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Original
Italian Renewable Energy Communities at the Crossroads: From Incentive Dependency to Market Integration / Schiera, D.S., Borchiellini, R.. - In: JOURNAL OF SUSTAINABILITY FOR ENERGY. - ISSN 2958-1907. - ELETTRONICO. - 5:1(2026), pp. 71-86. [10.56578/jse050104]

Availability:
This version is available at: 11583/3013167 since: 2026-07-16T08:00:20Z

Publisher:
Acadlore Publishing

Published
DOI:10.56578/jse050104

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18 November 2026

Journal of Sustainability for Energy
https://www.acadlore.com/journals/JSE

Italian Renewable Energy Communities at the Crossroads: From Incentive Dependency to Market Integration

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Received: 02-10-2026 **Revised:** 03-20-2026 **Accepted:** 03-27-2026

Citation: D. S. Schiera and R. Borchiellini, "Italian renewable energy communities at the crossroads: From incentive dependency to market integration," *J. Sustain. Energy*, vol. 5, no. 1, pp. 71–86, 2026. https://doi.org/10.56578/jse050104.

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Abstract: Renewable energy communities (RECs) are central to the European energy transition because they can turn passive consumers into active prosumers and support more decentralized, community-based energy systems. This perspective paper examines the evolution of RECs in Italy, asking whether their current development trajectory can move beyond incentive-dependent deployment toward more resilient and market-integrated models. Italy offers a particularly relevant case because it combines advanced regulatory transposition and rapid diffusion with persistent structural weaknesses. The analysis draws on regulatory documents, diffusion data, economic and governance evidence, market and grid data, and recent audit evidence from the European Court of Auditors. We trace the development of RECs from the European Union (EU)'s Clean Energy Package (CEP) through Italy's Legislative Decree 199/2021 and Autorità di Regolazione per Energia Reti e Ambiente (ARERA)'s Testo Integrato Autoconsumo Diffuso (TIAD) framework, and the emerging Testo Integrato del Dispacciamento Elettrico (TIDE) pathway for market integration. The paper argues that REC diffusion in Italy is constrained by an "incentive trap": although RECs are designed to promote local empowerment, they remain structurally dependent on national support schemes and are still weakly connected to wholesale markets, ancillary services, and grid flexibility mechanisms. We identify three strategic pillars for overcoming this limitation: governance innovation that combines economic viability, social equity, and digital solutions; regulatory pathways that enable aggregation, demand response, balancing-market participation, local flexibility, and storage; and diversified revenue streams based on local energy trading, demand response, multi-service provision, and grid-support services. The paper contributes to debates on energy democracy and decentralized energy systems by proposing an evolutionary framework through which Italian RECs can preserve their social value while becoming adaptive market actors.

Keywords: Renewable energy communities; Energy transition; Flexibility; Local energy markets; Energy democracy; Governance models

1 Introduction

The European energy transition is undergoing a fundamental transformation characterized by three interconnected trends: decentralization of generation assets, digitalization of energy systems, and democratization of energy decision-making [1]. At the intersection of these trends, Renewable energy communities (RECs) have emerged as key instruments for enabling distributed generation, collective self-consumption, and local value creation [2]. RECs represent more than a technical innovation in energy system architecture; they constitute a socio-technical infrastructure that redefines the relationship between citizens, energy, and territory [3].

The regulatory foundation for RECs was established by the EU's Renewable Energy Directive (RED II, Directive 2018/2001/EU) [4], which recognized the right of citizens to participate collectively in renewable energy generation, consumption, and sharing, thereby advancing the twin goals of decarbonization and energy democracy, which positions citizens as decision-makers in energy systems rather than mere recipients of energy services. This directive marked a paradigm shift from centralized, utility-dominated energy systems toward decentralized, citizen-driven configurations. The Internal Electricity Market Directive (Directive 2019/944/EU) further defined citizen energy communities and widened the role of collective actors within electricity markets [5].

Italy has been at the forefront of this movement. Following the transposition of RED II into national law through Legislative Decree 199/2021 [6], and the subsequent introduction of the Configurazioni di Autoconsumo per la Condivisione dell'Energia Rinnovabile (CACER) incentive scheme and the Testo Integrato Autoconsumo Diffuso (TIAD) regulatory framework [7, 8], the country has witnessed exponential growth in REC formations, also leveraging substantial funding from its National Recovery and Resilience Plan (PNRR). This rapid diffusion reflects strong policy support, favorable incentive structures, and growing public awareness of climate action and energy sovereignty.

At the same time, recent EU audit evidence helps to reframe the Italian experience. The European Court of Auditors (ECA) Special Report 10/2026 confirms that Italy is comparatively advanced in formal transposition, yet it also identifies several gaps that are directly relevant to the Italian pathway: Italy's National Energy and Climate Plan (NECP) target is not fully aligned with the EU objective of at least one renewables-based energy community in each municipality above 10,000 inhabitants; national guidance is extensive but often requires expert interpretation; Italy has not legally required citizen participation in RECs; grid connection procedures are not specific to energy communities; and storage/flexibility incentives remain underdeveloped [9].

These findings reinforce the central argument of this perspective paper. The current Italian model has successfully accelerated REC creation, but it risks creating structural dependency on public support. The vast majority of Italian RECs operate under a business model almost entirely dependent on public subsidies and capital grants, specifically, the abovementioned incentive for shared energy introduced by the CACER decree [8], and non-repayable grant from PNRR. While these instruments have jump-started the sector and supported distributed renewable generation, they can also insulate communities from market signals, flexibility needs, and long-term business-model innovation. This creates what we term an "incentive trap": a structural dependency that locks communities into passive roles as subsidy recipients, insulating them from electricity markets, flexibility demands, providing ancillary services, or engaging in peer-to-peer (P2P) energy trading.

As the ongoing energy transition reshapes power systems—demanding greater flexibility, digitalization, and decentralization—RECs risk becoming stranded assets, unable to adapt once incentives expire or are redirected. Indeed, as incentive schemes mature and public budgets tighten, this dependency poses a fundamental question:

How can Italian RECs evolve from incentive-dependent configurations toward market-integrated, digitally enabled, and socially inclusive energy platforms?

The paper contributes to analyze the evolutionary trajectory of Italian RECs from their current incentive-based configurations toward diversified, market-integrated platforms capable of providing flexibility services, participating in local energy markets, and supporting grid stability. We examine the regulatory evolution that has shaped REC development, document current diffusion patterns and governance models, analyze economic model transitions, identify system limitations, and propose future pathways for sustainable Italian REC development.

The remainder of the paper is structured as follows. Section 2 provides a brief conceptual background on RECs and their role in the energy transition. Section 3 outlines the research approach and data sources. Section 4 presents a comprehensive analysis of the Italian REC landscape. Section 5 proposes a three-phase evolutionary pathway from incentive dependency to market integration. Section 6 discusses implications for policy, industry, and research. Finally, Section 7 reports final remarks and conclusions.

2 Background and Theoretical Foundations

2.1 The Rise of the Energy Community in Europe

Energy Community is not a new phenomenon. Cooperative ownership of renewable energy infrastructure has deep roots in Denmark, Germany, and the Netherlands, where wind and solar cooperatives have operated for decades [10, 11]. What distinguishes the current wave of RECs is their explicit embedding in EU energy policy as a mechanism to achieve multiple objectives simultaneously: decarbonization, energy security, social inclusion, and grid modernization [1, 5].

The Clean Energy Package (CEP), comprising the revised RED II [4] and the Internal Electricity Market Directive (IEMD, Directive 2019/944/EU) [5], introduced two key legal entities: RECs and Citizen Energy Communities (CECs). While CECs are technology-neutral and emphasize citizen participation, RECs are specifically focused on renewable energy and allow for broader membership, including small and medium enterprises (SMEs) and local authorities [1, 5]. Both frameworks share a common principle: energy communities must be autonomous, open to voluntary participation, and primarily aimed at providing environmental, economic, or social benefits to members rather than financial profit.

2.2 Renewable Energy Community as a Socio-Technical System

RECs are not merely technical aggregations of distributed energy resources (DERs); they are **socio-technical systems** that integrate technology, governance, economics, and social values. At their core, RECs embody three main interrelated functions:

- **Energy production and sharing:** RECs enable collective investment in renewable generation (primarily solar photovoltaic) and the virtual sharing of produced energy among members within a defined perimeter, typically constrained by grid topology (e.g., the same primary substation);
- **Governance and decision-making:** RECs are legally constituted entities (cooperatives, associations, or non-profit organizations) in which members exercise democratic control over energy assets and benefit distribution. This governance distinguishes RECs from purely commercial aggregators or virtual power plants;
- **Value creation and distribution:** RECs generate economic value through multiple channels—incentives, energy cost savings, grid tariff reductions, and potentially market revenues—and distribute this value among members according to transparent, community-defined rules.

The RED II explicitly recognizes RECs as instruments of **energy democracy**, granting citizens the right to participate in energy markets on equal footing with traditional actors [1]. This legal recognition is a departure from earlier community energy initiatives, which often operated in regulatory grey zones [12]. However, the directive also leaves significant implementation discretion to Member States, resulting in diverse national frameworks with varying degrees of market access, incentive generosity, and administrative complexity [13].

From a systems perspective, RECs can be understood as **boundary organizations** between individual prosumers, distribution grids, wholesale markets, and public policy objectives. Their effectiveness depends on technical interoperability, regulatory enablement, economic viability, and social cohesion [14]. When these layers align, RECs can deliver multiple co-benefits: reduce emissions, lower energy costs, increase resilience, support local development, and address energy poverty. However, when they do not align, RECs can become locked into suboptimal configurations, especially when incentives support installation but do not build long-term capabilities for flexibility, aggregation, or market participation.

2.3 The Institutional Lock-In

RECs can be understood as a **niche innovation** within the broader energy transition. They embody principles, i.e., decentralization, participation, and local ownership, that challenge the centralized, utility-dominated model. Yet their success depends on whether they can scale beyond protected niches (subsidized by incentives and public funds) and compete, collaborate, or provide services in mainstream energy markets. This requires technological maturation, including smart metering, energy-management systems, storage, and interoperable digital platforms, as well as institutional change in market rules, distribution-system coordination, and tariff design [15, 16]. However, the conditions that enable RECs to emerge and stabilize as niche innovations may also constrain their long-term evolution. Supportive policy frameworks and simplified participation schemes, while essential in early stages, can create **path dependencies** that shape expectations, practices, and organizational routines. As a result, the transition from protected niches to competitive market environments is not merely a matter of scaling up, but of overcoming structural and behavioral inertia embedded in existing arrangements.

Institutional lock-in refers to the tendency of established rules, norms, and incentive structures to perpetuate themselves, even when they become suboptimal. In the context of RECs, lock-in manifests in two ways. First, **regulatory lock-in:** policies designed to jumpstart REC adoption (e.g., feed-in tariffs) may inadvertently discourage innovation by shielding communities from market signals. Second, **behavioral lock-in:** communities that become accustomed to stable, predictable incentive revenues may resist the uncertainty and complexity of market participation, even if it offers higher long-term returns [12].

Breaking these lock-ins requires deliberate policy design to gradually expose RECs to market dynamics while providing transitional support (e.g., capacity building, risk-sharing instruments, regulatory sandboxes) [15, 16]. The challenge is to manage this transition without undermining the social and environmental values that motivate community energy in the first place.

3 Methods and Data Sources

This perspective paper synthesizes multiple data sources to construct a comprehensive picture of Italy's REC landscape and to develop a policy-oriented evolutionary framework. The analysis is primarily qualitative and interpretive, aimed at identifying patterns, tensions, and opportunities rather than testing a single hypothesis. We adopt a critical policy-analysis approach that interrogates the assumptions, incentives, and trade-offs embedded in current REC policies. The evidence base includes

- **Regulatory documents:** we analyzed primary legislative texts (Legislative Decree 199/2021), regulatory frameworks Autorità di Regolazione per Energia Reti e Ambiente (ARERA), i.e., TIAD and TIDE regulations, and technical guidelines issued by Gestore dei Servizi Energetici (GSE), the agency responsible for administering REC incentives [6, 7, 17, 18];
- **Diffusion data:** we compiled data on REC registrations, geographic distribution, and installed capacity from GSE's public databases and reports by Italian Forum of Energy Communities (IFEC), a national multi-stakeholder platform for sharing experiences, establishing and managing REC implemented in Italy [19, 20];

- **Economic and governance data:** we reviewed case studies, surveys, and technical reports on REC business models, revenue structures, and governance arrangements, drawing on both academic literature and gray literature from industry associations [11, 13, 16, 21, 22];
- **Market and grid data:** we examined data on ancillary services markets, demand response programs, and distribution grid constraints from Terna (Italy's transmission system operator) and ARERA [23, 24];

The European Court of Auditors Special Report 10/2026, which provides an independent EU-level audit of energy communities in the Netherlands, Poland, Italy, and Romania [9]. The ECA report is particularly valuable for the purposes of this paper because it links EU objectives, national implementation, and Italy-specific evidence.

The three-phase evolutionary pathway proposed in Section 5 is conceptually validated through triangulation across these sources. However, this perspective has limitations. First, public REC data are evolving quickly, and registrations, capacities, and member numbers may change as the CACER framework matures. Second, available data does not always distinguish between legal status, operational maturity, and actual energy-sharing performance. Third, the framework is not an econometric validation of REC outcomes, but a policy-oriented synthesis designed to structure future empirical testing. Fourth, the Italian case is highly relevant but not universally generalizable, since local grid constraints, governance traditions, municipal capacity, and social acceptance differ by region. Future research should therefore test the proposed phases through longitudinal datasets, comparative case studies, and pilot projects that measure social, economic, technical, and grid impacts over time.

4 The Italian Renewable Energy Community Landscape: Regulatory Evolution, Diffusion, and Structural Models

4.1 Regulatory Evolution: From RED II to TIAD and TIDE

Italy's REC framework has evolved through several key regulatory milestones, each expanding the scope and ambition of community energy. Table 1 provides a synthesized overview before the detailed discussion that follows.

Table 1. Italy's renewable energy community (REC) regulatory evolution

Milestone	Year	Issuing Body	Key Provisions	Role
Renewable Energy Directive (RED II, Directive 2018/2001/EU) [4]	2018	European Parliament & Council	Established the legal right of citizens to act collectively in energy production and sharing; defined RECs as autonomous, non-profit entities open to citizens, small and medium enterprises (SMEs), and local authorities	Foundational–sets the EU legal basis for RECs
D.lgs. 199/2021 [6]	2021	Ministero dell'Ambiente e della Sicurezza Energetica (MASE)	Italian transposition of RED II; defined RECs as legal entities (cooperatives, associations); introduced virtual net metering; limited perimeter to single primary substation	Enabling–creates the national legal framework for REC formation
CACER Incentive Decree [8]	2022–2023	National Recovery and Resilience Plan (PNRR)	Introduced the shared energy incentive for 20-year duration, grid tariff reduction, and capital grants funded by PNRR (with an incentivized quota of 5 GW until 2027)	Incentive and capital grant–drives rapid REC diffusion; defines the current revenue model
Testo Integrato Autoconsumo Diffuso (TIAD) [7]	2024	Autorità di Regolazione per Energia Reti e Ambiente (ARERA)	Governs current REC operational configurations; extended geographic scope beyond the primary substation constraint; defines shared energy calculation rules, grid access, and Distribution system operator (DSO) interaction	Current framework–the operational regulation under which RECs function today

Milestone	Year	Issuing Body	Key Provisions	Role
Operational Rules [17]	2025	Gestore dei Servizi Energetici (GSE)	Defined technical and administrative procedures for REC registration, metering, and shared energy calculation; established the GSE portal for REC management	Operational–provides the procedural infrastructure for REC activation
Testo Integrato del Dispacciamento Elettrico (TIDE) [18]	2024–2025	ARERA/Terna	Opens advanced energy markets, ancillary services, and balancing to distributed resources; introduces Unità Virtuali Abilitate (UVA) aggregation mechanisms; enables RECs to act as active flexibility providers	Future-enabling–the regulatory bridge from incentive instruments to local flexibility actors

This regulatory trajectory reflects a gradual shift from enabling REC formation (RED II, Decree 199/2021) to incentivizing deployment (CACER) to governing current operations (TIAD) and, finally, to enabling future market participation (TIDE). However, the transition from TIAD-governed incentive dependency to TIDE-enabled market integration remains incomplete, creating the policy gap that this paper seeks to address. It is worth highlighting that the TIAD establishes multiple possible configurations for collective self-consumption and energy communities. However, only a subset of these configurations is currently eligible for the CACER framework, and eligibility further differs depending on the type of support mechanism. With respect to the CACER incentive tariff, the following configurations are eligible:

- Individual Remote self-consumer (AID);
- Collective self-consumption group (GAC);
- Renewable Energy Community (CER).

However, access to PNRR investment grants (e.g., up to 40% capital expenditures (CAPEX) support) is more restrictive and limited to the last two. This distinction is critical, as not all technically feasible configurations can access the incentive mechanisms, requiring RECs to carefully design their structure and membership in compliance with CACER eligibility criteria from the outset. For the sake of simplicity, in this article, the term REC will refer to those configurations eligible for the CACER framework, if not indicated otherwise.

4.2 Diffusion Dynamics: Growth, Drivers, and Barriers

Italy's REC sector has entered a phase of rapid expansion following the implementation of the CACER framework. Figure 1 presents a 2025 snapshot of RECs in Italy, where the choropleth gradient depicts total installed capacity by region and the normalized pie charts illustrate the percentage composition of configurations. For each region, the upper label reports the total number of projects, and the lower label reports the total installed capacity (MW).

The data highlights a strong acceleration: over 1,500 active configurations, involving more than 13,700 users, and a total installed capacity of around 147 MW. This confirms a dynamic but still early-stage market, largely driven by photovoltaic generation, reflecting both the maturity of photovoltaics (PV) technology and the favorable solar resource in Italy, particularly in the southern regions. The average REC remains small, with fewer than ten members per community and roughly 95 kW of installed capacity per community, indicating limited scale and limited bargaining or market power. The ECA report sharpens this interpretation. It estimates that, by early 2025, the EU had reached only about 27% of the objective of having at least one renewables-based energy community in each municipality above 10,000 inhabitants, while Italy reached only 2.1% of such municipalities. At the same time, Italy showed rapid momentum: the number of Italian configurations increased by 75% between January and June 2025, from 241 to 421 configurations [9]. This combination—low territorial penetration but fast acceleration—supports the paper's view that Italy is still in a formative phase rather than a mature REC market.

Regional heterogeneity remains significant. Northern RECs are frequently anchored by SMEs, industrial districts, or cooperative traditions, often with stronger technical and managerial capabilities. Southern RECs benefit from higher solar irradiation and different baseline energy-cost conditions, but they often face weaker institutional capacity, higher administrative barriers, and less developed energy-service markets. Central regions exhibit mixed configurations, with increasing municipal participation and experimentation with integrated energy and mobility services. These differences imply that successful REC models must be adapted to local institutional and socio-economic contexts rather than imposed uniformly.

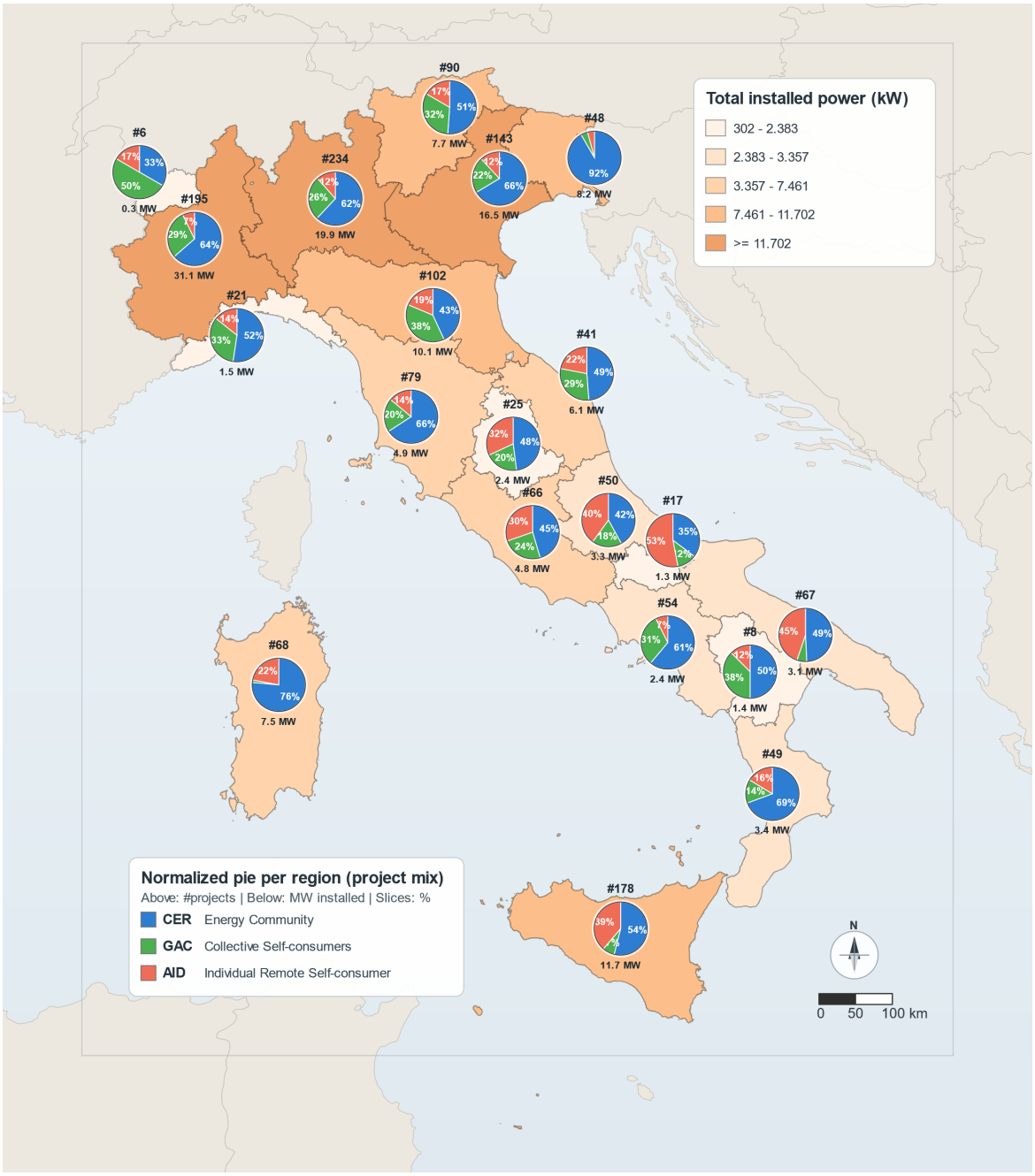


Figure 1. 2025 snapshot of renewable energy community (REC) diffusion in Italy; the choropleth map represents total installed capacity by region, while normalized pie charts show the composition of projects by type: energy community (CER), collective self-consumers (GAC), individual remote self-consumer (AID), indicating total projects and regional installed MW

Membership composition is diverse but uneven. Residential members remain central to the REC model, while industrial and SME members often provide stable daytime demand that improve shared-energy ratios. Public bodies can provide legitimacy, assets, and coordination capacity. However, The Italian law does not require citizen participation or specific support for vulnerable households, even though citizens were present in two thirds of the communities consulted and half of those communities provided some support to vulnerable households. This suggests that inclusion is emerging in practice but is not yet sufficiently embedded in regulatory design.

Operational data also reveal structural immaturity. Most RECs rely on one or two PV plants, with limited storage deployment and limited real-time digital monitoring. Shared energy depends on the hourly match between production and consumption; therefore, residential-only configurations often underperform compared with communities that include daytime loads. The implication is that REC maturity requires not only installed capacity but also data-driven design, forecasting, optimization, and active demand management.

In conclusion, the diffusion analysis demonstrates both the **rapid growth** and the **structural immaturity** of the Italian REC sector. On one hand, the scaling from zero to a thousand communities in four years is a remarkable achievement, reflecting effective policy design and strong citizen engagement. On the other hand, the small average size, modest shared energy performance, limited digital infrastructure, and variable governance maturity suggest that most RECs are still in an early developmental stage. This immaturity makes the sector vulnerable to external shocks—such as incentive reductions, regulatory changes, or economic downturns—and underscores the urgency of the evolutionary transition argued in this perspective. Without proactive efforts to strengthen governance, enhance digital capabilities, and diversify revenue streams, many of these nascent RECs risk becoming stranded assets once the 20-year CACER incentive period expires or if policy support weakens. Conversely, the rapid growth and diverse membership base also represent a significant opportunity: if RECs can successfully evolve toward market integration, they could become a major force in Italy's energy transition, delivering flexibility, resilience, and local economic value at scale.

4.3 Economic and Governance Models

The current economic model of Italian RECs is largely driven by the CACER framework, although additional value streams also play a relevant role. The overall revenue structure is multifaceted and depends on several variables, including energy prices, consumption profiles, regulatory parameters, and access to public funding. The main value components can be summarized as follows:

- **Shared Energy Incentive (≈60–120 €/MWh):** this represents the primary economic driver. The incentive is granted by the GSE for 20 years on the energy virtually shared within the community, defined as the hourly minimum between renewable generation and aggregated consumption. The exact value depends on plant size, geographic location, and market conditions. This component typically accounts for around 40–50% of the total economic value.
- **Network Component Contribution (≈8–10 €/MWh):** shared energy benefits from the partial avoidance of grid-related charges, which are redistributed through a specific regulatory contribution. This adds approximately 3–6% to the overall value.
- **Energy Cost Savings (≈150–250 €/MWh):** members directly benefit from self-consumed shared energy by avoiding retail electricity purchases. This is not a direct revenue for the REC itself but constitutes a major economic benefit for participants, often representing 40–55% of total value depending on retail price levels.
- **Wholesale Market Revenues (variable):** surplus energy physically injected into the grid (defined as the portion of renewable generation not self-consumed on-site) can be sold through the GSE's "Ritiro Dedicato" mechanism or other market arrangements. This revenue stream depends on wholesale electricity prices. (≈50–100 €/MWh). This represents a small and variable revenue stream, typically less than 5% of total value.
- **PNRR Capital Grant (up to 40% CAPEX):** eligible RECs located in municipalities with fewer than 50,000 inhabitants may access a non-repayable grant covering up to 40% of the investment cost for renewable generation assets. This measure does not directly affect operational revenues but significantly reduces upfront capital requirements, improves project bankability, and shortens payback periods.

For a typical REC configuration, the combined value of these revenue streams ranges from 250 to 350 €/MWh of shared energy. When combined with PNRR capital support (where applicable), this is generally sufficient to ensure a positive business case, with payback periods for renewable investments typically in the range of 8–12 years, well within the 20-year incentive duration. However, this economic model is **structurally fragile** for several reasons:

- **Incentive dependency:** the incentive accounts for nearly half of the economic value. If this incentive were reduced or eliminated, many RECs would become economically unviable, particularly those with low shared energy ratios or high administrative costs.
- **Temporal alignment challenge:** the economic value depends critically on the temporal alignment between renewable production and member consumption. RECs with poor alignment (e.g., residential-only communities with low daytime consumption) achieve low shared energy ratios and correspondingly low economic returns.
- **Limited revenue diversification:** current RECs have virtually no revenue streams beyond the incentive and energy savings. They do not participate in flexibility markets, provide ancillary services, or engage in P2P trading.
- **Regulatory uncertainty:** the 20-year incentive duration provides medium-term certainty, but there is no guarantee that similar support will be available for new RECs after the current scheme expires, or the regulatory framework will remain stable.
- **Uneven access to capital support (PNRR constraint):** the availability of PNRR grants is limited to municipalities below 50,000 inhabitants, creating a structural imbalance between rural/small urban RECs and those in larger cities. While the grant improves financial performance where available, it also risks distorting investment patterns and limiting REC diffusion in high-demand urban areas.

This economic fragility underscores the central argument of this perspective: RECs must evolve beyond incentive

dependency to ensure long-term sustainability.

The governance structure of REC in Italy plays a critical role in shaping its strategic orientation, operational capabilities, and long-term sustainability. As shown in Table 2, three main archetypes can be identified. Municipal-led RECs maximize public value and legitimacy but may lack technical and managerial speed. Industrial-led RECs can optimize energy costs and mobilize technical expertise but risk weakening the community dimension. Cooperative-led RECs emphasize inclusion and democratic control but often face capital and scaling constraints. Rather than representing rigid categories, these archetypes should be understood as ideal types along a spectrum. In practice, many RECs adopt hybrid configurations, combining elements from multiple models to balance technical efficiency, financial sustainability, and social value creation.

Table 2. The identified archetypes of renewable energy community (REC)

	Municipal-Led Model	**Industrial-Led Model**	**Cooperative-Led Model**
Typical leader	Local authorities and public bodies	Companies, industrial districts, small and medium enterprises (SMEs)	Energy cooperatives, NGOs, associations
Core objective	Public value, local development, social policy	Energy-cost optimization and operational efficiency	Social impact, inclusion, community empowerment
Strengths	Legitimacy, assets, public funding alignment	Technical capacity, stable demand, financial discipline	Participation, trust, democratic control
Weaknesses	Administrative slowness, limited technical expertise	Risk of weak inclusivity or corporate capture	Limited capital, volunteer dependence, scaling constraints
Policy needs	Technical assistance and procurement support	Citizen-value safeguards and transparency	Finance, capacity building, professional support

The comparison highlights a set of structural trade-offs. Municipal-led models benefit from strong legitimacy and alignment with public policy objectives but often struggle with technical complexity and speed of execution. Industrial-led models, by contrast, are more efficient and market-oriented, yet may face challenges in ensuring inclusivity and maintaining a strong community dimension. Cooperative-led models emphasize participation and social impact but frequently encounter limitations in scaling and accessing capital. Understanding these differences is essential for both policymakers and practitioners. From a policy perspective, a "one-size-fits-all" approach is unlikely to be effective: targeted support measures should reflect the specific needs and constraints of each archetype. From an operational standpoint, recognizing these strengths and weaknesses can help RECs design more balanced governance models, particularly as they evolve toward more advanced stages of digitalization and market integration.

4.4 Success Factors and Structural Limitations

Across models, successful RECs share several success factors: transparent benefit distribution, active member engagement, clear statutes, professional energy management, and access to digital data on production, consumption, sharing, and flexibility potential. These are not only organizational best practices; they are prerequisites for moving from incentive capture to market participation.

Beyond the economic fragility discussed above, current Italian RECs face several structural limitations that constrain their evolution:

- **Administrative and bureaucratic complexity**: the process of registering a REC, complying with GSE requirements, managing member data, and navigating evolving regulations is administratively burdensome, particularly for small communities without professional support. This complexity is further exacerbated by excessive documentation requirements and cumbersome onboarding procedures, which often discourage participation, especially among residential users. In addition, delays in GSE evaluation processes and PNRR-related applications have reduced investor confidence. Technical limitations of GSE digital platforms, including bugs and missing functionalities (e.g., member management and PNRR application handling), further complicated operations. Finally, grid connection timelines can exceed 540 days, significantly slowing project deployment. These delays are largely driven by the limited capacity and adaptability of the Italian distribution network to accommodate increasing volumes of DERs, resulting in connection bottlenecks, prolonged authorization procedures, and the need for grid reinforcement or upgrades before new capacity can be integrated. This highlights a critical misalignment between policy ambition and infrastructure readiness.
- **Weak business models beyond the incentive**: most RECs have not developed robust business plans or revenue strategies for the post-incentive era, leaving them vulnerable to economic shocks. This has also led to the emergence of "speculative" or "fake" RECs, often promoted primarily to capture upfront public subsidies, as the PNNR grant, without a long-term sustainability strategy. Many communities lack solid managerial governance structures and struggle to generate sufficient revenues to cover operational costs. In some cases, this

results in member dissatisfaction, internal conflicts, and eventual participant dropout. Additionally, excessive intermediation by external aggregators risks capturing a disproportionate share of the economic value, limiting the benefits retained by local communities.

- **Limited technical and digital capacity**: most RECs lack advanced digital infrastructure, energy management systems, or technical expertise to optimize operations or prepare for market participation. In many cases, there is also a lack of innovative digital platforms (e.g., AI- or blockchain-based solutions) that could automate management processes, reduce operational costs, and optimize energy flows. This technological gap limits the ability of RECs to scale efficiently and compete in more advanced energy systems and markets.
- **Regulatory uncertainty and policy instability:** while the current CACER incentive is guaranteed for 20 years once granted, significant uncertainty remains regarding the future regulatory framework. Moreover, the PNRR grant itself is limited either by a national capacity cap (5 GW) or by a deadline (31 December 2027), making long-term investment planning difficult, especially considering that we are still far from reaching the target capacity today. Furthermore, ongoing regulatory changes—including the reallocation and reduction of PNRR funds and legislative updates requiring statutory adjustments (e.g., under recent energy decrees)—have created additional uncertainty and administrative burdens. Furthermore, unresolved fiscal and accounting issues contribute to an unclear operating environment.
- **Exclusion from flexibility and ancillary services markets:** despite the TIAD framework opening a theoretical pathway to market participation, the detailed rules, technical requirements, and operational mechanisms for REC participation in flexibility and ancillary services markets are not yet fully implemented. As a result, RECs remain effectively excluded from these potentially important revenue streams.
- **Social, cultural, and local barriers:** limited awareness among citizens, SMEs, and local institutions about the functioning and benefits of RECs continues to hinder adoption. In some cases, local opposition or inconsistent permitting processes—particularly for ground-mounted installations below 1 MW—create additional barriers. This lack of alignment at the local level further slows down the development and scaling of RECs.

4.5 Summary of Findings and Implications for Renewable Energy Community Evolution

Italian RECs are rapidly growing but structurally immature. The sector has moved from legal experimentation to early deployment, but most communities remain small, dependent on incentives, weakly digitized, and only partially prepared for flexibility or market participation. The ECA evidence confirms this diagnosis: Italy has established an advanced legal framework and monitoring infrastructure, yet barriers remain in target alignment, practical support, citizen inclusion, grid connection, storage, and network-charge impacts [9]. Therefore, the strategic challenge is not simply to create more RECs, but to ensure that RECs accumulate the capabilities needed to remain socially valuable and economically viable after the current incentive cycle.

5 From Incentive Dependency to Market Integration: An Evolutionary Pathway

5.1 The Incentive Trap: Structural Dependency and Path Dependency

As explained previously, by design, CACER incentives are generous and predictable, providing stable revenues that reduce financial risk and attract participants. However, this very stability creates **structural dependency**: RECs become economically viable only as long as subsidies continue, and they have little incentive to develop alternative revenue streams or adapt to market conditions. This dependency is reinforced by **path dependency**: once communities invest in REC infrastructure and governance structures optimized for incentive capture, switching to market-based models becomes costly and risky. Members accustomed to stable returns may resist changes that introduce uncertainty, even if those changes offer higher long-term payoffs. Policymakers, facing political pressure to maintain support for community energy, may be reluctant to phase out incentives, perpetuating the cycle. These dependencies lead to what we call the **"incentive trap"**. It has three dimensions:

- **Economic fragility:** RECs that rely exclusively on CACER revenues are vulnerable to policy changes (e.g., subsidy reductions, eligibility restrictions). Preliminary evidence suggests that many RECs operate on thin margins, with little financial buffer to absorb shocks.
- **Innovation stagnation:** insulated from market competition, RECs have limited incentives to innovate—whether in technology (e.g., battery storage, smart controls), business models (e.g., P2P trading, flexibility services), or governance (e.g., adaptive management, stakeholder engagement).
- **Equity risks:** incentive-dependent RECs may prioritize maximizing shared energy (to capture subsidies) over broader social goals (e.g., energy poverty alleviation, community resilience). This can lead to "cream-skimming," where RECs target affluent, high-consumption members while excluding vulnerable households.

Breaking the incentive trap requires a deliberate policy shift—from subsidizing REC formation to enabling REC evolution. This shift must be gradual, providing transitional support while exposing RECs to market signals and flexibility demands.

5.2 The Renewable Energy Community Evolutionary Pathway

We propose a three-phase pathway from passive incentive dependency to active market participation—RECs that aggregate DERs, provide grid services, and respond dynamically to price signals. This evolution is not merely desirable; it is necessary for the long-term viability of RECs and the stability of the energy system. The phases are sequential but overlapping: mature RECs may move faster, while resource-constrained communities may need longer transitional support. Figure 2 outlines the three-phase development pathway that captures the progressive build-up of technical, organizational, and market capabilities. Each phase reflects a distinct stage in the maturation process of RECs, moving from foundational capacity building to full integration into energy markets and the provision of advanced, multi-service functionalities. This framework provides a coherent lens to face the challenges and opportunities discussed in the following sections, highlighting the key enablers required at each stage of development.

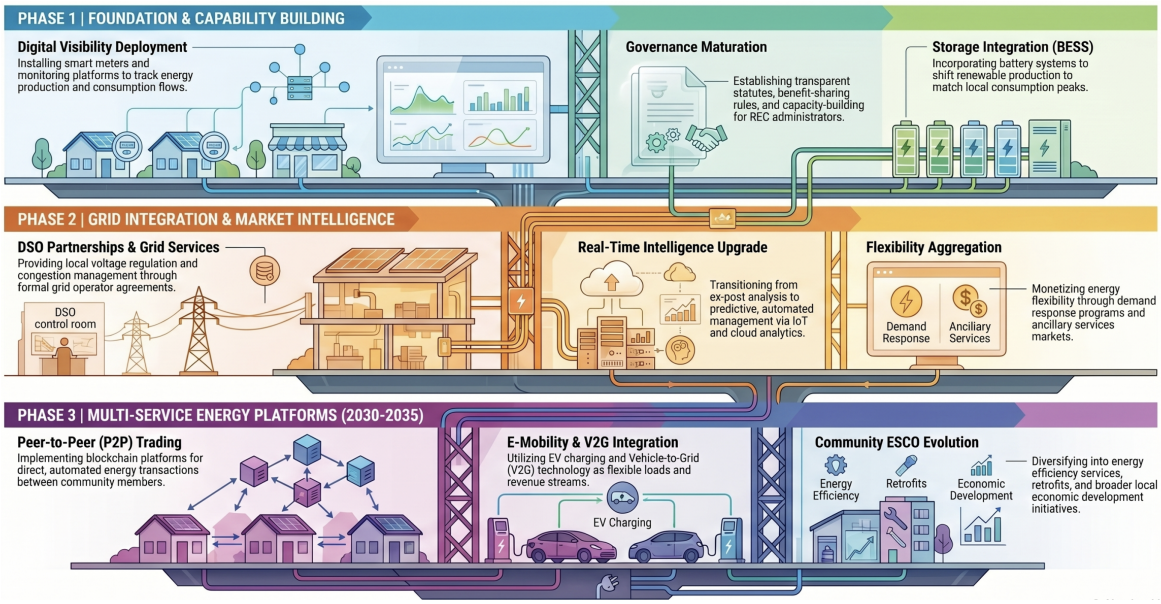


Figure 2. Conceptual roadmap for the evolution of renewable energy communities (REC) toward market integration; the framework is structured in three progressive phases: (1) foundation and capability building, (2) grid integration and market intelligence, and (3) multi-service energy platforms

5.2.1 Phase 1: Foundation and capability building

In Phase 1, RECs focus on strengthening the internal foundations of existing RECs, addressing the governance, technical, and digital gaps identified in Section 4. Key priorities include:

Governance maturation. Going towards market integration is not without risks. If poorly managed, it could erode the participatory, equity-oriented ethos that distinguishes RECs from purely commercial ventures. RECs must formalize governance structures, adopt transparent statutes and benefit-sharing rules, and establish clear decision-making processes. This includes training for REC administrators, development of governance toolkits, and peer-learning networks to share best practices. Policymakers can support this through capacity-building programs, legal templates, and recognition schemes for well-governed RECs. RECs must balance efficiency with inclusivity, ensuring that members retain meaningful voice and control [12].

Market integration may exacerbate inequalities, favor well-resourced, technically sophisticated RECs while marginalizing smaller, less-capitalized ones. Policymakers must ensure that capacity-building programs, financial instruments, and regulatory support are accessible to all RECs, not just the most capable. As RECs pursue market revenues, they may prioritize profit over social and environmental goals. Governance structures must include safeguards (e.g., mission statements, member oversight, impact reporting) to ensure that market integration serves community values [25]. We propose three governance principles for market-integrated RECs:

- **Transparency:** members must have access to clear, timely information about market participation, revenues, and risks.
- **Accountability:** decision-makers must be accountable to members, with mechanisms for feedback, dispute resolution, and leadership turnover.
- **Adaptability:** governance structures must be flexible enough to respond to changing market conditions, member needs, and policy environments.

Digital infrastructure deployment. In the initial phase, RECs must prioritize deploying basic digital infrastructure to provide reliable visibility into energy flows, rather than full real-time control. This includes the implementation of smart meters, monitoring platforms, and energy management systems that track production, consumption, and shared energy at the aggregated level, tracking also the most relevant key performance indicators of interest [26, 27]. In most cases, this data is not fully real-time but is delivered with delays (e.g., hourly or daily), which is sufficient for understanding system behavior and supporting operational transparency.

The primary objective of this phase is to enable:

- **Energy flow visibility:** clear understanding of how much energy is produced, consumed, self-consumed, and virtually shared within the REC;
- **Performance tracking:** monitoring key indicators such as shared energy ratios and overall system efficiency;
- **Operational transparency:** providing members and administrators with accessible information on REC performance and benefits;
- **Initial optimization:** supporting basic, ex-post adjustments in consumption patterns and system configuration.

At this stage, digital infrastructure is not yet designed for automation or market interaction, but rather to build awareness, trust, and data availability within the REC. Public funding mechanisms should prioritize support for these foundational digital tools, ensuring that all RECs can reach a minimum level of data visibility.

Member engagement and capacity building. RECs must actively engage members through regular communication, participatory planning, and education on energy management and flexibility [12]. Engaged members are more likely to adapt consumption patterns to maximize shared energy, participate in demand response programs, and support the REC's long-term strategic evolution. Moreover, one-stop guidance, technical assistance, and simplified onboarding should reduce dependence on professional intermediaries while preserving quality.

At the end of this phase, RECs should have robust governance, reliable digital infrastructure, improved energy performance (higher shared energy ratios), and an engaged membership base. These capabilities form the foundation for the next phase of market integration.

5.2.2 Phase 2: Grid integration and market intelligence

Phase 2 transforms RECs from passive sharing configurations into grid-aware actors. Key priorities include:

Energy storage integration. To increase shared energy ratios and enhance flexibility, RECs should integrate battery energy storage systems (BESS) where economically viable [28, 29]. Storage allows RECs to time-shift renewable production to match consumption peaks, increasing the value captured from the CACER incentive and preparing for future participation in flexibility markets [30]. Regulatory reforms should ensure that storage within RECs is eligible for incentives and does not face discriminatory grid charges [31].

Distribution system operator (DSO) partnerships and grid services. RECs should establish formal partnerships with DSOs to provide local grid services such as voltage regulation, congestion management, and peak load reduction [32]. The TIDE framework provides the regulatory basis for such partnerships, but detailed implementation requires pilot projects, standardized contracts, and fair compensation mechanisms. DSOs, in turn, must recognize RECs as valuable partners in managing distributed energy resources and maintaining grid stability.

Demand response and flexibility aggregation. RECs should participate in demand response programs, either individually (if sufficiently large) or through aggregation platforms that pool multiple RECs. Demand response allows RECs to monetize their flexibility by reducing or shifting consumption in response to grid signals or market prices. This requires advanced control systems, member consent for automated load management, and integration with national or regional flexibility markets.

Ancillary services provision. Where technically feasible, RECs with storage or controllable loads should provide ancillary services (frequency regulation, reserve capacity) to transmission or DSOs [18]. This requires compliance with technical standards (response time, reliability, communication protocols) and access to ancillary services markets, which are currently restricted to large, centralized assets in most European countries. Regulatory reform is needed to lower barriers to entry for distributed resources.

Data imperative: from monitoring to market-ready intelligence. While Phase 1 focuses on deploying basic digital infrastructure for monitoring and operational optimization, Phase 2 requires a significant evolution toward advanced, real-time data capabilities that enable active market participation. To transition into Phase 2, RECs must upgrade their data infrastructure to fully integrated, real-time systems capable of supporting adaptive and automated decision-making. This includes the deployment of IoT sensors, advanced metering infrastructure, cloud-based analytics, and control platforms that enable continuous interaction with grid operators and market signals.

In this context, the concept of a digital twin emerges as a key enabling tool. A digital twin is a virtual replica of the REC's physical energy system—encompassing generation assets, storage, loads, and network interactions—continuously updated with real-time data. By mirroring system behavior and simulating future states under different scenarios (e.g., price signals, weather conditions, demand patterns), Digital Twins allow RECs to move beyond static monitoring toward predictive, scenario-based, and optimized decision-making [33]. This

capability is particularly valuable for testing operational strategies, improving forecasting accuracy, and supporting automated control in complex, distributed environments [34].

Enhanced data capabilities, further strengthened through digital twin applications, allow RECs to:

- **Optimize operations in real time:** move from ex-post analysis to predictive and automated management of generation, storage, and consumption patterns.
- **Enable market participation:** provide accurate forecasts, submit bids, respond dynamically to price signals, and meet performance and reliability requirements for flexibility and ancillary services.
- **Support flexibility aggregation:** coordinate distributed assets (loads, storage, generation) across members and potentially across multiple RECs.
- **Enhance member engagement:** deliver real-time feedback, enable behavioral change, and support participation in demand response programs through digital interfaces

In this sense, data and digital twin frameworks become not just operational tools but a core enabling infrastructure for REC evolution, bridging the gap between local energy sharing and active participation in energy markets. However, this transition entails high costs and technical complexity. Many RECs still rely on limited data (e.g., monthly billing) and lack the expertise to manage advanced systems. Policymakers should therefore support this evolution through targeted funding, standardization efforts, and the promotion of interoperable, open platforms to avoid vendor lock-in and enable scalability.

By the end of this phase, RECs should be active participants in flexibility and ancillary services markets, generating diversified revenue streams beyond the CACER incentive. This market integration enhances economic resilience and demonstrates the systemic value of RECs to grid operators and policymakers. Nevertheless, successful implementation of Phase 2 requires regulatory reforms to finalize and operationalize the TIDE provisions on flexibility market access, establish fair compensation mechanisms for grid services provided by RECs, reduce technical and administrative barriers to market participation for small-scale aggregators, and ensure that RECs are not penalized by discriminatory grid tariffs or market rules.

5.2.3 Phase 3: multi-service energy platforms

In Phase 3, RECs evolve into multi-service local energy platforms. They combine shared renewable generation with local trading, flexibility services, energy-efficiency services, EV charging, heat electrification, social tariffs, and community-development functions. At this stage, the REC is no longer defined mainly by the incentive it receives, but by the portfolio of social, technical, and market services it provides. Key priorities include:

P2P energy trading. RECs should develop internal P2P trading platforms that allow members to buy and sell energy directly within the community and with other communities, based on real-time production, consumption, and price signals [35–37]. P2P trading enhances economic efficiency, member engagement, and local energy autonomy. It requires blockchain or other distributed ledger technologies for transparent, automated transactions, as well as regulatory clarity on the legal status of intra-community energy trading.

Integration with electric mobility. RECs should integrate electric vehicle (EV) charging infrastructure, offering members access to low-cost, renewable-powered mobility. EV charging represents both a new revenue stream (charging fees) and a flexible load that can be optimized to increase shared energy and provide grid services (vehicle-to-grid, V2G) [11, 38]. This integration aligns with broader decarbonization goals and enhances the value proposition of REC membership.

Energy service company (ESCO) functions. Mature RECs can evolve into community-based ESCOs, offering energy efficiency services, building retrofits, and energy management consulting to members and the broader community. This diversification leverages the REC's local knowledge, trust relationships, and technical expertise to generate additional revenue and deepen community impact.

Local economic development. Beyond energy, RECs can serve as platforms for broader local economic development, including local food systems, circular economy initiatives, and social services [16, 39]. This holistic approach aligns with the RED II vision of RECs as instruments of community benefit, not merely energy projects [4].

By the end of this phase, RECs operate as mature, multi-service energy platforms with diversified revenue streams, strong community engagement, and significant contributions to local economic development and decarbonization. They are no longer dependent on public subsidies and are economically sustainable in the long term. As observed also for the other phases, Phase 3 requires legal frameworks for P2P energy trading within RECs, integration of RECs into local and regional energy markets, support for REC-led ESCO and community development initiatives, and long-term policy stability and recognition of RECs as permanent features of the energy system.

5.3 Cross-Cutting Enablers

In summary, successful progression through these three phases requires several cross-cutting enablers:

- **Aggregation mechanisms:** individual RECs are often too small to access markets or negotiate with DSOs. Aggregation platforms that pool multiple RECs can achieve the scale needed for market participation while preserving local autonomy.

- **Capacity building and technical assistance:** RECs need ongoing access to training, technical assistance, and professional services. This can be provided by energy agencies, cooperative federations, research institutions, or specialized ESCOs.
- **Financing and investment:** the transition requires upfront investment in digital infrastructure, storage, and governance capacity. public funding, cooperative finance, and innovative financing mechanisms (e.g., community bonds, crowdfunding) are all needed.
- **Policy stability and long-term vision:** policymakers must provide long-term policy stability, clear regulatory roadmaps, and recognition of RECs as strategic assets in the energy transition. Short-term, ad-hoc policy changes undermine investment and erode trust.
- **Research and innovation:** ongoing research is needed to develop and test new technologies, business models, and governance approaches. Pilot projects, demonstration programs, and knowledge-sharing platforms are essential.

This three-phase evolutionary pathway represents a fundamental transformation in the role and identity of RECs. In Phase 1, RECs are primarily **incentive-takers**, focused on maximizing shared energy to capture CACER subsidies. In Phase 2, they become **grid service providers**, offering flexibility and ancillary services to DSOs and system operators. In Phase 3, they evolve into **multi-service energy platforms**, integrating local trading, mobility, efficiency, and community development.

This evolution is not automatic or inevitable. It requires proactive strategic choices by RECs, supportive regulatory reforms by policymakers, and enabling investments by public and private actors. However, the Italian experience—and international best practices—demonstrate that this pathway is both technically feasible and economically viable. The question is not whether RECs can evolve, but whether they will be given the opportunity and support to do so.

6 Implications for Policy, Industry, and Research

The transition of RECs toward market-integrated models requires coordinated action. For policymakers, the priority is to transform incentives from endpoints into transitional tools. This means progressively linking support to capability building: digital monitoring, citizen participation, vulnerable-household inclusion, storage-readiness, flexibility potential, and transparent benefit distribution. It also means developing Specific, Measurable, Achivable, Relevant, and Time-Bound (SMART) objectives for energy communities, improving registration and monitoring, and aligning national targets with EU objectives, as recommended by the ECA [9]. For Italy specifically, the ECA report implies five priorities. First, the Ministry should complete and publish a systematic assessment of barriers to and potential for RECs. Second, citizen participation should be strengthened through explicit legal or incentive-based provisions, without undermining the role of municipalities and SMEs. Third, support for vulnerable households should move from isolated regional incentives to a national design principle. Fourth, storage and flexibility incentives should be targeted at RECs and not only at generic renewable generation. Fifth, tariff and network-charge design should remain cost-reflective to avoid shifting costs to non-participants [9].

Industry actors—ESCOs, aggregators, technology providers, cooperatives, and municipal utilities—should help RECs move from administrative compliance to operational optimization. Their role is not merely to build PV assets, but to provide forecasting, data platforms, aggregation services, market interfaces, and capacity-building tools. The development of aggregation platforms is critical to enable collective market participation and risk-sharing, while advanced data analytics tools can support real-time optimization and market interaction. In addition, structured capacity-building initiatives—delivered through training programs, toolkits, and peer-learning networks—are essential to strengthen technical, financial, and governance capabilities across different REC archetypes.

For research, the agenda is broad. Empirical studies should measure REC performance over time, including shared energy, social inclusion, energy poverty impacts, benefit distribution, grid impacts, and post-incentive viability. [40, 41]. Technical research should develop sizing, storage, control, and forecasting methods tailored to REC heterogeneity [33, 40–42]. Market-design research should test aggregation mechanisms, local flexibility procurement, P2P trading, and revenue-sharing schemes. Socio-technical research should examine how communities preserve democratic control while interacting with markets [43]. Pilot and demonstration projects, supported by public funding, are instrumental in testing advanced functionalities, such as flexibility provision, P2P trading, and vehicle-to-grid integration, while enabling evidence-based policy refinement. These efforts should be complemented by structured knowledge-sharing platforms and interdisciplinary approaches integrating engineering, economics, and social sciences.

7 Conclusions

RECs represent a bold experiment in democratizing energy systems, but their current trajectory is unsustainable. Italy's experience of rapid growth fueled by generous incentives, but limited integration into competitive markets, illustrates both the promise and the peril of community energy. Without deliberate policy intervention, RECs risk

becoming stranded assets, dependent on subsidies that cannot last and are unable to adapt to the demands of a decarbonized, decentralized, and digitalized energy system.

This perspective has argued for a fundamental reorientation: from viewing RECs as temporary beneficiaries of the energy transition to reimagining them as permanent, adaptive actors within it. This requires bridging RECs into competitive markets, while preserving the participatory, equity-oriented values that define community energy. It requires phased incentive reduction, regulatory clarity, capacity-building programs, and governance innovations that balance efficiency with inclusivity.

The stakes are high. If RECs succeed in this transition, they could become a cornerstone of a resilient, equitable, and sustainable energy system, aggregating local flexibility, empowering citizens, and demonstrating that decentralization and decarbonization are not only compatible but mutually reinforcing. If they fail, they risk becoming a cautionary tale of well-intentioned policies that created dependency rather than empowerment. The crossroad is here. The path forward is uncertain. But the imperative is clear: RECs must evolve—or risk obsolescence.

Author Contributions

Conceptualization, D.S.S. and R.B.; methodology, D.S.S.; software, D.S.S.; validation, D.S.S.; formal analysis, D.S.S.; investigation, D.S.S.; resources, D.S.S.; data curation, D.S.S.; writing—original draft preparation, D.S.S.; writing—review and editing, D.S.S. and R.B.; visualization, D.S.S.; supervision, R.B. All authors have read and agreed to the published version of the manuscript.

Data Availability

The data used to support the research findings are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflicts of interest.

Declaration on the Use of Generative AI and AI-assisted Technologies

During the preparation of this work, the authors used generative AI for minor language editing and to assist in the creation of illustrative figures and a conceptual overview diagram. After using these tools, the authors carefully reviewed and edited all generated content as necessary and take full responsibility for the content of the publication.

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