access and affordability [141]. Integrating such KPI-based systems would facilitate the replication and continuous improvement of SBM-REC initiatives in diverse territorial contexts.

3.5 Cross-typology synthesis: scalability and contextual drivers

The scalability of the nine SBM-REC typologies varies considerably depending on their organisational requirements, technological dependencies, and regulatory needs. P2P trading, aggregated community, and technologically enabled RECs (typologies 2, 6 and 9) generally display the highest scalability potential, as they rely on modular ICT infrastructures, smart metering, and digital platforms that can be replicated relatively easily once the appropriate regulatory and market conditions are in place [30,59,114,120]. In contrast, LEMs, ESCO, and electric mobility cooperatives (typologies 3, 7 and 8) exhibit medium scalability. This is because their expansion depends on the availability of suitable building stocks, energy-efficiency frameworks, urban mobility infrastructures, and robust partnerships between municipalities, private actors, and civil society organisations [59,81,109]. *Community-owned* and *collective generation* RECs (typologies 1 and 4) are more context-dependent: they scale effectively in regions with strong cooperative traditions, stable citizen financing instruments, and high levels of civic trust. These conditions are well documented in countries such as Denmark, Germany, northern Spain and the UK [25,43,49] but are harder to replicate in contexts with lower social cohesion or restrictive energy policies. *Externally managed projects* (typology 5) can scale rapidly when backed by utilities or large investors, although the extent to which such scaling translates into community benefits remains contingent on the contractual and governance arrangements that define local participation [58,59,79].

Differences in scalability are largely influenced by the broader contextual drivers, like the regulatory, socio-institutional, technological and resource-related conditions that make particular typologies more suitable in certain countries. Regulatory conditions are particularly decisive: market-oriented typologies *P2P, LEMs*, and *aggregated* community require advanced digitalisation, smart metering penetration, and liberalised electricity markets that permit decentralised trading and participation in flexibility services [24,57,59]. In contrast, community-owned and collective generation models depend on enabling cooperative legislation, frameworks for shared self-consumption, and citizen-financing mechanisms, which explains their stronger presence in robust cooperative traditions [25,49]. Socio-institutional factors further condition suitability: typologies grounded in collective action flourish in contexts with high civic trust and strong community engagement [56,118], while externally managed models tend to dominate where communities lack organisational capacity or access to capital [16,26]. Technological drivers also play a key role: digital maturity, platform infrastructures and the availability of smart grid technologies are essential enablers for *P2P trading*, *LEMs, aggregated community* and *technologically enabled* configurations [74,114,115], ESCOs and electric mobility cooperatives, on the other hand, require advanced building automation and EV charging infrastructures [59,107]. Finally, resource conditions and energy-system characteristics influence the territorial fit of each typology: *community-owned* and *collective generation* models perform particularly well in regions with high solar irradiation or carbon-intensive electricity mixes, where local renewable generation yields greater environmental benefits [142]. Urban density and transport infrastructures shape the feasibility of energy-efficiency and *mobility* models [109], while grid constraints and balancing needs can make *aggregated community* models especially relevant [121,123].

4 Conclusions

This study provides a structured framework for classifying and characterising SBM-RECs, based on a systematic analysis of 193 documented RECs from 43 articles. By consolidating diverse and often inconsistently labelled configurations into nine typologies, it helps overcome current fragmentation in the literature and enables clearer comparison and replication across initiatives. This typological framework is further enriched by the introduction of an extended SBMC that captures both economic logic and governance and sustainability impact dimensions, critical to RECs but largely absent in traditional BM approaches.

Governance emerges as a fundamental design variable rather than a secondary operational feature. Models with bottom-up, citizen-led governance such as community-owned networks and collective generation tend to support stronger local involvement, fairer benefit sharing, and greater trust. In contrast, models led by external actors or digital platforms may offer efficiency or scale but often limit community voice and ownership. Including governance directly in the BM, as done through the extended SBMC, is crucial. It helps clarify how decisions are made and by whom and ensures that social sustainability is given the same importance as environmental or economic goals.

In terms of sustainability, the analysis shows that while most SBM-REC typologies contribute positively to the deployment of RE, their social and economic performance is more variable. By characterising each typology through the SBMC, and defining its TBL impact, this paper highlights both strengths and limitations in the sustainability performance of REC models (section 3.4, Table 6). Nonetheless, current evaluations often rely on qualitative data, limiting comparability and policy applicability. To advance the implementation of REC aligned with sustainability goals, there is a need to define specific indicators and use robust analytical tools. These tools should incorporate life cycle and system thinking, to help measure social, economic, and environmental impact. Such indicators would allow municipalities and planners to design place-based REC schemes tailored to their neighbourhoods or cities.

Therefore, further research should focus on developing robust sustainability assessment frameworks, toolboxes, and indicator databases that can be applied across diverse REC contexts. SBM-REC design should also be integrated into broader energy planning processes, supported by decision-making tools that combine sustainability indicators and life cycle thinking. Such integration would enable municipalities and communities to co-develop energy strategies aligned with long-term decarbonisation goals at the neighbourhood or city scale.

This study used a PAR approach to improve and validate the SBM-REC typologies, based on real experiences from the local REC ecosystem. Regular meetings with local stakeholders including community members, cooperatives, public institutions, and technical advisors, revealed that many of the needs and challenges identified in the literature are also present in practice. In particular, the lack of clear information and structured models seen in academic studies is also common in the real-life development of RECs, making implementation slower and more complex. Moreover, evidence from the region suggests that communities organised through bottom-up governance models tend to build greater trust and participation among members, even if these models require more time to set up.

While the SBM-REC typology provides a structured lens to interpret common patterns, insights from the PAR process show that sustainability outcomes are shaped by both the BM type and how it is implemented in practice. Some impact stem from the model itself, while others depend on the individual performance. This highlights the need to combine typological analysis with context-sensitive evaluation to guide more effective REC design.

This study is not without its limitations. First, the underlying literature sample is predominantly European, reflecting both the geographical concentration of REC research and the origin of the REC and CEC concepts in the European policy framework. As in other recent reviews and taxonomies of REC BMs (e.g. Reis et al.[43]; Rossetto et al[59]; Vernay & Sebi [49]; Kubli, [53]; Horstink et al.[16]), this concentration may limit the direct transferability of the typologies to non-European contexts, even though many of the underlying mechanisms are likely to apply elsewhere. Second, the sustainability analysis developed in this paper is primarily qualitative, building on a structured synthesis of social, economic and environmental aspects reported in the literature. As discussed in section 3.4, moving towards more systematic and quantitative evaluation frameworks remains an important avenue for future work [143]. Third, the PAR-based validation was conducted in a single regional context (Gipuzkoa), which necessarily reflects the specific institutional and socio-cultural conditions of that ecosystem. However, this limitation is partly mitigated by the triangulation between PAR insights and international literature. In addition, relying solely on Scopus may also introduce a publication bias, despite the mitigation measures applied.

Finally, the results suggest that the SBM-REC typologies and extended SBMC framework developed here may offer value not only for researchers and practitioners, but also for local governments, community leaders, and policy designers aiming to assess and scale up REC initiatives. Future research should explore the adaptability of this framework to other regional contexts, including non-European settings where REC concepts are emerging. It should also investigate the links between governance models, community acceptance, and measurable social, economic, and environmental impact. In line with the discussion (Section 3.4), this will require complementing qualitative typology analysis with more systematic, quantitative evaluation approaches capable of assessing the differentiated sustainability performance of SBM-REC configurations across contexts. This will ensure that energy communities become more effective tools for inclusive, local-based, sustainability transitions. These findings will also assist in the development of a decision-support tool to guide the selection and adaptation of SBM typologies in diverse implementation settings. In doing so, this study also contributes to circular economy debates by showing how RECs operationalize CE principles in practice.

CRediT author statement

Lierni Rabanete: Conceptualisation, Methodology, Investigation, Writing – Original Draft, Writing – Review & Editing. **Dorleta Ibarra: :** Conceptualisation, Methodology, Writing – Review & Editing, Supervision, Project Administration and Funding Acquisition. **Joan Manuel F. Mendoza:** Conceptualisation, Methodology, Writing – Review & Editing and Supervision **Eneko Arrizabalaga** Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used OpenAI's ChatGPT as a writing assistant to support the refinement of language and structure during the preparation of this manuscript. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

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Supplementary material
The supplementary materials include extended data and methods supporting this study: the literature search and review process (S1–S2), the database and characterization of 193 SBM-REC alternatives (S3–S5), details of the nine identified typologies (S6–S14), additional BM not fitting these categories (S15), and a sustainability analysis of the SBM-REC typologies (S16).

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